Towards EU climate neutrality

Progress, policy gaps and opportunities

Assessment Report 2024

European Scientific Advisory Board on Climate Change

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Manuscript completed in January 2024

Luxembourg: Publications Office of the European Union, 2024

Print	ISBN 978-92-9480-611-6	doi:10.2800/73564	TH-02-23-251-EN-C
PDF	ISBN 978-92-9480-612-3	doi:10.2800/216446	TH-02-23-251-EN

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About the European Scientific Advisory Board on Climate Change

The European Scientific Advisory Board on Climate Change is an independent scientific advisory body providing the EU with scientific knowledge, expertise and advice relating to climate change. The Advisory Board identifies actions and opportunities to achieve the EU's climate neutrality target by 2050. The Advisory Board was established by the European Climate Law of 2021 with a mandate to serve as a point of reference for the EU on scientific knowledge relating to climate change by virtue of its independence and scientific and technical expertise.

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The Advisory Board is supported in the execution of its tasks by a secretariat, hosted by the European Environment Agency.

Recommendations

The European Union (EU) is committed to reducing its greenhouse gas (GHG) emissions to net zero by 2050 at the latest and to aiming to achieve net-negative emissions thereafter. To ensure the EU and its Member States remain on track to meet their climate objectives, the European Climate Law foresees a regular assessment of progress made towards them, together with an assessment of whether EU and national measures are consistent with the climate neutrality objective. This process should be supported by the best available and most relevant scientific evidence, including reports from the European Scientific Advisory Board on Climate Change (hereafter "the Advisory Board"). With this report, the Advisory Board presents its recommendations for achieving the EU's climate targets, as shown in Figure 1 and further detailed below.

Figure 1 Overview of the Advisory Board's recommendations

Source: Advisory Board (2024)

1. Achieving the EU's 2030 climate target: fully implement the Fit for 55 package and conclude outstanding European Green Deal initiatives

1.1 Fully and swiftly implement the Fit for 55 package

Key recommendation 1 - Member States should urgently adopt and implement national measures to increase the pace of emissions reductions and reverse the declining EU carbon sink in time. If necessary, the European Commission should take enforcement action to ensure that Member States' updated national energy and climate plans (NECPs) fully comply with the requirements set out in the Governance Regulation.

The EU has substantially reduced its net GHG emissions since 2005. But the pace of reductions needs to increase considerably (to more than twice the average rate over 2005-2022) if the EU is to achieve its 2030 target (a net decrease in GHG emissions of at least 55% compared to 1990) and climate neutrality by 2050. Additional efforts are required in all sectors, especially in the land use, land use change and forestry (LULUCF) sector, where the carbon sink has decreased sharply since 2015.

With the European Green Deal and the Fit for 55 package, the EU has substantially strengthened its climate policies to bring about such an acceleration and reach its 2030 target, as a milestone towards climate neutrality.

Achieving the 2030 target depends on **rapid, robust and effective implementation of the Fit for 55 package**, in particular at the national level: central elements of the package – such as the Effort Sharing Regulation (ESR), the LULUCF Regulation, the Renewable Energy Directive (RED III) and the Energy Efficiency Directive (EED) set out general objectives, whose achievement primarily relies on ambitious national policies and measures.

These measures should be included in Member States' NECPs which are currently being updated. So far, Member States have not sufficiently complied with their obligations regarding NECPs, both in terms of process and content. The European Commission's assessment of the draft updated NECPs found that their collective ambition was insufficient to achieve the EU's 2030 targets. Many draft updates did not include sufficient information or were submitted late, and not all Member States have set up permanent multi-level dialogues or conducted public consultations on their plans.

- Member States' updated NECPs, which must be submitted by 30 June 2024, should fully reflect the new EU legislative framework and demonstrate enough ambition to enable achievement of the EU's energy and climate objectives.
- All Member States must rapidly adopt and implement the updated NECPs' planned measures to have a chance of achieving the necessary emissions reductions in time.
- The European Commission should ensure the updated NECPs are fully compliant with the Governance Regulation, in terms of both their content and the process supporting their set-up and implementation, and take enforcement action if necessary.

1.2 Conclude pending legislative initiatives under the European Green Deal

Key recommendation 2 - The Advisory Board recommends that the EU adopts pending legislative initiatives aimed at supporting the required emissions reductions. This includes in particular the revision of the Energy Taxation Directive (ETD).

- To contribute to further emissions reductions, EU legislators should conclude the Fit for 55 package by adopting an ambitious revision of the ETD which would align energy taxation with the EU's climate objectives. In particular, the revision should set higher minimum tax rates for fossil fuels and remove environmentally harmful tax exemptions, such as for aviation, maritime and professional road transport fuels, as part of a full and urgent phase-out of fossil fuel subsidies (see key recommendation 4).
- Several initiatives could deliver additional emissions reductions but they have yet to be concluded. These include some launched or planned under the European Green Deal's sectoral strategies (e.g. the Farm to Fork Strategy, the Sustainable and Smart Mobility Strategy, the 2020 circular economy action plan (CEAP 2)), as well as a number of initiatives introduced after the Fit for 55 package (e.g. the revision of carbon dioxide (CO_2) emission performance standards for heavy-duty vehicles (HDVs) and the Net-Zero Industry Act). EU legislators should conclude the legislative process related to these initiatives, while maintaining a high level of environmental ambition.

Key recommendation 3 - Both EU and national policy-makers should provide a stable investment outlook for renewable energy by adopting pending legislation and implementing existing policies.

- Timely adoption and implementation of the electricity market reform, the Net-Zero Industry Act and the Critical Raw Materials Act should reinforce long-term investment signals to support the scale-up in wind and solar photovoltaics (PV). These acts complement the REPowerEU plan, the RED III, the Trans-European Networks for Energy (TEN-E) regulation and the EU action plan for grids, which aim at overcoming key bottlenecks in the roll-out of renewable energy sources (RES), including inadequate electricity networks and administrative permitting. Mechanisms supporting RES need to be stable, offer a long-term market outlook, and find a balance between least-cost RES at scale and nurturing technological innovation. Better use of public funds will be key in this respect, e.g. through de-risking tools and tailored financing solutions (see key recommendation 11).

1.3 Phase out fossil fuel subsidies

Key recommendation 4 - The Advisory Board recommends urgently and fully phasing out fossil fuel subsidies in the EU, in line with existing commitments.

– Member States should fully and urgently phase out fossil fuel subsidies. In line with the 8th Environment Action Programme (8th EAP), they should set a deadline for phasing out such subsidies, and their updated NECPs should include a clear plan and timeline to achieve this.
– Fossil fuel subsidies supporting vulnerable households should be redirected towards well-targeted interventions that adequately address regressive effects while maintaining an incentive for energy savings and a shift towards RES.
– The EU rules affecting state aid for companies should become more consistent with EU climate goals and be brought in line with the Aarhus Convention, notably to safeguard public access to justice.

2. Towards climate neutrality by 2050: address remaining policy inconsistencies and gaps

Assuming swift and effective implementation of the European Green Deal, the Advisory Board has identified opportunities for further policy action to help the EU achieve climate neutrality. The recommendations below are primarily aimed at strengthening the EU policy framework post 2030. However, some of the actions suggested should start before then to reduce the risk of carbon lock-in, decrease the probability of abrupt changes in the EU economy, and help the EU exceed its 55% reduction target by 2030.

2.1 Remove policy inconsistencies

Key recommendation 5 - The EU policy framework should be made fully consistent with the climate neutrality objective and the phase-out of fossil fuels in the EU.

– The European Climate Law requires the European Commission to check that any draft measure or legislative proposal is consistent with EU climate goals. These checks have been done on many, but not all, relevant measures and proposals; they should apply to the delegated and implementing acts under the Fit for 55 package and the European Green Deal, as well as other measures such as climate-relevant state aid decisions and communications.
– EU policies should be better aligned with the 2050 climate neutrality objective, notably in the fields of energy infrastructure and markets (e.g. TEN-E and the internal energy market framework), finance (e.g. the EU Taxonomy), industrial emissions (e.g. the Industrial Emissions Directive) and competition (e.g. state aid rules).
– Practices within the EU policy framework, such as scenario-building for the planning and development of cross-border energy infrastructure, should be consistent with EU pathways to climate neutrality. According to these, fossil fuel use decreases sharply and is almost fully phased out from EU’s public electricity and heat generation by 2040.

- The use of carbon capture technologies and hydrogen should not lead to fossil gas infrastructure lock-ins (see key recommendation 10).

2.2 Further improve existing policies

Key recommendation 6 - The Advisory Board recommends strengthening EU climate governance and compliance frameworks.

- The upcoming revisions of the Governance Regulation and the European Climate Law represent an opportunity to improve the existing governance framework for climate action in the EU. In particular, national long-term strategies (LTSs) should be subject to an iterative review process (like the current process with draft and final NECPs), and the link between LTSs and NECPs should be strengthened. The requirement to set up permanent multi-level energy and climate dialogues should be reinforced, and the establishment of national climate advisory bodies should be mandatory.
- The EU should also consider more effective compliance mechanisms, in particular for Member States' obligations to reduce emissions from sectors outside the EU Emissions Trading System for stationary installations and aviation (EU ETS), i.e. under the Effort Sharing and LULUCF Regulations.

Key recommendation 7 - The two EU emissions trading systems must be made fit for net zero.

- The functioning of the EU ETS when the emissions cap for stationary installations approaches or equals zero must be clarified shortly, including the potential role of carbon removals. The EU should also develop alternatives to free allocation to address the risk of carbon leakage for sectors not yet covered by the Carbon Border Adjustment Mechanism (CBAM), especially as the cap further reduces towards zero.
- The initial years of operation of the EU emissions trading system for buildings, road transport and additional sectors (EU ETS 2) should help inform future adjustments and design choices. After 2030, the system should aim for a carbon price signal high enough to incentivise emissions reductions in line with reaching EU climate neutrality, and for an increasing convergence of the carbon price between the two emissions trading systems. This should be accompanied by well-provisioned and targeted measures to address adverse socio-economic effects, based on a thorough analysis of the expected impacts (see key recommendation 8).

Key recommendation 8 - To ensure a just transition and effective implementation, EU policies should build on systematic impact assessments and *ex post* evaluations of the socio-economic aspects of climate policies and measures in specific contexts.

- More systematic and context-specific impact assessments and *ex post* evaluations (e.g. considering local and national needs) should help reinforce synergies between EU social and climate policies and improve climate policy narratives. They should also help design compensatory measures like the Social Climate Fund and the Just Transition Fund. Assessments should be transparent and include public consultations. By informing and engaging citizens and other stakeholders, consultations can increase public support for climate policies and measures.

Key recommendation 9 - The Advisory Board recommends providing stronger incentives for climate action in the agricultural sector and food system, including through the upcoming revision of the common agricultural policy (CAP).

- The CAP should be better aligned with EU climate goals. This could include (i) a standalone emissions reduction objective; (ii) moving towards mandatory good practices that support methane (CH_4) and nitrous oxide (N_2O) reductions and soil carbon increases; and (iii) shifting CAP support away from emission-intensive agricultural practices, including livestock production, and towards lower-emitting products, carbon removals, environmental services and economic diversification.

- In parallel, the EU should strengthen measures to encourage healthier, more plant-based diets, and develop a strategy for a just transition to a food system consistent with climate neutrality.
- The EU should start preparations now with a view to extending the EU emissions pricing regime to the agricultural/food and LULUCF sectors to incentivise further climate action in these areas (see key recommendation 13).
- The actions recommended (reforming the CAP, introducing emissions pricing and strengthening measures to encourage healthier, more sustainable diets) should be pursued in parallel and in a coherent manner to avoid conflicting policy signals. This would be consistent with the EU approach for other sectors, where carbon pricing is combined with other policy instruments such as minimum performance standards and subsidies.

Key recommendation 10 - The deployment of carbon capture and utilisation/storage (CCU/CCS), hydrogen, and bioenergy should be targeted towards activities with no or limited alternative mitigation options.

- CCU/CCS, indirect electrification through the use of hydrogen, and the use of bioenergy are less efficient or have higher sustainability risks compared to other mitigation pathways such as energy efficiency improvements and direct electrification. EU policies in support of CCU/CCS, hydrogen and bioenergy should be better targeted towards applications with no or very limited other mitigation options.

Key recommendation 11 - The EU should take further policy action to drive the required increase in public and private investments in climate mitigation.

- The reporting methodology under the Multiannual Financial Framework (MFF) (i.e. 7-year EU budget) should be improved to track more accurately EU expenditures that contribute to climate action, and to identify spending on potentially harmful activities.
- The EU should consider continuing the common debt approach under the current Recovery and Resilience Facility (RRF) beyond 2026 to increase investors' certainty and boost EU public investment in climate action.
- To boost private investments, the supply of bankable climate mitigation projects must be increased. To this end, policies should address technology-specific risks and funding gaps by speeding up permitting, removing regulatory uncertainties, and providing tailored financing incentives and solutions where investments are not yet profitable with the current carbon price trajectory.

2.3 Develop new policies

Key recommendation 12 - The Advisory Board recommends pursuing more ambitious reductions in energy and material demand through new and strengthened policies.

- EU policies should incentivise more vigorously the reduction of energy and material demand (in mobility, housing, material use and diets), both through efficiency improvements and behavioural changes. To enable this, policies should establish structures and introduce end-use innovations which increase the quality, affordability and convenience of lower-emissions products and services. The European Green Deal sectoral strategies have several initiatives which could contribute to this (e.g. a legislative framework of sustainable food systems, a regulation on railway infrastructure and revision of the Combined Transport Directive, mandatory green public procurement requirements), but these remain to be proposed/adopted (see key recommendation 2).

Key recommendation 13 - The Advisory Board recommends expanding the EU GHG pricing regime to all major sectors (including agricultural/food, LULUCF and upstream fossil fuel operations) and providing EU-level incentives for carbon removals.

- The EU should start preparations now with a view to introducing pricing instruments in the agricultural/food and LULUCF sectors, in order to incentivise emissions reductions and carbon removals. Such instruments should reflect the specific characteristics of these sectors, including the technical complexity of measuring emissions and removals, attributing them to land management and mitigation actions, the differences in the permanence of various natural removals and the risk of international leakage. Their impact – in particular on small farms and farms in vulnerable regions – should be assessed *ex ante*, and potentially adverse economic, social and environmental impacts should be addressed to ensure a just and fair transition. This could be done in different ways directly targeting the problems at hand. The CAP budget or revenues from such pricing mechanisms could be used to finance redistributive measures, and to support climate mitigation and adaptation efforts. The EU carbon removal certification framework (CRCF), which is currently being developed, could serve as a first step towards a robust monitoring, reporting and verification system for such instruments.
- The EU should address upstream emissions from fossil fuel extraction and handling, both domestically and related to imported fossil fuels. Building on the Methane Regulation, it should consider expanding the EU ETS to fugitive emissions from domestic fossil fuel operations, and in parallel introduce a border adjustment mechanism for upstream GHG emissions from fossil fuel imports. Pricing upstream emissions from fossil fuels would also contribute to the necessary phase-out of fossil fuels in the EU (see key recommendation 5).

Summary

Context and objectives of the report

Under the European Climate Law, the EU should regularly track progress towards its climate objectives and assess whether its policies are consistent with achieving these goals

The Paris Agreement sets out the goal of strengthening the global response to the threat of climate change by holding global warming to well below 2° C and pursuing efforts to limit it to 1.5°C, relative to pre-industrial levels. As its contribution to this goal, the EU is legally committed, under the European Climate Law, to reduce its GHG emissions to net zero by 2050 at the latest, and to aim to achieve negative emissions thereafter. The law also sets the intermediate target of reducing net GHG emissions by at least 55% by 2030 compared to 1990 levels.

On 12 December 2023, a comprehensive assessment of the progress made by the global community towards the goals of the Paris Agreement – the first global stocktake – was concluded at the 28th Conference of the Parties under the UN FCCC in Dubai. This process resulted in a call for accelerated action, recognising the need for deep, rapid and sustained emissions reductions in line with 1.5°C pathways. Similarly, to ensure the EU remains on track to meet its climate objectives, the European Climate Law foresees a regular stocktake of progress towards the law's objectives, including an assessment of whether EU measures are consistent with these goals.

The EU has significantly strengthened its climate policies (primarily through the Fit for 55 package) to reach its 2030 target and to respond to new challenges posed by a rapidly changing international environment. Achieving climate neutrality by 2050 will require further development of climate policies.

To achieve its 55% reduction target by 2030, the EU has significantly revised its climate policy framework in the past 3 years, primarily through the Fit for 55 package. In addition, the European Commission launched several sectoral strategies and actions to achieve further GHG emissions reductions. These include the Sustainable and Smart Mobility Strategy, the Farm to Fork Strategy, the Biodiversity and Forest Strategies, and the CEAP 2.

In parallel, several developments in the socio-economic and geopolitical context in which the EU is pursuing its climate objectives have provided strong arguments to accelerate the transition, to reduce the EU's dependence on imported fossil fuels and to strengthen its position to benefit from clean energy and the industries of the future:

- The 2020-2021 COVID-19 pandemic and the 2021-2022 energy crisis resulting from Russia's war of aggression against Ukraine resulted in distorted supply chains, high inflation and greater attention to security, including supply of energy and raw materials. The economic slowdown and large support measures in the context of the pandemic, as well as the energy crisis, have reduced EU Member States' fiscal leeway. Furthermore, higher interest rates have increased financing costs.
- The global race for green investments has accelerated with the US Inflation Reduction Act and due to strategic rivalry with China, leading to a re-evaluation of China's dominance in key strategic sectors and products which threatens the EU's long-term competitiveness and resilience.

In response to these developments, measures have been introduced at the EU level to enhance economic and security-related elements of the climate transition, such as the REPowerEU plan and the Green Deal

Industrial Plan. Member States have also put in place a range of policies that will shape future GHG emissions trends in the EU.

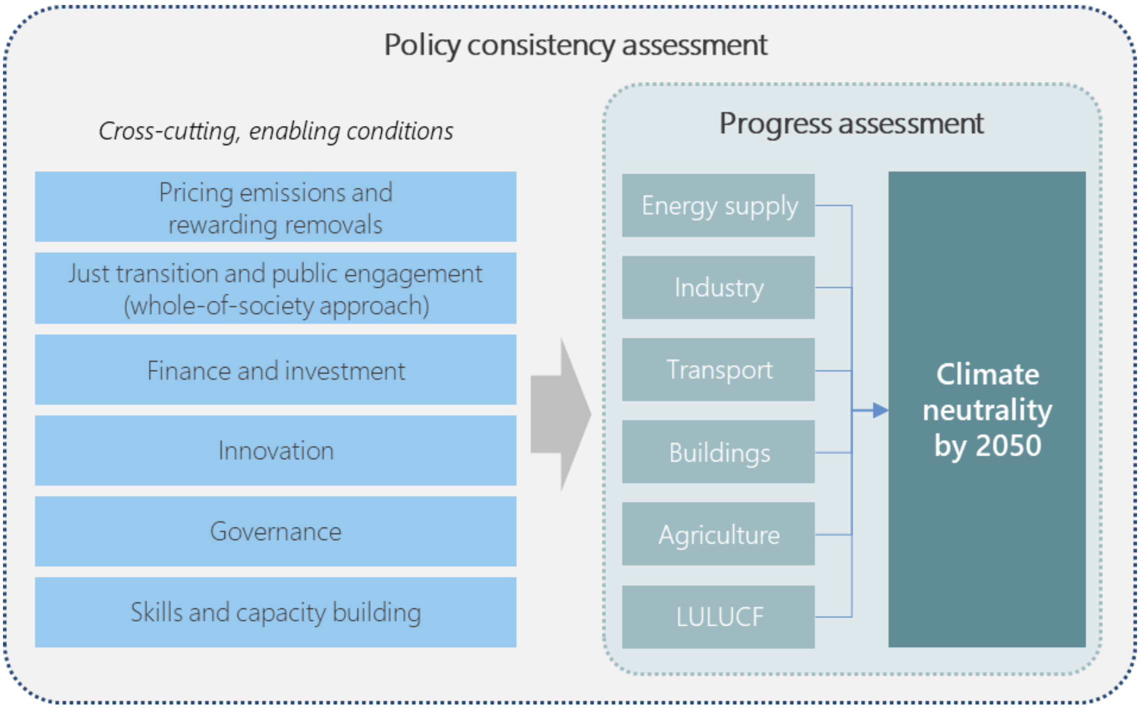
In the context of this strengthened EU climate policy framework, this report aims to provide the EU with scientific advice on policy actions that can support the achievement of climate neutrality by 2050 at the latest.

With this report, the European Scientific Advisory Board on Climate Change (hereafter Advisory Board) aims to advise EU policy-makers on how to make the EU's policies and measures 'fit for net zero', by flagging up areas for improvement and gaps in the current framework. To that end, it assesses the progress made towards the EU's climate objectives, as well as the consistency of EU policies with the climate neutrality objective. Where sufficient scientific evidence is available, it also puts forward recommendations to address these gaps. By doing so, the Advisory Board aims to provide an independent input to the stocktake process established at EU level under the European Climate Law, in complement to existing assessments by the European Environment Agency (EEA, the annual Trends and Projections reports (EEA, 2023p)) and the European Commission (the Climate Action Progress Report (EC, 2023ax)).

This report is an integral part of the Advisory Board's effort to provide scientific advice on existing and proposed EU measures and their consistency with the EU's climate objectives, and to identify actions and opportunities to successfully achieve these targets, in line with the mandate set out in the European Climate Law (EU, 2021c).

The report provides a first general assessment of progress and policy consistency in different sectors (energy supply, industry, transport, buildings, agriculture and LULUCF) and for cross-cutting issues (pricing of emissions and rewarding removals, just transition and public engagement, finance and investments, innovation, governance, and skills and capacity building) (see Figure 2 below). All recommendations include explanations of the evidence and rationale supporting them.

Figure 2 Scope of the progress and policy consistency assessment



Source: Advisory Board (2024).

Given the broad scope of an analysis addressing progress towards meeting climate objectives in the EU, the Advisory Board chose to limit its assessment to the EU level and did not include specific Member State-level analysis. Progress and consistency of policies with climate objectives at the national level are regularly assessed by the European Commission and other stakeholders, such as national climate advisory bodies established in certain Member States ([1]).

In addition to objectives on climate mitigation, the European Climate Law sets out an obligation for the relevant EU institutions and Member States to ensure continuous progress in enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change. Although climate adaptation is not specifically covered in this report, the Advisory Board highlights its importance both as a critical issue on its own and because of potential synergies between adaptation and mitigation measures.

Analytical approach

For each of the six sectors covered by the analysis (see Chapters 4-9 of the report), the Advisory Board performed the following two main tasks:

1. An assessment of **progress**, based on the analysis of relevant indicators and their comparison with indicative benchmarks.
2. An assessment of the **consistency** of relevant existing or recently adopted policies in each sector with the EU's climate objectives, starting from the assessed progress and based on a thorough review of recent scientific and expert findings.

To assess progress across the different sectors, the Advisory Board identified 76 indicators specific to the different sectors. It then compared historical trends with indicative benchmarks for 2030 and 2050 derived from existing EU targets and objectives, as well as European Commission scenarios and other scientific scenarios used by the Advisory Board to prepare its recommendations for the determination of an EU-wide 2040 climate target and a GHG budget for 2030-2050 (ESABCC, 2023b).

For its assessment of policy consistency in the different sectors, the Advisory Board assessed whether EU policies are (or can be expected to be) sufficiently driving the required changes to deliver the necessary GHG emissions reductions. This assessment led to identifying four main types of gaps or inconsistencies: **policy gaps** (no policies in place to address the required change), **ambition gaps** (the policies in place are not ambitious enough to deliver the required change), **implementation gaps** (policies are not implemented adequately), and **policy inconsistencies** (policies provide counterproductive incentives).

The assessment was based on a thorough review of recent scientific findings, reports and data from international organisations (such as the International Energy Agency (IEA)) and from European institutions (e.g. European Court of Auditors (ECA), European Commission and its Joint Research Centre (JRC)). The Advisory Board also considered insights from reports and data from non-governmental organisations, think tanks and industry, provided they were underpinned by robust and credible analysis. Given the difficulties inherent to the *ex ante* assessment of impacts of newly adopted policies, some level of judgement was involved in translating the available evidence into expectations of gaps. The sources used are referenced throughout the report.

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(1) The European Climate Law invites each Member State that has not done so yet to establish a national climate advisory body.

For the cross-cutting issues (Chapters 10-15 of the report), the assessment mainly focused on policy consistency, based on the same approach as for the sectoral assessments.

Based on its analysis of progress and consistency, the Advisory Board drew conclusions on:

1. '**needs**' – changes required to deliver the necessary emissions reductions (or removals) in line with a meaningful contribution to EU climate neutrality;
2. '**gaps**' – barriers in the current policy framework that must be addressed to deliver the required changes;
3. '**recommendations**' – policy options recommended to overcome the identified gaps.

Figure 3 Structure of the Advisory Board conclusions

Needs	**Required outcomes or changes to deliver the necessary emissions reductions**	*Example: The need to shift road transport to rail*
Gaps	**Barriers in the policy framework, including:** • **Policy gaps** - no policies in place • **Ambition gaps** - policies are not ambitious enough • **Implementation gaps** - implementation is inadequate • **Policy inconsistencies** - counterproductive incentives	*Example: Existing EU policies (Combined Transport Directive/Rail Freight Corridors Regulation) have been ineffective (ambition/implementation gap)* *Initiatives to revise/replace these policies are still pending*
Recommendations	**Policy options to address the gaps**	*Example: EU legislators should adopt an ambitious revision of the Combined Transport Directive & the proposed Regulation on the use of Railway Infrastructure Capacity*

Source: Advisory Board (2024).

While the Advisory Board's assessment of progress and policy consistency draws on a large body of scientific and grey literature, it is not fully comprehensive. It focuses on selected progress indicators and their respective indicative benchmarks, EU policies, and does not consider Member State policies. It uses a sectoral approach but does not address sectoral interactions in detail, although some cross-cutting topics which are important across many sectors are included. Because of these limitations, the findings and recommendations of the report do not exhaust the list of EU-level actions that may be needed to achieve climate neutrality by 2050. Nevertheless, the report does provide an overview of some key areas where further policy action can help move the EU closer to meeting its climate goals, based on existing evidence.

1. Achieving the EU’s 2030 climate target: fully implement the Fit for 55 package, conclude pending European Green Deal initiatives, and address implementation gaps

The Advisory Board makes the following recommendations to the EU to ensure the 55% reduction objective for 2030 is reached or exceeded, as further detailed below:

1. Fully and swiftly implement the Fit for 55 package.
2. Conclude pending legislative initiatives under the European Green Deal.
3. Phase out fossil fuel subsidies.

1.1 Fully and swiftly implement the Fit for 55 package

Key recommendation 1 - Member States should urgently adopt and implement national measures, to increase the pace of emissions reductions and reverse the declining EU carbon sink in time. If necessary, the European Commission should take enforcement action to ensure that Member States’ updated NECPs fully comply with the requirements set out in the Governance Regulation.

The EU has substantially reduced its net GHG emissions since 2005 and largely exceeded its 20% reduction target by 2020, compared to 1990.

In 2022, the EU had reduced its net GHG emissions by 31% compared to 1990 levels. It surpassed the 20% reduction target for 2020, and trends over the past 5 years show an increase of average emissions reductions. Consumption-based CO_2 emissions decreased at a similar pace to territorial CO_2 emissions in the 2010-2020 period.

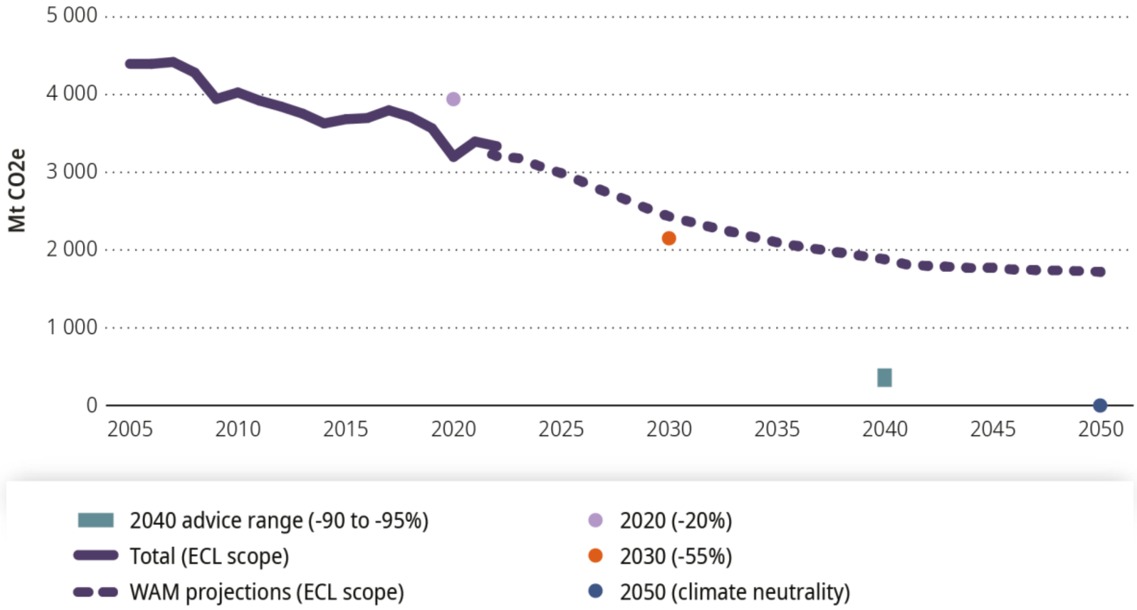
While recent emissions reductions have accelerated, achieving the EU’s 55% objective for 2030 requires a significant increase in the pace of reductions to more than twice the 2005-2022 average.

While encouraging, the observed trends are not sufficient to indicate that the EU is on track to meet its climate targets: achieving these requires the pace of emissions reductions to increase even further (see Figure 4). To reach the EU’s 55% reduction target by 2030, average annual reductions during the 2022-2030 period should be more than twice those observed on average in 2005-2022.

For the time being, Member States' latest projections show that net GHG emissions would be reduced by only 49% by 2030, with current and planned policies at the national level (see Figure 4). According to the European Commission’s assessment of the draft updated NECPs submitted in 2023, the measures they include would result in net emissions reductions of 51% by 2030, compared to 1990, which is still short of the 55% objective. Additional efforts would be required in all sectors, particularly those covered by the Effort Sharing Regulation (buildings, transport and agriculture) and the LULUCF sector. The biggest step change is needed in the latter, where the carbon sink has been sharply decreasing since 2015.

These projections do not yet fully reflect the expected impact of the Fit for 55 package or the final updated NECPs, which must be submitted in 2024. But they underline the crucial importance of rapid and effective implementation of the strengthened EU climate policy framework.

Figure 4 Overall progress towards the EU's 2030 and 2050 objectives since 2005



Notes: WAM: projections 'with additional measures'. These reflect the expected impacts of existing policies and additional ones that Member States were expecting to adopt at the time the projections were made. The projections do not necessarily reflect all the recently adopted elements of the Fit for 55 package. The 2040 range corresponds to the 90-95% reduction compared to 1990 recommended by the Advisory Board. Except for the 2020 target, the scope considered for the GHG emissions includes all domestic emissions and removals, 64% of the international maritime emissions reported in the GHG inventory, and all international aviation emissions reported in the GHG inventory (see Box 1 in Chapter 3 for more information). The 2020 target includes gross domestic GHG emissions (excluding LULUCF) and international aviation.

Sources: Historic GHG emissions: EU GHG inventory (EEA, 2023f). WAM projections: Member States' March 2023 submissions to the European Commission under the Governance Regulation (EEA, 2023m).

To enable the significant acceleration of emissions reductions required to achieve the 55% target by 2030, the EU strengthened its climate policy framework substantially, in particular with the Fit for 55 package. Delivery of this package will depend on rapid, robust and effective implementation, especially at the national level.

A wide range of EU climate and energy policies have been adopted or revised in recent years to support the necessary acceleration of GHG emissions reductions, primarily under the Fit for 55 package. Central elements of this package set out overall objectives for Member States (the Effort Sharing Regulation, the LULUCF Regulation) or at EU level (the RED III and the EED) that must be achieved primarily through policies and measures at the national and subnational levels.

Member States are required to outline their overall strategies as well as concrete policies and measures to achieve the EU energy and climate objectives in their NECPs, including an overview of the investments needed to reach the national objectives, and a clear plan and timeline to phase out fossil fuel subsidies. Under the Governance Regulation, Member States must update their NECPs to align them with recent policy developments, including the Fit for 55 package. Draft updates had to be submitted by June 2023, and final updates are due by June 2024.

So far, Member States have not sufficiently complied with their obligations regarding NECPs, both in terms of process and content. Many Member States did not fully comply with the Governance Regulation under the first NECP cycle in 2020 (**implementation gap**): several submissions were late and did not include the minimum required content (e.g. lacking sufficiently detailed information on investment needs and the expected socio-economic impacts of planned measures), and not all Member States ensured permanent multi-level engagement as required. The EU is also in breach of the Aarhus Convention in relation to public engagement in the NECP process (**implementation gap**). The European Commission's assessment of the draft updated NECPs in 2023 found that, despite steps in the right direction, the collective ambition of NECPs was insufficient to achieve the Fit for 55 package's objectives. Many draft updates did not include sufficient information or were submitted late, and not all Member States had set up permanent multi-level dialogues nor conducted public consultations on the plans.

- ➔ **Member States' updated NECPs, which must be submitted by 30 June 2024, should fully reflect the new EU legislative framework and demonstrate enough ambition to enable achievement of the EU's energy and climate objectives.**
- ➔ **All Member States must proceed with rapid adoption and implementation of the planned measures outlined in their updated NECPs to have a chance of achieving the necessary reductions in time.**
- ➔ **The European Commission should ensure that Member States' updated NECPs are fully compliant with the Governance Regulation – in terms of both their content and the process supporting their set-up and implementation – and take enforcement action if necessary** (see Chapter 14, recommendation G1)**.**

1.2 Conclude pending legislative initiatives under the European Green Deal

Key recommendation 2 - Adopt pending legislative initiatives which aim to support the required emissions reductions, including the ETD.

While almost all the Fit for 55 package's legislative proposals have now been adopted, the revision of the ETD put forward by the European Commission is still pending. The current ETD is not aligned with the EU's climate ambitions, as it gives preferential treatment to GHG emission-intensive energy carriers compared to less emission-intensive alternatives. It also includes harmful tax exemptions for aviation, maritime and professional road transport, agriculture, energy-intensive industries and heating of buildings (**policy inconsistency**). Adopting the revision as proposed would go a long way to addressing the inconsistencies identified. However, by the end of 2023, legislators had made limited progress towards this, making it the only proposal from the original Fit for 55 package (published in July 2021) that had not been adopted yet.

- ➔ **To contribute further emissions reductions, EU legislators should conclude the Fit for 55 package by adopting an ambitious revision of the ETD, aligning energy taxation with the EU's climate objectives. In particular, the revision should set higher minimum tax rates for fossil fuels and remove environmentally harmful tax exemptions (for aviation, maritime and professional road transport, agriculture, heating of buildings and energy-intensive industries), as part of a full and urgent phase-out of fossil fuel subsidies** (see key recommendation 4, and Chapter 10, recommendation C5).

Since the Fit for 55 package was published in July 2021, the European Commission has made further legislative proposals aimed at accelerating GHG emissions reductions. These include revisions of the Energy Performance of Buildings Directive (EPBD) and of CO_2 emission performance standards for HDVs, as well as a Methane Regulation. It also launched initiatives to boost clean technologies and make the EU more competitive and autonomous, in particular the Net-Zero Industry Act, the Critical Raw Materials Act, and the reform of the electricity market design, as well as the hydrogen and decarbonised gas market package. Most of these proposals were at advanced stages of the legislative process by the end of 2023.

However, progress on the operationalisation of the different sectoral strategies under the European Green Deal (e.g. the Farm to Fork Strategy, the Sustainable and Smart Mobility Strategy, the CEAP 2) has been slower, with many initiatives still in the legislative process or not yet proposed by the European Commission. These remain to be converted into ambitious EU legislation.

➔ **EU legislators should conclude the legislative process on the other pending initiatives under the European Green Deal, such as the revised CO_2 emission performance standards for HDVs, while maintaining a high level of environmental ambition** (see Chapter 4, recommendation E4; Chapter 5, recommendation I3; Chapter 6, recommendation T2; Chapter 7, recommendation B1; Chapter 8, recommendation A3).

Key recommendation 3 - Provide stable investment outlooks for renewable energy by adopting pending legislation and implementing existing policies.

The deployment of solar PV and wind energy needs to accelerate across the EU to achieve the 42.5% renewable energy objective for 2030 and to lead to a net-zero electricity system by 2040 at the latest. Progress is challenged by changing investment landscapes as well as inadequate infrastructure planning and development, spatial planning and permitting, workforce skills, and supply chains. This lowers investment certainty and affects system planning and decision-making (e.g. in PV and wind value chains, as they are not yet adjusted to the required deployment and industry growth).

EU policies have been adapting to this challenge, in particular through the REPowerEU plan, the RED III, the TEN-E Regulation and the EU action plan for grids. Several of the above-mentioned pending legislative initiatives also aim to improve the investment framework for renewables, including the electricity market reform, the Net-Zero Industry Act and the Critical Raw Materials Act.

➔ **Timely adoption and implementation of the electricity market reform, the Net-Zero Industry Act and the Critical Raw Materials Act should reinforce long-term investment signals to support the scale-up in wind and solar PV. Mechanisms supporting RES must be stable, offer a long-term market outlook, and find a balance between least-cost RES at scale and nurturing technological innovation. Better use of public funds will be key in this respect, e.g. through de-risking tools and tailored financing solutions** (see Chapter 4, recommendation E4).

1.3 Phase out fossil fuel subsidies

Key recommendation 4 - Phase out fossil fuel subsidies in line with existing commitments.

Fossil fuel subsidies undermine the climate transition, by hindering the reorientation of private financial flows towards climate mitigation, locking in GHG emissions from fossil fuel-dependent infrastructure, and reducing the public budget available to support climate investments.

The EU and its Member States have repeatedly committed to phasing out fossil fuel subsidies, for which they are required to set a deadline under the 8th EAP. Despite these commitments, fossil fuel subsidies remained relatively stable in the last decade (around €50 billion per year), and even increased sharply in 2022, in the context of the energy crisis (€120 billion). Only a minority of Member States currently have, in their NECPs, clear plans and timelines for phasing out such subsidies (**implementation gap**).

➔ **Fossil fuel subsidies should be phased out fully and urgently. Member States should include clear plans and timelines to achieve this in their updated NECPs** (see Chapter 12, recommendation F2).

➔ **Fossil fuel subsidies supporting vulnerable households should be redirected towards well-targeted interventions that adequately address regressive effects while maintaining an incentive for energy savings and a shift towards RES** (see Chapter 12, recommendation F2).

Fossil fuel subsidies continue being channelled through state aid approved by the European Commission. While the Temporary Crisis and Transition Framework includes a very positive opening for more public investment towards a net-zero economy, it is not fully consistent with the EU climate neutrality objectives. Adopted in response to the energy crisis, the Temporary Crisis Framework of March 2022 and its successor the Temporary Crisis and Transition Framework of March 2023 allow Member States to shield fossil fuel power plant operations and energy-intensive companies from high and volatile energy prices. Despite its temporary and crisis-led nature, the framework provisions keep being extended, allowing vast public support which is inconsistent with the energy transition (**policy inconsistency**). In addition, by restricting public rights to internal administrative review of state aid decisions, the EU is in breach of the Aarhus Convention in relation to access to justice (**implementation gap**).

➔ **EU state aid rules affecting national support measures for EU companies should be made more consistent with EU climate goals and brought in line with the Aarhus Convention, notably to safeguard public access to justice** (see Chapter 4, recommendation E1).

2. Towards climate neutrality by 2050: address remaining policy inconsistencies and gaps

Looking beyond 2030, emissions reductions in the EU will need to accelerate even faster to achieve climate neutrality by 2050. Building on the Fit for 55 package, the EU can become climate neutral by 2050 through several well-identified actions and opportunities. Early action on these could bring multiple benefits.

While the recent strengthening of the EU climate policy framework is expected to go a long way towards achieving the EU's 2030 target – provided that it is implemented swiftly and effectively – becoming climate neutral by 2050 at the latest will require further policy developments.

The Advisory Board identified several remaining policy options that can help the EU achieve the necessary emissions reductions to deliver on its long-term climate objectives. The board makes the following recommendations to the EU, as further detailed below:

1. Remove remaining inconsistencies of EU policies with climate objectives.
2. Further improve existing policy instruments.
3. Develop new policies.

Certain decisions made today have long-lasting effects and might strongly impact the EU's ability to reach its climate neutrality objective in time, for example, when linked with a risk of fossil fuel lock-in. Therefore, although the recommendations below are primarily aimed at strengthening the EU policy framework post 2030, some of the recommended actions should start already in the coming years. This would provide multiple benefits, including avoiding lock-ins, reducing the risk of abrupt changes in the EU economy, supporting the achievement of the 2030 objective and potentially even enabling this goal to be exceeded (thereby decreasing the EU's cumulative emissions until 2050 and thus increasing the fairness of its contribution to global mitigation).

2.1 Remove policy inconsistencies

Key recommendation 5 - Make EU policies fully consistent with the EU climate neutrality objective and the phase-out of fossil fuels in the EU.

The European Climate Law requires the European Commission to check that draft measures and legislative proposals are consistent with EU climate goals. These checks have been done on many, but not all, relevant measures, including at least two delegated acts with high climate relevance (i.e. acts establishing taxonomy criteria for sustainable investment and defining renewable transport fuels) (**implementation gap**).

- ➔ **The European Commission should assess more systematically the consistency of any draft measure or legislative proposal with the climate neutrality goals as set out in the European Climate Law. This also applies to the delegated and implementing actions under the Fit for 55 package and European Green Deal, as well as other measures such as climate-relevant state aid decisions and communications** (see Chapter 14, recommendation G3).

Scenarios towards net-zero emissions in the EU imply that fossil fuel use decreases sharply and is almost fully phased out from public electricity and heat generation by 2040. While the revised EU ETS provides a strong signal to this end, not all EU policies are consistent with a progressive phase-out of fossil fuels in future energy systems (e.g. the TEN-E Regulation, the proposed Gas Directive and Gas Regulation, state aid rules, and the EU Taxonomy). Due to the necessary speed of change in the energy sector, decisions made today risk costly infrastructural and contractual carbon lock-ins (**policy inconsistency**).

The 10-year network development plan (TYNDP) process, which informs today's energy infrastructure investment decisions across Europe and beyond, is not yet in line with the EU 2050 climate neutrality objective as required under the revised TEN-E Regulation (**implementation gap**).

- ➔ **EU policies should be better aligned with the 2050 climate neutrality objective, notably in the fields of energy infrastructure and markets (for example, TEN-E and the internal energy market framework), finance (e.g. the EU Taxonomy), industrial emissions (for instance, the Industrial Emissions Directive) and competition (e.g. state aid rules)** (see Chapter 4, recommendation E1).
- ➔ **Practices within the EU policy framework, such as scenario-building for cross-border infrastructure planning and development, should be consistent with EU pathways to climate neutrality. According to these, fossil fuel use decreases sharply and is almost fully phased out from EU's public electricity and heat generation by 2040** (see Chapter 4, recommendation E1).
- ➔ **Application of CCU/CCS technologies and hydrogen should not lead to unnecessary fossil gas infrastructure lock-ins** (see Chapter 4, recommendations E6 and E7).

2.2 Further improve existing policies

Key recommendation 6 - Strengthen the EU climate governance and compliance frameworks.

The Governance Regulation requires Member States to develop national LTSs and to ensure consistency between their NECPs and LTSs. However, the LTS governance process does not foresee an iterative review process as is currently provided for the NECPs. The regulation also does not require the European Commission to thoroughly check whether the NECPs are consistent with national LTSs. Therefore, the regulation does not sufficiently ensure that the NECPs are consistent with the LTSs, nor that the latter are adequate to enable achievement of the EU's long-term objectives (**ambition gap**). Furthermore, the provisions on multi-level climate and energy dialogues are not sufficiently clear regarding the permanent and systematic nature of stakeholder engagements (**ambition gap**).

The current provisions of the European Climate Law are not sufficient to incentivise the establishment by Member States of independent national climate advisory bodies (**ambition gap**). These could play a particular role in the NECP preparation process at the national level, but this role is currently not yet foreseen in the Governance Regulation (**ambition gap**).

➔ **The upcoming revisions of the Governance Regulation and European Climate Law represent an opportunity to improve the existing governance framework for climate action in the EU. In particular, (i) the national LTSs should be subject to an iterative review process (similar to the current process for NECPs) and the link between LTSs and NECPs should be strengthened, (ii) the requirement to set up permanent multi-level energy and climate dialogues should be reinforced, and (iii) the establishment of independent national climate advisory bodies should be made mandatory** (see Chapter 14, recommendations G1, G3 and G4).

The ESR sets annual binding targets at national level for domestic GHG emissions not covered by EU ETS or the LULUCF Regulation. The 5-year cycle of formal compliance checks under ESR leads to a substantial time lag between the emissions and the compliance assessment's conclusions, which risks undermining its effectiveness (**ambition gap**).

➔ **The EU should consider more effective compliance mechanisms, in particular for Member States' obligations to reduce emissions from sectors outside the EU ETS, i.e. under the Effort Sharing and LULUCF Regulations** (see Chapter 14, recommendation G2).

Key recommendation 7 - Make the two EU emissions trading systems fit for net zero.

Successive revisions have strengthened EU ETS. However, there is not yet a clear strategy to prepare the carbon market for when the cap – which determines the amount of emission allowances allocated to the market – reaches zero, which will occur before 2040 (**policy gap**).

Furthermore, whereas free allocation will be gradually phased out for sectors covered by the new CBAM (even if only by 2034), it will continue for sectors considered to be exposed to carbon leakage which are not covered by the CBAM. This risks creating distortions and complexities, and could reduce mitigation incentives for consumers and downstream industries (**ambition gap**). Furthermore, the number of allowances available for free allocation will decrease rapidly and eventually reach zero in line with the cap. Free allocation is therefore not a long-term solution to address the risk of carbon leakage.

➔ **The functioning of EU ETS when the emissions cap for stationary installations is approaching or equalling zero needs to be clarified shortly (including the potential role of carbon removals). The EU should also develop alternatives to free allocation to address the risk of carbon leakage for sectors not yet covered by the CBAM, especially as the cap further reduces towards zero** (see Chapter 10, recommendations C1 and C2).

The introduction of a separate scheme for buildings and road transport will substantially increase the share of EU GHG emissions covered by an EU-wide carbon price, and provides an additional incentive for emissions reductions in those sectors. However, if the system's carbon price exceeds €45/tonne of carbon dioxide equivalent (tCO_2e), a predefined number of additional emissions allowances will be released on the market, on top of the original cap. As most models predict that prices well above €45/tCO_2e will be needed to deliver the required reductions in the sectors covered, this mechanism is likely to be triggered. This would *de facto* increase the emissions budget under the system, and could jeopardise the envisaged GHG emissions reductions of 62% by 2030 (compared to 2005) (**ambition gap**). This would require more ambitious national measures to achieve the reduction targets under the

ESR which could be riskier, given the weaknesses in the governance and compliance framework described above.

The split between the two emissions trading systems can be justified for pragmatic reasons in the short term. In the longer term, having different prices for 1 tonne of CO_2 might fail to encourage emissions reductions where they are least expensive. It could also create distortions and perverse incentives, e.g. by discouraging electrification of energy uses if electricity (covered by the EU ETS) is subject to a higher carbon price than fuels used for heating of buildings (covered by the EU ETS 2) (**ambition gap**).

➔ **The initial years of operation of EU ETS 2 should help inform future adjustments and design choices. After 2030, the system should aim for a carbon price signal high enough to incentivise emissions reductions in line with reaching EU climate neutrality, and for an increasing convergence of the carbon price between the two emissions trading systems** (see Chapter 10, recommendation C3). **This should be accompanied by well-provisioned and targeted measures to address adverse socio-economic effects, based on a thorough analysis of the expected impacts** (see key recommendation 8)**.**

Key recommendation 8 - Base EU policies on a systematic impact assessment and *ex post* evaluations of the socio-economic impact of climate policies and measures to ensure a just transition and effective implementation.

Despite the many benefits of climate mitigation (e.g. reduced dependency on energy imports, improved air quality and human health, avoided costs of inaction), climate policy measures can have disruptive and regressive socio-economic impacts, placing a disproportionate burden on low-income households and vulnerable groups. The net-zero transition relies on properly understanding and addressing its costs and benefits at household, community and wider society levels.

Many EU policies build on a limited recognition and narrow understanding of the socio-economic impacts that could arise from climate policy implementation, particularly in relation to inequality. This limitation suggests that the connection between EU climate and social policies could be reinforced (**ambition gap**).

This also partly explains why the narratives surrounding climate policy instruments do not pay due attention to their co-benefits as well as local needs and values (**ambition gap**).

➔ **More systematic and context-specific impact assessments and *ex post* evaluations (e.g. considering local and national needs) should help reinforce synergies between EU social and climate policies and improve climate policy narratives. They should also help design compensatory measures such as the Social Climate Fund and the Just Transition Fund. Assessments should be transparent and include public consultations. By informing and engaging citizens and other stakeholders, consultations increase public support for climate policies and measures** (see Chapter 11, recommendations W1, W2 and W3; Chapter 15, recommendation S2).

Key recommendation 9 - Provide stronger incentives for climate action in the agricultural sector and food system, including through the upcoming revision of the CAP.

The lack of emissions reductions in the agricultural sector since 2005 highlights the need for stronger incentives in this sector. The CAP is the EU's flagship agricultural policy, which aims to deliver on 10 key objectives including on climate action. However, its effective contribution to GHG emissions reductions is uncertain at best. Its goal, among others, to contribute to mitigation is largely qualitative and forms part of a broader set of agri-environment objectives (**ambition gap**).

The CAP's green architecture provides opportunities for Member States to promote sustainable practices, but the emphasis given to climate change mitigation is largely discretionary and difficult to quantify *ex ante* (**ambition gap**).

Furthermore, the CAP continues to provide financial support to emission-intensive agricultural practices such as livestock production, rather than focusing on the transition to less emission-intensive activities (**policy inconsistency**).

➔ **The CAP should be better aligned with the EU climate objectives. This could include (i) a standalone emissions reduction objective, (ii) moving towards mandatory good practices that support CH_4 and N_2O reductions and soil carbon increases, and (iii) shifting CAP support away from emission-intensive agricultural practices, like livestock production, and towards lower-emitting products, carbon removals, environmental services, and economic diversification** (see Chapter 8, recommendation A1).

➔ **In parallel, the EU should strengthen measures to encourage healthier, more plant-based diets, and develop a strategy for a just transition to a food system consistent with the climate neutrality objective** (see Chapter 8, recommendation A3).

➔ **The EU should start preparations now with a view to extending the emissions pricing regime to the agricultural/food and LULUCF sectors to incentivise further climate action in these areas** (see key recommendation 13)**.**

➔ **The recommended options (reforming the CAP, introducing emissions pricing and strengthening measures to encourage healthier, more sustainable diets) should be pursued in parallel and in a coherent manner to avoid conflicting policy signals. This would be consistent with the EU approach for other sectors, where carbon pricing is combined with other policy instruments such as minimum performance standards and subsidies.**

Key recommendation 10 - Target the deployment of CCU/CCS, hydrogen and bioenergy towards activities with no or limited alternative mitigation options.

CCU/CCS, indirect electrification through renewable hydrogen and its derivatives, and bioenergy are less efficient or raise sustainability concerns compared to other mitigation pathways, such as energy efficiency improvements and direct electrification. Even so, they remain necessary to achieve deep emissions reductions in sectors where direct electrification is technically challenging (e.g. in aviation and maritime transport and energy-intensive industries).

A harmonised carbon price applied across all sectors would ensure that the most efficient mitigation options are prioritised, and that less efficient options are only applied where there is a lack of alternatives, provided that the price signal is not distorted by other interventions such as subsidies. However, this is currently not the case:

- Different sectors are subject to different carbon prices, which distorts the level playing field for different mitigation pathways. For example, electricity production is currently subject to the highest price under the EU ETS, whereas the absence of a pricing mechanism in agriculture and LULUCF means that bioenergy is not covered by any carbon price. As a result, the EU carbon pricing regime favours bioenergy use over electrification technologies (**policy gap/inconsistency**).
- EU policies support CCU/CCS, including CO_2 infrastructure, but do not currently target their deployment to applications with no, or limited, other mitigation options (**policy gap**).
- The EU's massive policy support for the hydrogen value chain does not sufficiently reflect the techno-economic limits of hydrogen and its most efficient uses in an integrated and decarbonised energy system (**policy gap**).

- The promotion of bioenergy under the REDI and II has resulted in substantial volumes of national subsidies for bioenergy use, even in sectors where available mitigation options (e.g. electricity and low-temperature heat production) are more efficient and carry lower land-use and biodiversity risks (**policy inconsistency**).

➔ **EU policies in support of CCU/CCS, bioenergy and hydrogen should be better targeted towards applications with no, or very limited, other mitigation options** (see Chapter 4, recommendations E6 and E7; Chapter 6, recommendation T4; Chapter 9, recommendations L1, L2 and L3).

Key recommendation 11 - More policy action is needed to increase public and private investments in climate mitigation.

Annual investments in climate mitigation need to be multiplied more than fourfold (from €200-300 billion per year in recent years to €1,250-1,400 billion a year up to 2030). This requires a reorientation of existing investments and an increase in overall investments in the energy and transport sectors (by at least €500bn per year). Given the magnitude of the investment gap, a concerted effort by both public and private sectors is needed.

The EU aims to spend 30% of its long-term budget (the MFF) and at least 37% of the RRF's national envelopes on climate action. However, flaws in the methodology for tracking climate spending results in over-reporting and, in the case of the MFF, does not capture spending on potentially harmful activities (**ambition gap**).

Reporting under the RRF is more robust as it applies the 'do no significant harm' principle, in line with the EU Taxonomy. However, the facility is expected to cease after 2026 and there is no clarity on whether it will be succeeded by a similar instrument, which limits the outlook for investors (**policy gap**).

The investment gap also needs to be closed through Member States' public budgets. Their fiscal space is however constrained by high expenditures to tackle recent crises, increased competition for public budgets, higher interest rates, and the EU's fiscal rules set out in the Stability and Growth Pact. Recent changes to state aid rules provide more leeway for Member States to support mitigation projects. However, this could fragment the internal market, and measures to address this (the proposed Strategic Technologies for Europe Platform) have insufficient budget (**ambition gap**).

➔ **The reporting methodology under the MFF should be improved to track more accurately EU expenditures that contribute to climate action, and to identify spending on potentially harmful activities** (see Chapter 12, recommendation F2).

➔ **The EU should consider continuing the common debt approach under the current RRF beyond 2026 to increase investors' certainty and boost EU public investment in climate action** (see Chapter 12, recommendation F3).

The private sector will need to make a substantial contribution to achieve the required level of climate-related investments. This must be driven by sufficiently ambitious EU policies that address technology-specific risks and funding gaps, to increase the supply of bankable climate mitigation projects. Measures could include regulations, carbon pricing and – where investments are not yet profitable under current carbon pricing trajectories – other tailored financial incentives and solutions. In addition, the policy framework must address permitting, access to capital, long-term regulatory visibility, supply chains and labour availability.

➔ **EU policies should address technology-specific risks and funding gaps by speeding up permitting, removing regulatory uncertainties, and providing tailored financial incentives and solutions where investments are not yet profitable with the current carbon price trajectory** (see Chapter 12).

2.3 Develop new policies

Key recommendation 12 - Pursue more ambitious reductions in energy and material demand through new and strengthened policies.

The Advisory Board's advice on a 2040 target highlighted that pathways with more emphasis on demand-side measures have multiple co-benefits compared to those prioritising supply-side technological solutions. So far, the EU policy framework has primarily concentrated on supply-side, technology-focused measures, and much less on initiatives aimed at moderating consumption of GHG-intensive products and services. The latter are either absent (e.g. no dedicated policies to moderate transport demand, to promote healthy diets, etc.) (**policy gap**) or ineffective (for instance, a lack of progress in reducing energy demand, achieving a modal shift, or increasing material circularity) (**ambition/implementation gaps**).

Several sectoral strategies under the European Green Deal include initiatives to address the issue, but many of these have not yet been proposed (e.g. a legislative framework of sustainable food systems) or adopted (such as the Regulation on the Use of Railway Infrastructure Capacity and the revision of the Combined Transport Directive). Furthermore, some of these initiatives are primarily focused on voluntary consumer responsibility, which is unlikely to be effective on its own (**ambition gap**).

➔ **EU policies should incentivise more vigorously the reduction of energy and material demand (in mobility, housing, material use and diets), both through efficiency improvements and behavioural changes. To enable this, policies should establish structures and introduce disruptive end-use innovations which increase the quality, affordability and convenience of lower-emissions products and services. The European Green Deal sectoral strategies include several initiatives that could contribute to this, but these remain to be proposed/adopted** (see key recommendation 1, Chapter 3, recommendations E2 and E3; Chapter 5, recommendations I2 and I3; Chapter 6, recommendations T1 and T2; Chapter 7, recommendations B1, B2 and B4; Chapter 8, recommendation A3; Chapter 11, recommendation W2).

Key recommendation 13 - Expand the EU GHG pricing regime to all major sectors (including agricultural/food, LULUCF and upstream fossil fuel operations), and provide EU-level incentives for carbon removals.

The recent revision of the EU ETS Directive substantially extends the scope of the EU GHG pricing regime, from 36% of total emissions and removals today to 74% by the end of this decade. However, the remaining 26% would still be excluded from any EU-wide GHG pricing regime (**policy gap**).

Most of this gap is due to the absence of an EU-level pricing mechanism in the agricultural and LULUCF sectors. The European Commission is currently studying ways of introducing some form of pricing mechanism in these areas but has not yet tabled a formal proposal. A GHG pricing mechanism for the agricultural/food and LULUCF sectors would provide a clear financial incentive for farmers and forest managers to reduce emissions and increase removals, and for consumers to reduce consumption of GHG-intensive agricultural products. It would also address the uneven distribution of incentives for biomass use versus carbon removal and reduce the risk of intra-EU leakage of agricultural and LULUCF-related emissions.

➔ **The EU should start preparations now with a view to expanding the pricing regime of EU GHG emissions to all major emitting sectors, including agricultural/food and LULUCF. For these areas, pricing instruments should incentivise both emissions reductions and carbon removals. Instruments should reflect the specific characteristics of the agricultural/food and LULUCF sectors. This includes the technical complexity of measuring emissions and removals, attributing them to land management and mitigation actions, differences in the permanence of various natural removals, and the risk of international leakage. The impact – in particular on small farms and farms in vulnerable regions – should be assessed *ex ante* and potentially adverse economic, social and environmental impacts addressed to ensure a just and fair transition. This could be done in different ways directly targeting the problems at hand. The CAP budget or revenues from such pricing mechanisms could be used to finance redistributive measures and to support climate mitigation and adaptation efforts** (see Chapter 8, recommendation A2; Chapter 9, recommendations L3 and L4; Chapter 10, recommendation C4).

Fugitive emissions from fossil fuel extraction and handling are not covered by the EU ETS and, until recently, were not covered by any other EU reduction policy (**policy gap**). The Methane Regulation aims to address this gap, but its ambition level will depend on the implementing acts to be adopted by the European Commission. It does not set a price on upstream GHG emissions from fossil fuel extraction and handling, either in the EU or abroad. As a result, climate externalities are not fully internalised in the price of fossil fuels supplied to the EU market (**policy gap**).

The emission intensity of oil and gas extraction and handling could be lowered considerably by setting a price on upstream emissions in the energy sector. Expanding the EU ETS to fugitive emissions from fossil fuel operations within the EU, and setting up a border adjustment mechanism (reflecting the EU ETS price) on upstream GHG emissions from fossil fuels imports, would incentivise fossil fuel exporters to adopt adequate regulations; it could take into account comparable reduction efforts outside the EU (e.g. the CH_4 emission charge under the US Inflation Reduction Act). The Methane Regulation could serve as a first step towards a robust monitoring, reporting and verification system for such instruments.

➔ **The EU should address upstream emissions from fossil fuel extraction and handling, both domestically and related to fossil fuels imported into the EU. Building on the Methane Regulation, it should consider expanding the EU ETS to fugitive emissions from domestic fossil fuel operations. In parallel, a border adjustment mechanism should be introduced for upstream GHG emissions from fossil fuel imports** (see Chapter 4, recommendation E9)**. Pricing upstream emissions from fossil fuels would also contribute to the required phase-out of these fuels in the EU** (see key recommendation 5).

1 Introduction

1.1 Context

The European Climate Law (EU, 2021c) sets out legally binding objectives for the EU to reduce its GHG emissions by at least 55 % by 2030 (compared to 1990), to reach net zero GHG emissions by 2050 at the latest, and to aim to achieve negative emissions thereafter. Achieving the 2030 and 2050 climate objectives under the European Climate Law requires GHG emission reductions at an unprecedented rate and scale, which will need to be driven by a comprehensive portfolio of ambitious and effective policies covering all sectors of the economy. To put the EU on track towards the 2030 – 55 % objective, the European Commission has proposed a wide range of policies under the European Green Deal (EC, 2019c) and the Fit for 55 package (EC, 2021m), building on the existing climate and energy *acquis*, which helped the EU to achieve its climate and energy objectives for 2020.

Since the launch of the Fit for 55 package, the broader socioeconomic and geopolitical context in which the EU is pursuing its climate objectives has become increasingly challenging. The COVID-19 pandemic in 2020–2022 and subsequent recovery have resulted in global supply shortages and inflation. These worsened following the start of Russia's war of aggression against Ukraine, which resulted in historically high energy prices in the EU and increased food prices globally. High levels of inflation led to a cost-of-living crisis in the EU and undermined the international competitiveness of EU businesses – notably in energy-intensive sectors (ESABCC, 2023a). As a response to the increasing inflation, central banks increased interest rates and therefore the cost of capital, which further increased overall investment costs. Furthermore, the economic slowdown and various support measures in the context of the COVID-19 pandemic and the energy crisis have led to a surge in public debt. This constrains the available budgetary space of the various EU Member States, which are facing competition in allocating scarce public budgets between the climate transition, digitalisation, military expenditure and investments in social infrastructure. In parallel, the global race for green investments accelerated when the Biden administration adopted the US Inflation Reduction Act, which risks drawing investments in green technologies away from the EU. China's dominance in key strategic low-carbon technologies (IEA, 2023j) also continues to threaten the long-term competitiveness and resilience of the EU. These developments have made the EU's climate transition more challenging, and have made the need for a cost-effective, fair and just transition more important than ever.

On the other hand, these developments also provide strong arguments to accelerate the transition, notably to reduce the EU's dependence on imported fossil fuels, to increase its strategic autonomy in important areas and to strengthen its position in the race towards the industries of the future. In line with these arguments, the European Commission took further steps to enhance the EU climate policy framework. In response to the energy crisis triggered by Russia's aggression, it launched the REPowerEU plan (EC, 2022p), which aims to reduce the EU's dependence on Russian fossil fuels, including by reducing energy demand and increasing the domestic renewable energy supply. In 2023, after the launch of the Inflation Reduction Act in the United States, the European Commission launched a Green Deal Industrial Plan to enhance the competitiveness of Europe's net zero industry (EC, 2023u).

At the time of publication of this report, the legislative proposals under the Fit for 55 package have been adopted (with the exception of the revision of the ETD), and political attention is increasingly shifting towards implementation and the post-2030 climate policy framework. The European Climate Law requires the European Commission to put forward a legislative proposal for an intermediate 2040 reduction objective within 6 months after the first global stocktake, which implies in spring 2024 at the latest. To this end, it launched a public consultation on the 2040 target and related climate policy framework in spring 2023 (EC, 2023z). The European Climate Law requires the European Commission's proposal to consider, among other things, the advice of the Advisory Board, which was published on 15 June 2023 and recommends a reduction objective of 90–95 % by 2040 (compared to 1990), in combination with increased efforts outside the EU to achieve a fair contribution towards the 1.5 °C objective and climate neutrality by 2050 (ESABCC, 2023b).

1.2 Objective of the report

The main objective of this report is to advise EU policymakers on how to make the EU policy framework fit for net zero, by flagging potential gaps in the current framework to be addressed in order to keep the 2030 and 2050 climate objectives within reach. Where sufficient scientific evidence is available, the report also puts forward policy recommendations to address these gaps. To serve its purpose, the report focuses on two key research questions.

— To what extent is the EU on track towards achieving its climate objectives? This step makes it possible to identify areas where progress is lagging, which could be an indication of a lack of sufficiently ambitious and effective policies, or policy inconsistencies.
— To what extent are EU policies consistent with the objectives of the European Climate Law, and where is there a need for policy change to ensure such consistency?

This report is an integral part of a broader effort of the Advisory Board to provide scientific advice on existing and proposed Union measures and their coherence with EU climate objectives, and to identify actions and opportunities needed to successfully achieve those objectives, as mandated by the European Climate Law. It provides a broad overview of progress and policy consistency, across sectors and cross-cutting issues. Specific topics raised in this report will be elaborated on in subsequent, in-depth reports, such as the dedicated report on carbon dioxide removal (CDR), which is planned for publication in 2024 (ESABCC, 2022a). The Advisory Board also intends to provide periodical updates of this report.

With this first edition of the report, the Advisory Board in particular wishes to provide input to the discussions on the post-2030 EU climate policy framework, which are expected to accelerate in the after the publication of the European Commission's proposal for a 2040 GHG emission reduction objective. It is also intended as an input for new EU legislators, including the new European Commission, who will come into office after the 2024 European elections.

There are existing reports that assess progress towards the EU climate and energy objectives, including the EEA's annual Trends and Projections reports (EEA, 2023p) and the European Commission's annual Climate Action Progress reports (EC, 2023ax). For the latter, the scope of the 2023 edition was expanded to meet the requirements of the European Climate Law, which mandates the European Commission to, by 30 September 2023 and every 5 years thereafter:

— assess the collective progress made by all Member States towards the achievement of the 2050 climate neutrality objective;
— review the consistency of Union measures with that objective;
— assess the consistency of national measures – those that are identified as relevant to the achievement of the 2050 climate neutrality objective – with that objective.

Although the 2023 Climate Action Progress report does include highly relevant information on progress towards climate neutrality at both the EU and national levels, as well as recent policy developments, it does not include a systematic assessment of the consistency of EU policies with the objectives of the

European Climate Law (2). With the present report, the Advisory Board wishes to complement the reports by the EEA and the European Commission, by providing its own, independent assessment.

1.3 Scope of the report

This first edition of the report focuses on progress towards and policy consistency with the climate neutrality objective for 2050, with at least 55 % GHG emission reduction as a first milestone. Where possible (through availability and comparability of data), the assessment will also consider progress required by 2040, based on the Advisory Board's advice on the 2040 reduction objective.

The assessment will cover all major GHGs –CO_2, CH_4, N_2O and fluorinated gases (F-gases) – and all major emitting sectors of the EU economy, including energy systems, industry, transport (including international bunker fuels), buildings, agriculture and the LULUCF sector. The waste sector is not treated as a separate sector, but the consistency of waste policies is included under the industrial chapter in the context of the circular economy. Technological emission removals are not covered in this edition of the report but will be covered in a dedicated report on CDR in early 2024. In addition to this sectoral perspective, the report covers several cross-cutting issues, including carbon pricing, a fair and just transition, public engagement, finance and investments, innovation, governance, labour, skills and capacity building. The assessment in this report focuses on progress and policy consistency at the EU level and does not provide a detailed assessment of specific developments within the different Member States of the EU.

Climate adaptation, although an integral part of the European Climate Law, is not covered by this first edition of the report. The Advisory Board intends to publish a dedicated report on progress towards and policy consistency with the EU's climate adaptation objectives in the future.

The Advisory Board intends to broaden and deepen the scope of its assessment in subsequent updates of this report.

1.4 Outline

The report is structured as follows. Chapter 2 describes the underlying methodology that was used for the assessment. Chapter 3 provides a short overview of overall progress towards the EU's climate mitigation objectives. Chapters 4 to 9 describe progress towards and policy consistency with the climate objectives in each of the major emitting sectors, namely energy supply (Chapter 4), industry (Chapter 5), transport (Chapter 6), buildings (Chapter 7), agriculture (Chapter 8) and the LULUCF sector (Chapter 9). Chapters 10 to 14 cover cross-cutting issues including pricing GHG emissions and rewarding removals (Chapter 10), the need for a whole-of-society approach (which covers a fair and just transition and public engagement; Chapter 11), finance and investments (Chapter 12), innovation (Chapter 13), climate governance (Chapter 14) and labour, skills and capacity-building (Chapter 15).

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(2) The report states that 'for the first time this year this report assesses progress under the European Climate Law, including the collective progress made by Member States towards the EU's goal to achieve climate-neutrality by 2050', without referring to the issue of policy consistency. The report does acknowledge in general terms that there is scope to further improve the consistency of EU policies with climate objectives, and briefly refers to the updated better regulation instruments. However, it does not include a systematic overview of the consistency of existing EU policies with these objectives.

2 Methodology

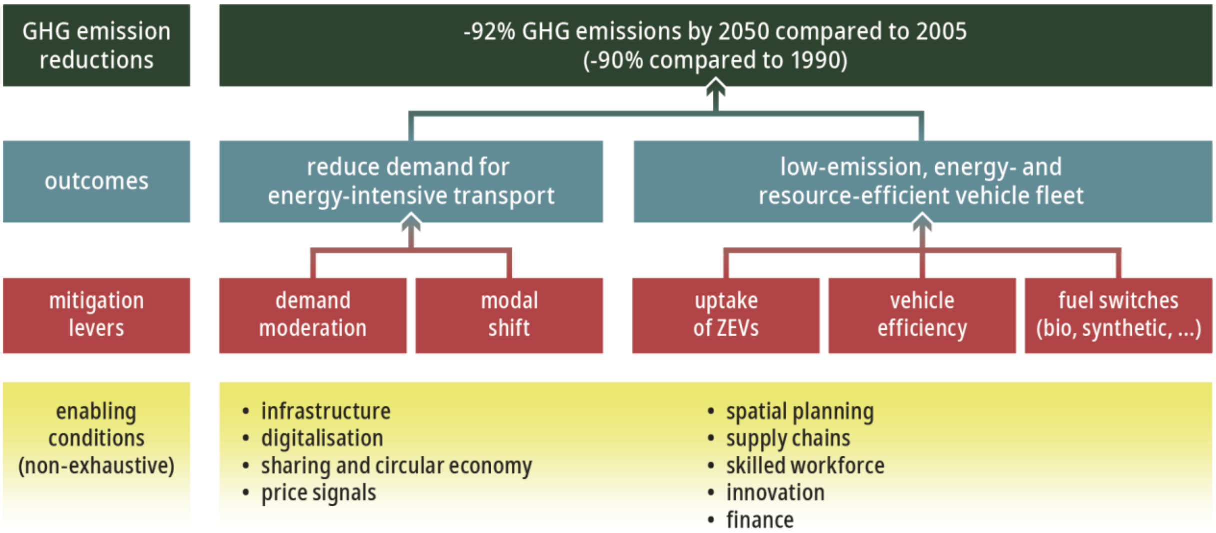
2.1 Assessment framework

Achieving deep GHG emission reductions across all sectors of the economy will require a combination of different solutions – both demand- and supply-focused – that are often interlinked, as well as a broad supporting framework to facilitate those solutions. To structure the progress and policy consistency assessment, the Advisory Board has developed a framework that structures these different elements into:

— **GHG emission reductions**, which represent the GHG emission reductions (or, in the LULUCF sector, net emission removals) that would need to be achieved in each sector by 2050 as a contribution to the economy-wide climate neutrality objective;
— **outcomes**, the main results that need be obtained both on the demand side and on the supply side, to drive GHG emission reductions in line with the required GHG emission reductions;
— **mitigation levers**, which are physical changes that, all other things being equal, are certain to contribute to the achievement of the outcomes;
— **enabling conditions**, either physical or non-physical changes that do not directly contribute to the achievement of the outcomes but can facilitate (and are in some cases crucial for) the activation of one or more mitigation levers.

This approach – which was inspired by the UK Climate Change Committee's monitoring framework (UK CCC, 2022) – is illustrated in Figure 5 (based on the assessment framework for the transport sector).

Figure 5 Illustration of the assessment framework based on its application to the transport sector



Source: Advisory Board (2024).

The GHG emission reductions required by 2050 for each sector are primarily based on the European Commission's scenarios that underpin the EU's 2030 and 2050 climate objectives, or – where available – on specific sectoral targets in official EU documents. For example, – 90 % by 2050 compared with 1990 for the transport sector is based on the European Green Deal communication (EC, 2019c).

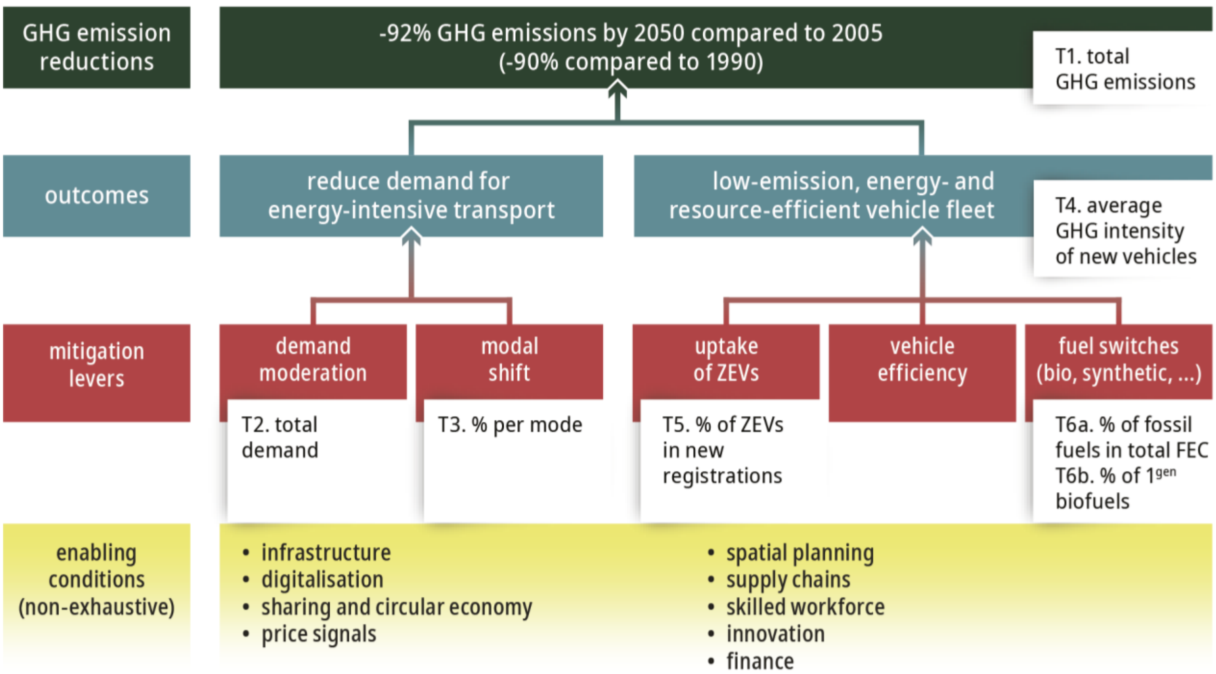
The outcomes, mitigation levers and enabling conditions draw on the mitigation pathways presented in the Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Report (AR6) (IPCC, 2022d), complemented by insights from similar assessment frameworks developed by national advisory bodies in Europe.

2.2 Methodology for the progress assessment

Progress tracking based on indicators

To assess whether the EU is on track towards its climate objectives, the Advisory Board used an indicator-based approach which was inspired by similar existing assessments (Boehm et al., 2023, ECNO, 2023, Velten et al., 2021). Several indicators were selected to track progress on overall GHG emission reductions, outcomes, mitigation levers and some (but not all) of the enabling conditions (shown in Figure 6). This selection was made taking into account (i) the need for completeness (covering the required GHG emission reductions, outcomes and most of the mitigation levers), (ii) representativeness (indicators that representatively reflect progress on the related contribution, outcome, mitigation lever or enabling condition) and (iii) data availability. The relationship between the assessment framework described above and the indicators to track progress is illustrated in Figure 6, based on the assessment framework for the transport sector. Indicators are labelled based on the title of their respective capters (e.g. O1 to O3 for indicators discussed under Chapter 3 'Overall progress', T1 to T6 for indicators discussed under Chapter 6 'Transport', etc.).

Figure 6 Illustration of indicators (white boxes) for tracking progress based on their application to the transport sector



Source: Advisory Board (2024).

Comparing historical progress with linear trajectories towards 2030 and 2050 benchmarks

For each of the selected indicators, it was assessed whether historical developments are progressing at a sufficient pace to meet specific benchmarks for 2030 and 2050. More specifically, their average annual rate of change in the past (e.g. the average annual GHG emission reductions in megatonnes of CO_2e), or the average annual increase in solar PV capacities in gigawatts (GW) was compared with the required average annual rate of change to meet benchmarks set for 2030 and 2050 (which implies linear progress towards those benchmarks).

Historical progress was measured based on data from 2005 onwards, or – where 2005 data was not available – from the most recent year for which data was available. Tracking progress on GHG emission reductions is based on the average annual reduction between 2005 and 2022. For other indicators, recent historical progress was calculated as the average annual rate of change for the last 5-year period for which data is available. In some cases, an earlier 5-year period was taken, to exclude years with outlier values. This is particularly the case for indicators in the transport sector, which showed non-representative values in 2020 and 2021 due to the COVID-19 pandemic. Historical data is primarily based on official databases, including Eurostat, the EU GHG inventories and data from the EEA. In some cases, this was complemented with data from sectoral federations.

The 2030 and 2050 benchmarks for each indicator were based on a cascading set of possible sources (in descending order of priority):

1. legally binding objectives, which are embedded in EU legislation,
2. political objectives, which are objectives not embedded in EU legislation but politically endorsed by EU institutions such as the European Council, the Council of the European Union or the European Parliament,
3. proposed objectives, which are objectives put forward by the European Commission (either in legislative proposals or in strategic documents) but are not (yet) endorsed or approved by the other EU institutions,
4. outputs of the European Commission's scenarios that underpin the EU climate objectives, notably the scenarios underpinning the Fit for 55 package (EC, 2021v), the scenarios underpinning the 2020 Climate Target Plan (EC, 2020s) ([3]), and the scenarios from the in-depth assessment accompanying the 2018 LTS 'A Clean Planet for all' (EC, 2018e) ([4]); here, priority was given to the most recent scenarios.

Five categories of progress

The final step in the progress assessment methodology is to compare the ratio of the required rates of change (based on linear trajectories towards each chosen benchmark) to the recent historical rate of change ([5]). This ratio is referred to as the '**required change**'. Depending on this required change, each indicator is assigned to one of five categories of progress, as shown in Table 1.

([3]) For the Fit for 55 and Climate Target Plan scenarios, the MIX scenario was used as a source for the benchmarks. For most indicators, the difference in the outputs for 2030 across the different policy scenarios is very limited.

([4]) The 2018 in-depth analysis is based on the EU-28. Where necessary, values were recalibrated for the EU-27 based on the EU-27/EU-28 ratio in 2015.

([5]) For indicators that are heading in the wrong direction, the final ratio was inverted (recent historical rate of change / required rate of change) to better represent the magnitude of the divergence between the historical and required future rates of change. The ratio was also inverted for some indicators that put an upward pressure on GHG emissions, but whose benchmarks still allowed for a positive rate of change in the future, to better reflect progress. For example, under the European Commission's scenarios, transport demand is projected to increase further in the future, but at a much slower rate

Table 1 Categories of progress

On track	The required change is ≤ 1.
Almost on track	The required change is between 1 and 1.5.
Somewhat off track	The required change is between 1.5 and 2.
Considerably off track	The required change is ≥ 2.
Wrong Direction	The required change is < 0.

Note: The required change is calculated as the ratio of the required rates of change (based on linear trajectories towards each chosen benchmark) to the recent historical rate of change. For indicators that are heading in the wrong direction or that put upward pressure on GHG emissions on GHG emissions but whose benchmarks still allow a positive rate of change in the future, the ratio was inverted to calculate the rate of change (see footnote (5) for more details).

Source: Advisory Board (2024).

This assessment is based on both the required change until 2030 and the required change between 2031 and 2050. The progress category for 2031–2050 is by default limited to the category assigned to the period up to 2030. If, for example, progress is considerably off track towards the 2030 benchmark, but adequate to be consistent with the trajectory between 2031 and 2050 (because the benchmarks expect most progress up to 2030, and a slowdown after that), the indicator will be considered considerably off track for 2031–2050 too.

An overview of progress in the six different sectors covered by this report, including the categorisation of progress for each of the selected indicators, is included in a summary table at the end of each chapter. A full overview of the sources and assumptions underlying the progress assessment is included in Annex I.

Limitations of the progress assessment methodology

In practice, no legal, political or proposed objectives are in place for most indicators, and the benchmarks are therefore based on the outputs of the European Commission's scenarios that underpin the EU's overall climate objectives. The Advisory Board acknowledges that the detailed outputs of these scenarios are not intended as specific objectives that need to be achieved, and that there are several possible pathways towards achieving the climate objectives for 2030 and 2050. However, it is nevertheless useful to compare progress with these scenario outputs because the non-attainment of the benchmark for one indicator would require outperformance in other indicators to attain the overall objective. If most indicators within a sector are off track compared with these scenarios, it could be a strong indication that the sector in general is not progressing in line with the EU's overall climate objectives.

It is also important to note that the overall methodology to track progress is based on benchmarks that are set by EU institutions and the European Commission in particular, without questioning the validity or adequacy of those benchmarks.

than the observed rate of change in 2015–2019. Under the standard methodology, the required change would be ≤ 1 and therefore the indicator would be categorised as 'on track'. To prevent this unrepresentative outcome, for these types of indicators the ratio to determine the required rate of change was inverted.

Finally, the progress assessment is based on linear trajectories towards the benchmarks up to 2030, and between the benchmarks for 2030 and 2050. Using such linear trajectories is a simplification which does not consider the following.

— The uptake of new technologies is non-linear. It is usually characterised by an S-shaped curve, when uptake is slow at the beginning and then accelerates strongly, to slow down again as the market saturates.
— A non-linear GHG reduction trajectory would need to be followed between 2030 and 2050, to be consistent with the 90–95 % reduction objective for 2040 as recommended by the Advisory Board (ESABCC, 2023b). To reflect this, the progress assessment for some indicators ([6]) will also refer to the progress required to be consistent with the scenarios that underpin the recommended 90–95 % reduction objective for 2040. When this is the case, it will be explicitly specified throughout the report.

2.3 Methodology for the policy consistency assessments

Focus on internal and horizontal policy consistency

Policy consistency is a broad concept that can be interpreted in different ways, at different levels and across different dimensions. At a minimal level, it implies that there are no contradictions or counteractive signals in the policy framework, implying a neutral coexistence between different policies and policy objectives. At a more comprehensive level, it could also refer to the presence of policies that are mutually reinforcing, therefore resulting in synergies, which is also often referred to as policy coherence (Evans et al., 2023; Lenschow et al., 2018; Rogge and Reichardt, 2016). Furthermore, policy consistency can be assessed internally within a specific policy domain (e.g. whether EU climate policies are consistent with its climate objectives), horizontally across different policy domains (e.g. whether EU transport policies are consistent with the EU climate objectives) and vertically across different governance levels (e.g. whether national policies are consistent with the EU climate objectives) (Evans et al., 2023).

The scope of the policy consistency assessment for this report is summarised in Table 2. This assessment is focused on identifying potentially counterproductive EU policies, which hinder progress towards its climate objectives, and on assessing the suitability of EU policies to achieve those objectives, but does not go as far as assessing synergies between different policies (for lack of available evidence in existing literature). Furthermore, it focuses on consistency across the internal and horizontal dimensions, and therefore includes an assessment of EU policies in other policy areas (e.g. agriculture, transport, energy) that can have a substantial impact on GHG emissions. The consistency of specific national policies ('vertical consistency') with the EU climate objectives is beyond the scope of this report.

([6]) Depending on availability and comparability of data.

Table 2 Scope of the policy consistency assessment

	Internal	Horizontal	Vertical
Lack of conflicts	EU climate policies do not conflict with the EU climate objectives	EU non-climate policies do not conflict with the EU climate objectives	(Sub-)national policies do not conflict with EU climate objectives
Adequacy of policies	EU climate policies are adequate to deliver on the EU climate objectives	EU non-climate policies are adequate to deliver on the EU climate objectives	(Sub-)national policies are adequate to deliver on the EU climate objectives
Synergies between policies	EU climate policies are mutually reinforcing	EU climate and non-climate policies are mutually reinforcing	EU and (sub-)national policies are mutually reinforcing

Notes: The scope of this report is included in the green box. The grey text illustrates aspects of policy consistency that are not included in the scope of this report.

Source: Advisory Board (2024), adapted from Evans et al. (2023).

Consistency assessment based on the overall assessment framework

The methodology to assess policy consistency is based on the overall assessment framework described in Section 2.1. In short, the Advisory Board has assessed to what extent EU policies are (or can be expected to be) sufficiently driving the various mitigation levers and enabling conditions to achieve the outcomes and eventually the required GHG emission reductions. The aim of this assessment is to identify:

— **policy gaps**, when there are no EU policies in place to drive the required change in the specific mitigation lever or enabling conditions;
— **policy inconsistencies**, understood as cases where EU policies are providing incentives that counteract the required change in the relevant mitigation levers or enabling conditions;
— **ambition gaps**, which means there are EU policies in place to target the relevant mitigation lever or enabling condition, but their overall ambition level – in terms of either their objectives or their delivery mechanisms – is considered to be insufficient to achieve the outcomes;
— **implementation gaps**, which means there are ambitious EU policies in place, but implementation at the EU, national or subnational level has been ineffective so far.

Focus on existing and new key EU policies

The consistency assessment was carried out both for existing EU policies that have already been in force for several years (and therefore can be assessed *ex post* to some extent) and for new EU policies that have been recently adopted or are still under development (and of which therefore only an *ex ante* assessment is possible). The latter category includes the various new policies and revisions of existing legislation under the Fit for 55 package (EC, 2021m), other relevant strategies under the European Green Deal (e.g. the Farm to Fork Strategy (EC, 2020f), the Sustainable and Smart Mobility Strategy (EC, 2020k), the CEAP 2 (EC, 2020g)), REPowerEU (EC, 2022p) and the Green Deal Industrial Plan (EC, 2023u). As many of these policies are very recent (or even not yet fully adopted), the assessment of their consistency is preliminary.

Given the wide scope of this report, the assessment focuses on the key EU policies that the Advisory Board considers to be most relevant to the EU climate objectives. Going back to our building block framework in Figure 5, it also focuses on key mitigation levers and some but not all enabling conditions. Whereas this does not constitute an exhaustive, comprehensive analysis of all EU policies that might affect the climate transition, the approach should provide a reasonably broad and robust overview of policy consistency at the EU level.

Assessment based on existing literature and independent assessment reports

The Advisory Board has based its assessment primarily on existing studies and reports that assess the consistency of EU policies with its 2030 and 2050 climate objectives. A wide variety of literature was consulted to this end, based on the following hierarchy:

1. scientific, peer-reviewed literature, with an effort to include evidence from recent publications (2019 or after),
2. reports and assessments by independent official institutions and organisations, including European organisations such as the ECA, the EEA, Science Advice for Policy by European Academies (SAPEA), the European Academies Science Advisory Council (EASAC), and international organisations including the IEA and the Organisation for Economic Co-operation and Development (OECD),
3. the European Commission’s own data and impact assessments, including reports and studies by the JRC and the European University Institute/Florence School of Regulation,
4. reports and studies written or commissioned by other, independent research institutes and think tanks.

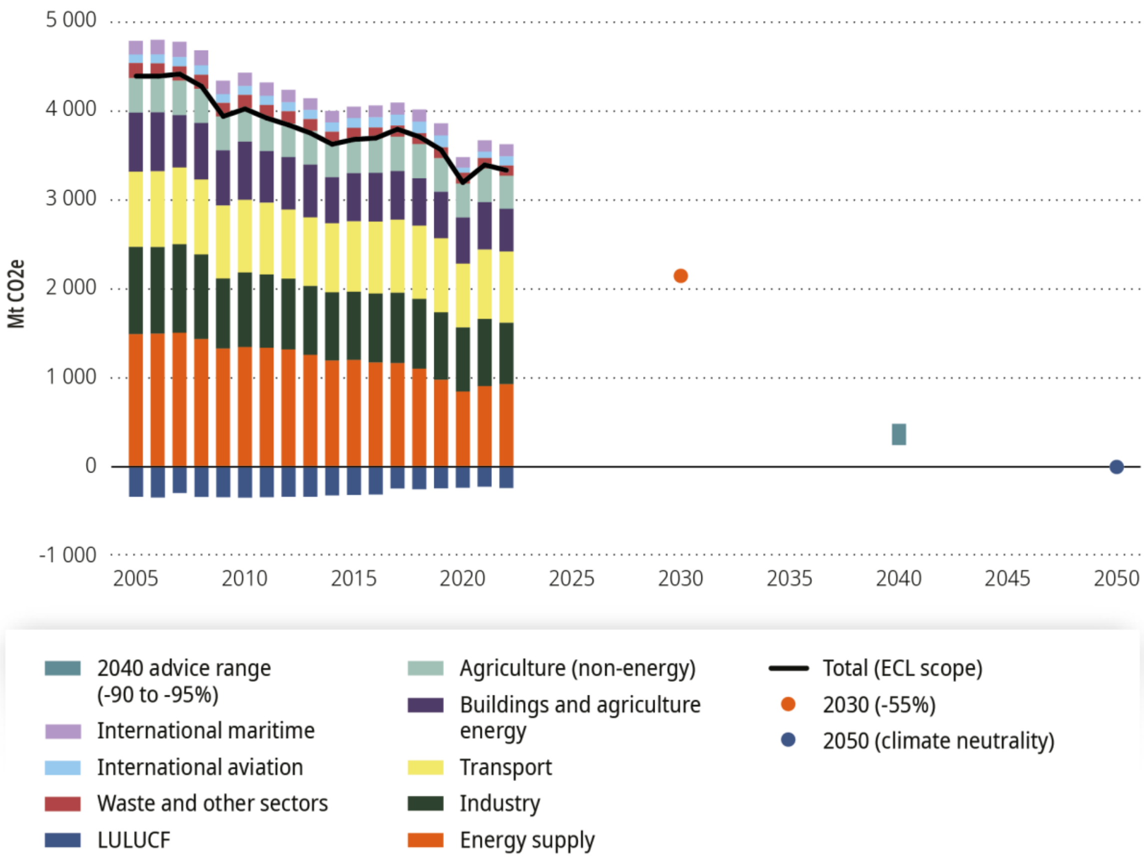
Although a wide range of literature was consulted to underpin the consistency assessment, it does not constitute a full review of all relevant available literature on the wide range of topics covered in this report. The Advisory Board has striven to give its assessment a broad scientific foundation by prioritising sources that are also synthesis assessments based on extensive literature reviews, including IPCC AR6, and by combining the joint expertise of its 15 members.

3 Overall progress

3.1 Progress on reducing greenhouse gas emissions

In 2022, total net greenhouse gas emissions in the EU (including emissions from international aviation) had decreased by 31% compared to 1990 (EEA, 2023p). Overall, the EU has managed to structurally reduce its GHG emissions by more than 1 Gt CO_2e, or 24 %, between 2005 and 2022 (based on proxy data), as shown in Figure 7. GHG emissions reduced by on average 62 Mt CO_2e per year in 2005–2022.

Figure 7 Indicator O1 – overall progress towards the EU's 2030 and 2050 GHG emission reduction objectives



Notes: Historic emissions up to 2021 from the EU GHG inventory, with 2022 data based on proxy data received from the EEA. The 2030 -55% objective and 2040 90-95% range were calculated based on a reduction from 1990 historic emission levels, the 2050 objective is set at zero in line with the EU's climate neutrality objective. Indicators are labelled based on the title of their respective capters (e.g. O1 to O3 for indicators discussed under Chapter 3 'Overall progress', T1 to T6 for indicators discussed under Chapter 6 'Transport', etc.)

Sources: GHG inventories (EEA, 2023f)

While this is substantial progress, the pace of reductions must accelerate even further for the EU to remain on track towards its current 2030 and 2050 climate objectives (see Box 1 on the assumed scope of the GHG reduction objectives under the European Climate Law). Between 2022 and 2030, emissions would need to reduce by on average 141 Mt CO_2e per year, more than a doubling of the reduction trend observed since 2005. After 2030, the pace of reductions would need to remain high, at an average of 106 Mt CO_2e per year, towards the 2050 climate neutrality objective. To achieve the recommended 90–

95 % objective for 2040, GHG emission reductions would even need to accelerate to on average 171–198 Mt CO_2e per year in 2031–2040. A promising development is that GHG reductions have been accelerating in recent years (– 94 Mt CO_2e per year in 2018–2022), a trend that had already started in 2018–2019, before COVID-19 and the energy crisis. Furthermore, the deployment of key decarbonisation technologies such as solar energy, battery electric vehicles (BEVs) and heat pumps is picking up pace.

Box 1 Scope of the reduction objectives under the European Climate Law

The European Climate Law covers all emissions and emission removals regulated by Union law. The scope of the objectives under the European Climate Law is therefore considered to include all domestic emissions and emission removals (including LULUCF), and parts of international maritime and aviation transport.

For maritime transport, the 2021 emissions that are expected to be covered by the EU ETS ('at berth', intra-EU and 50 % of extra-EU maritime transport) correspond to 64 % of the international maritime emissions reported in the GHG inventory (EC, 2023k; EEA, 2023f). Therefore, 64 % of all international maritime emissions as reported in the GHG inventories (from 1990 to 2022) are assumed to be covered by the European Climate Law.

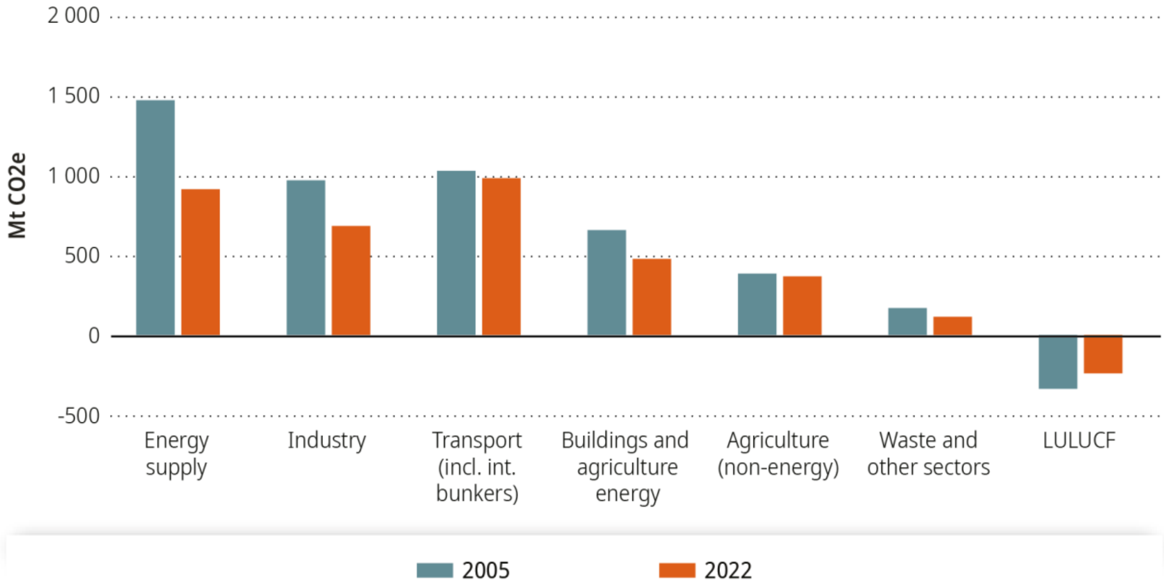
For aviation, the current EU ETS Directive covers in principle all flights arriving at and departing from airports located in the European Economic Area. However, it also provides a temporary derogation for extra-EU flights until 2026, thereby de facto limiting the EU ETS to intra-EU flights. Without further changes to the legislation, the EU ETS will again apply to both intra- and extra-EU flights as of 1 January 2027. However, Article 28b(3) of the directive requires the European Commission to – where appropriate – submit a proposal to apply the EU ETS to all flights departing from airports located in states in the European Economic Area. This would closely correspond with the GHG emissions for international aviation currently reported in the EU GHG inventories. The Advisory Board has therefore – by approximation – considered that international aviation emissions as reported in the EU GHG inventories correspond with the scope of the European Climate Law.

Whereas this report focuses on territorial (or production-based) emissions, in line with the objectives of the European Climate Law, Eurostat data on the EU's carbon footprint indicates that, in 2010–2020, consumption-based CO_2 emissions decreased on a par with production-based (or territorial) CO_2 emissions (Eurostat, 2023l). For the period before 2010, other studies have found that the technology-adjusted carbon footprint ([7]) of the EU and some of its Member States was below its territorial emissions (Jakob, 2022; Kander et al., 2015; Jiborn et al., 2018).

From a sectoral perspective (shown in Figure 8), GHG emission reductions between 2005 and 2022 were achieved primarily in energy supply (– 565 Mt CO_2e, – 38 %), followed by industry (– 290 Mt CO_2e, – 30 %) and buildings (– 183 Mt CO_2e, – 28 %). Progress in emission reductions has been considerably slower in the transport (– 47 Mt CO_2e, – 5 %) and agricultural sectors (– 19 Mt CO_2e, – 5 %). The LULUCF sector has been a net sink of GHG emissions; however, the size of the sink reduced by almost 30 % (– 98 Mt CO_2e).

([7]) This considers both embedded emissions of products imported into the EU and emissions avoided by exporting relatively GHG-efficient products from the EU.

Figure 8 Sectoral GHG emissions in 2005 and 2022



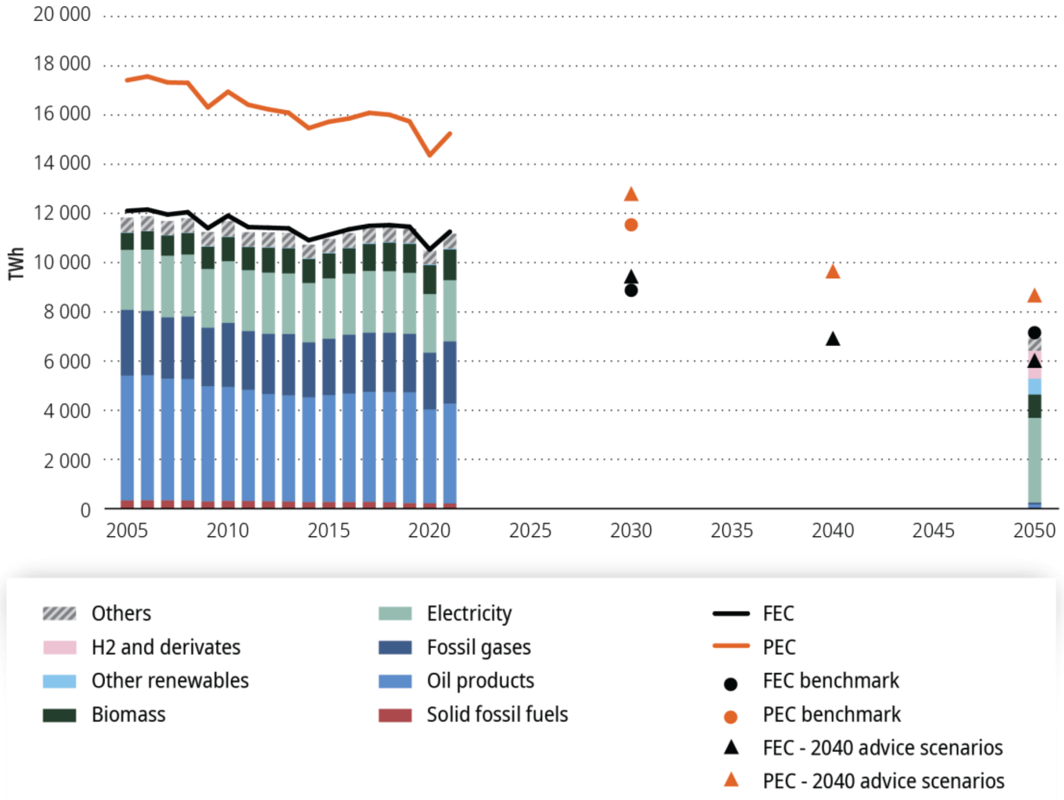
Notes: 2005 emissions based on the EU GHG inventory, 2022 emission data based on proxy data received from the EEA. Energy supply includes common reporting format (CRF) categories 1.A.1 and 1.B. Industry includes CRF categories 1.A.2 and 2. Transport includes CRF categories 1.A.3, emissions from international aviation (CRF memo item) and 64% of emissions from international shipping (CRF memo item). Buildings and agriculture energy include CRF category 1.A.4. Agriculture (non-energy) includes CRF category 3. LULUCF includes CRF category 4. Waste and other sectors includes CRF categories 1.A.5 and 5.

Sources: GHG inventories (EEA, 2023f)

3.2 Progress on energy efficiency and phasing out fossil fuels

As shown in Figure 9, in 2005–2021 the EU reduced its use of primary energy (– 12 %) and final energy (– 7 %), thereby achieving the 2020 energy efficiency target of 20 % set out under the EED (EU, 2012). However, the achievement of the 2020 target was in large part due to the COVID-19 pandemic. Without this external shock, the EU would not have reduced its energy demand sufficiently to achieve its 2020 objective, making it the only area where the EU had underdelivered its 2020 climate targets (EEA, 2022i). The average pace of reduction in final energy use in 2005–2021 (– 53 terawatt-hours (TWh) per year) would need to increase fivefold (– 265 TWh per year) in 2022–2030 to achieve the legally binding objective of 763 million tonnes of oil equivalent (Mtoe) (which corresponds to 8 874 TWh) under the revised EED (EU, 2023e). The latest EEA Trends and Projections report states that the Member States' latest projections – which date from 2019 – would only reduce final energy use to 885 Mtoe (10 293 Twh) by 2030, which is well above the newly agreed legal objective (EEA, 2023p). Such acceleration depends on energy efficiency policies; the complexities and challenges of this are addressed in more detail in Section 4.3.

Figure 9 Indicator O2 - progress in reducing primary and final energy consumption



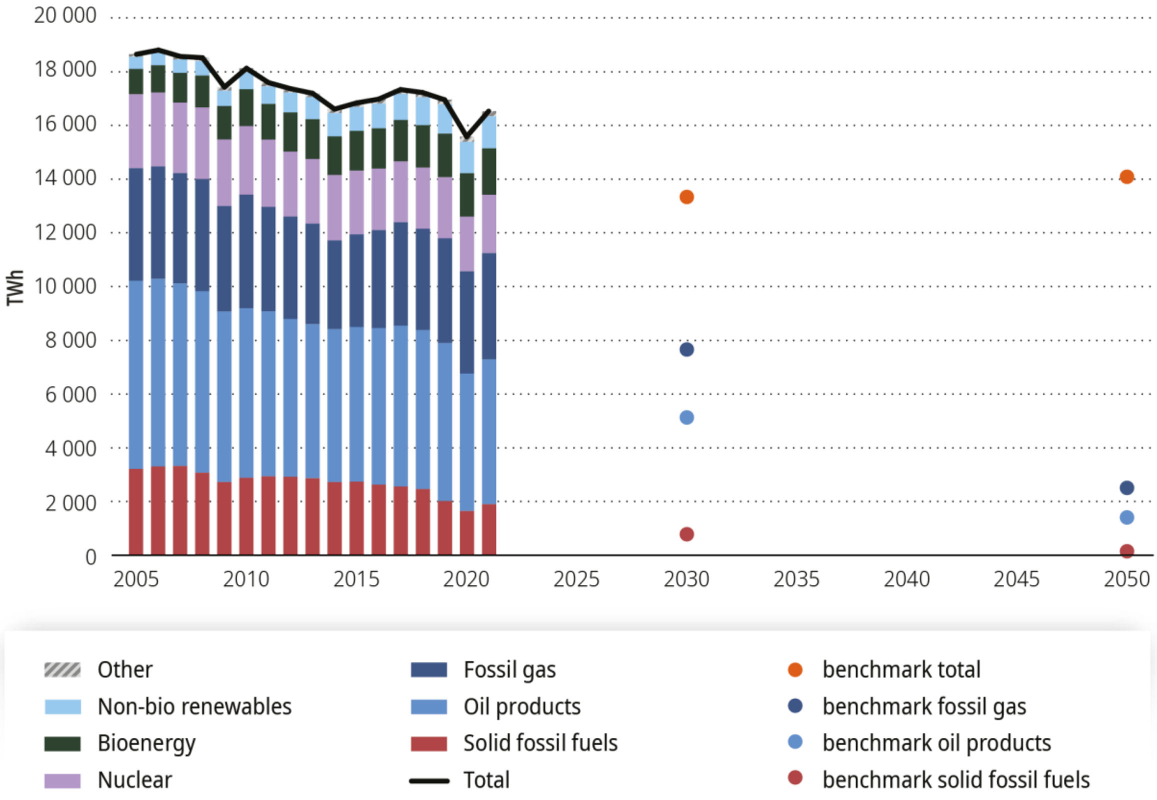
Notes: Historic energy use based on Eurostat energy balances. 2030 benchmarks based on the targets in the revised EED, while 2050 benchmarks based on the MIX Scenario from the Climate Target Plan impact assessment (Figure 17 & 37). Triangles represent the values of the scenarios underpinning the Advisory Board's advice on a 2040 reduction objective. Values converted to TWh.

Sources: Eurostat energy balances (2023b), revised EED (EU, 2023e), Climate Target Plan impact assessment (EC, 2020s), Advisory Board advice on a 2040 reduction objective (ESABCC, 2023b).

The share of fossil fuels in gross inland consumption ([8]) fell from 77 % in 2005 to 68 % in 2021, mainly achieved by a decrease in the use of solid fuels (– 5 percentage points (pp)) and oil products (– 5 pp), whereas the share of fossil gas increased (+ 2 pp). In 2021, the majority of the EU's gross inland energy use was still largely based on fossil fuels, notably oil products (33 %), fossil gas (24 %) and solid fossil fuels (12 %). To be consistent with the European Commission's scenarios that underpin the EU climate objectives, the phase-out rate for fossil fuels (on average – 0.6 pp per year in 2005–2021) would need to double up to 2030 (on average – 1.2 pp per year) and even more than triple thereafter (– 2 pp per year). By 2050, coal use would need to be phased out completely, whereas the use of oil (10 %) and fossil gas (7 %) would need to be reduced to less than 25 % of today's levels.

([8]) This includes non-energy use, but excludes energy use in international aviation and maritime transport.

Figure 10 indicator O3 - EU gross inland energy consumption



Notes: Historic energy use up to 2021 based on Eurostat energy balances. 2030 and 2050 benchmarks based on the MIX scenario of the Climate Target Plan impact assessment (figure 36). Peat and peat products included under solid fossil fuels, oil shale and oil sands included under oil products. The 'others' category includes waste and imports/exports of electricity and heat. All values have been converted to TWh.

Sources: Eurostat energy balances (2023b), Climate Target Plan impact assessment (EC, 2020s).

3.3 Progress on policy development

In 2019, the European Commission launched the European Green Deal as a strategic agenda to make the EU the first climate-neutral continent in the world (EC, 2019c). It initiated an extensive revision of the EU's policy and legal framework, with new legislation, revisions to existing legislation and additional funding all required to ensure consistency with the EU's climate ambitions. A key part of this was the Fit for 55 package, which was published in July 2021 and included a range of legislative proposals to put the EU on track towards the 2030 – 55 % objective (EC, 2021m).

While not an exhaustive list of all legislation and policy proposals stemming from the European Green Deal, Table 3 illustrates that the EU has already made substantial progress on several major pieces of legislation to align its policy and legal framework with its climate objectives. Many of the measures in the table have already been adopted at the time of writing, with those related to transport, effort sharing, carbon pricing, and finance and investments generally being the most advanced of all policy areas. Most of these adopted measures are already in force, while others, such as the EU ETS 2 and the Social Climate Fund, will come into effect in the coming years. Other policy areas are significantly less advanced and are still under negotiation between the institutions, notably many of the policies contained in the European Commission's recent Green Deal Industrial Plan and the CEAP 2. Although it is clear from this table that climate policy and legislative development have greatly accelerated since 2019, it remains to be seen whether this pace will be maintained in the coming years.

This overview illustrates the substantial progress that has been made over the last few years in developing policies to set the EU on track towards its climate objectives. However, achieving the targets set by the European Climate Law not only depends on having certain legislation or policies in place, but requires them to be sufficiently ambitious, strong and comprehensive to deliver on the change required in the coming decades. Nor does this broad overview give insights into potential challenges or gaps in the implementation of different policies, which ultimately depends on the collective efforts and resources committed by the EU and Member States. This report therefore aims to provide a more comprehensive overview of the EU's progress towards climate neutrality by assessing current and future policies, identifying potential gaps or inconsistencies in their design and implementation, and providing recommendations on how to build on the progress that has been achieved to date on the path to climate neutrality.

Table 3 Summary overview of progress on the adoption of climate-relevant policies

Topic	Initiative	Legislative status
Carbon pricing and effort sharing	EU ETS for stationary installations (revision)	Adopted
	EU ETS 2 for buildings, road transport and additional sectors	Adopted
	Carbon Border Adjustment Mechanism	Adopted
	Effort Sharing Regulation (revision)	Adopted
Energy	Renewable Energy Directive (revision)	Adopted
	Energy Efficiency Directive (recast)	Adopted
	TEN-E Regulation (revision)	Adopted
	REPowerEU plan	Adopted
	EU electricity market design (revision)	Tabled
	Hydrogen and decarbonised gas market package	Close to adoption
	Methane Regulation	Close to adoption
	Energy Taxation Directive (revision)	Tabled
Buildings	Energy Performance of Buildings Directive (recast)	Close to adoption
	Construction Products Regulation (revision)	Close to adoption
Industry	Batteries Regulation	Adopted
	F-Gas Regulation (revision)	Close to adoption
	Net-Zero Industry Act	Tabled
	Critical Raw Materials Act	Close to adoption
	Industrial Emissions Directive (revision)	Close to adoption
	Ecodesign for Sustainable Products Regulation	Close to adoption
	Packaging and Packaging Waste Regulation (revision)	Tabled
	Waste Framework Directive (revision)	Tabled
	Right to Repair Directive	Tabled
	Green Claims Directive	Tabled
Transport	CO_2 emission standards for cars and vans (revision)	Adopted
	Alternative Fuels Infrastructure Regulation	Adopted
	ReFuelEU Aviation Regulation	Adopted

Topic	Initiative	Legislative status
	Carbon Offsetting and Reduction Scheme for International Aviation	Adopted
	EU ETS for aviation (revision)	Adopted
	FuelEU Maritime Regulation	Adopted
	CO_2 emission standards for heavy-duty vehicles (revision)	Tabled
	End-of-life vehicles Regulation (revision)	Tabled
	Trans-European Transport Network Regulation (revision)	Close to adoption
	Regulation on the use of railway infrastructure capacity in the single European railway area	Tabled
	Combined Transport Directive (revision)	Tabled
Carbon removal	Certification framework for carbon removals	Tabled
Agriculture	Sustainable food systems legislative framework	Announced
Land use	LULUCF Regulation (revision)	Adopted
	Nature Restoration Law	Close to adoption
	Soil Health Law	Tabled
Finance and investment	Taxonomy Regulation (for sustainable investment)	Adopted
	Social Climate Fund	Adopted
	Just Transition Fund	Adopted
	European Green Bond Regulation	Adopted

Notes: Measures are classed as 'adopted' if the legislative process has been fully completed, 'close to adoption' if interinstitutional/trilogue agreement has been reached, 'tabled' if at a different stage of the legislative process and 'announced' when they have been announced (e.g. in one of the sectoral strategies under the European Green Deal or in the European Commission's annual work programme) but a formal proposal has not yet been tabled by the European Commission.

4 Energy supply

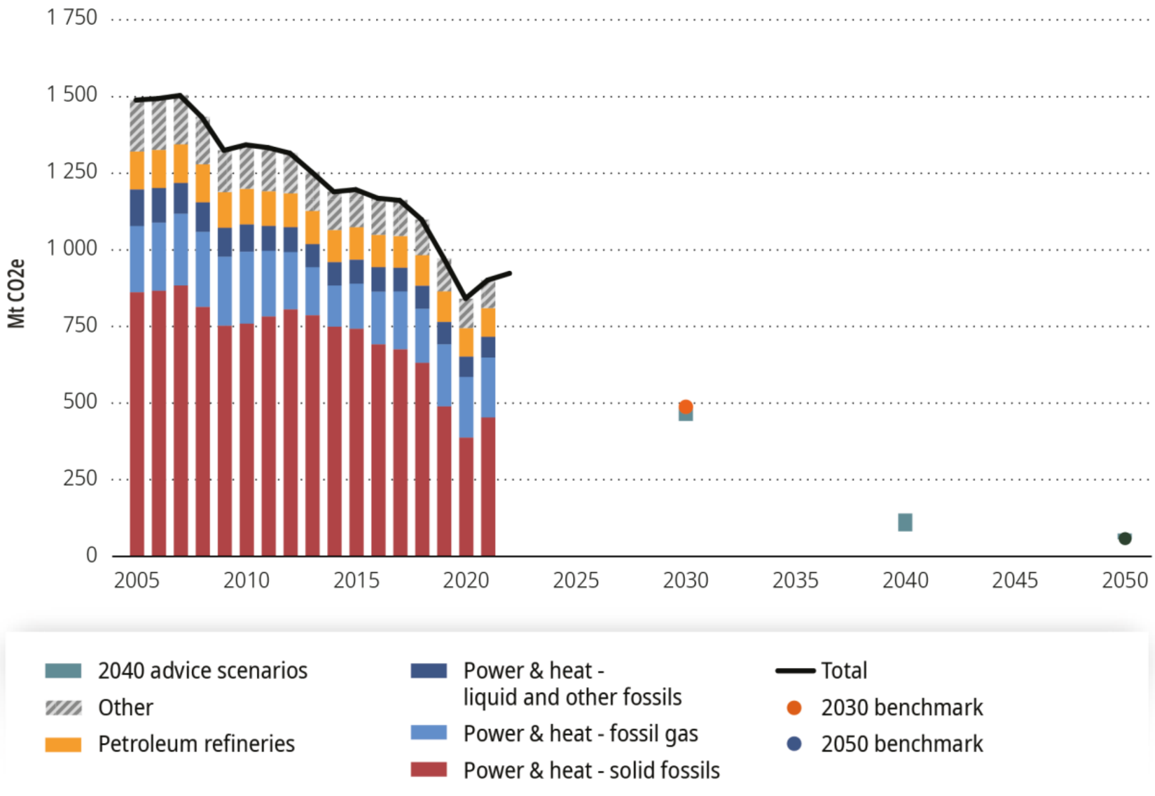
Key messages

Despite substantial progress since 2005, the rate of reductions in the energy supply sector needs to increase to be consistent with the overall 2030 – 55 % objective.

The energy supply sector has reduced its GHG emissions by 38 % since 2005, as shown in Figure 11. However, the average rate of reduction up to 2030 needs to increase by a factor of 1.6 compared with 2005–2022 to be consistent with the European Commission's scenarios underpinning the 2030 – 55 % reduction objective. At the same time, the sector's output in terms of electricity generation would need to increase considerably to enable the electrification of end use sectors.

To decarbonise the EU's energy supply in the long term, the end use electrification rate has to pick up and reach annual increases of 1 pp, so that at least one third of end use demand is electrified by 2030. Non-biomass RES need to be scaled up, mainly by doubling the annual rate of solar power capacity installation and a fivefold increase in the annual rate of offshore wind installation. This needs to be accompanied by increases in the annual rate of CH_4 emission reduction in the energy sector by a factor of 1.4, and in the annual rate of reduction of fossil fuel use in electricity generation by a factor of 1.5. To underpin this changing energy supply structure, it is estimated that annual electricity grid investment must increase by at least a factor of 1.5 to reach nearly EUR 60 billion per year, with a large share of new investment directed towards distribution grids (low and medium voltages).

Figure 11 Indicator E1 – overall progress in reducing GHG emissions in the energy supply sector



Sources and Notes: See Figure 13 for detailed sources and notes.

The decline in coal and fossil gas is too slow as a result of insufficient price signals, continuing subsidies and inconsistencies in the EU policy framework.

Needs. To be consistent with the European Commission's scenarios underpinning the 2050 climate neutrality objective, the EU needs to sharply decrease the use of fossil fuels (see Section 3.2), and almost fully phase out the use of coal and fossil gas in public electricity and heat generation by 2040 The share of oil in energy supply also needs to decline. Oil decline is not covered in this chapter given its relatively small share in the overall EU (non-transport) energy supply structure.

Gaps. The revised EU ETS provides a strong signal to phase out fossil fuel use in public electricity and heat production. However, not all EU policies are consistent regarding the declining role of fossil gas in future energy systems (e.g. the TEN-E Regulation, the proposed Gas Directive and regulation, State aid rules and the EU Taxonomy), and, because of the necessary speed of change in the energy sector, decisions made today are risking costly infrastructural and contractual carbon lock-ins **(policy inconsistency)**.

Recommendation E1. Practices within the EU policy framework, such as the scenarios and assumptions used in cross-border infrastructure planning and development, should be consistent with EU pathways to climate neutrality. According to these, fossil fuel use decreases sharply and is almost fully phased out from EU's public electricity and heat generation by 2040 ([9]). In this respect, and with a view to helping the EU avoid costly carbon lock-in effects, EU policies should be better aligned with net zero goals, notably in the field of energy infrastructure and markets (e.g. TEN-E, the internal energy market framework), finance (e.g. the EU Taxonomy), industrial emissions (e.g. the industrial emission directive) and competition (e.g. State aid rules).

The EU's target for final energy demand reduction is fit for net zero, but achieving it calls for energy efficiency – including its multiple benefits – to be better measured and understood, and for the energy efficiency first principle to be systematically put into practice.

Needs. The EU needs to substantially increase and accelerate energy savings in both primary and final energy consumption to reach the 2030 targets under the EED (see also Section 3.2).

Gaps. Energy efficiency is the only area where the EU made insufficient progress to achieve its 2020 target (which was met thanks to the impact of the COVID-19 pandemic). Progress was hampered by, among other things, insufficient understanding and measurement of energy efficiency and its multiple benefits as part of planning and reporting under the EED and energy retrofit investment schemes. Understanding issues also led to insufficient operationalisation of the energy efficiency first principle so far **(implementation gap)**. While the EED aims to reinforce the application of the energy efficiency first principle, it sets a very high investment value (EUR 100 million) threshold, which means that many relevant projects will be exempted from assessment of energy efficiency solutions, including demand-side resources and system flexibilities **(ambition gap)**.

Recommendation E2. To achieve the 2030 energy efficiency targets under the EED, EU policies should foster public awareness of the multiple benefits of energy efficiency, such as energy security and health, and increase common understanding and measurement of energy efficiency under the EED. To this end, policies should be informed by insights from the energy efficiency obligation schemes and the coordinated measures to reduce demand for fossil gas.

([9]) Any remaining fossil gas share in the EU's 2040 energy mix for public electricity and heat generation is marginal.

Recommendation E3. Putting the energy efficiency first principle into practice should be mandatory for all energy infrastructure projects advancing energy system integration. The investment value threshold set out in Article 3 of the EED should be lowered.

The deployment of solar PV and wind energy needs to accelerate across the EU and lead to a net zero electricity system by 2040 at the latest. Progress is challenged by changing investment landscapes, and by inadequate infrastructure planning and development, spatial planning, issuing of permits, workforce skills and supply chains.

Needs. The EU needs to massively scale up solar PV and wind energy deployment, with a view to decarbonising electricity supply by 2040 at the latest. The considerable obstacles to accelerating and enabling deployment must be urgently overcome, including electricity grid infrastructure development, permit-issuing, supply chain and workforce barriers.

Gaps. EU policies have been adapting to this challenge, among others, through the REPowerEU plan, new permit-issuing rules, the revised RED III, legislative proposals on the electricity market design and the Net-Zero Industry Act. The RED III, including the newly adopted target of a 42.5 % renewable energy share in final energy consumption and the electricity market reform are mostly in place, the RES value chain reinforcement is still under negotiation **(policy gap)**. This lowers investment certainty and affects system planning and decision-making, for instance in PV and wind value chains, as they have not yet been adjusted to the required deployment and industry growth. Moreover, while changes to the design of RES support schemes allow adaptive improvements, they may also increase investment risks and decrease investors' certainty.

Recommendation E4. EU policies reflecting the growth needs in wind and solar PV need to be adopted and implemented without further delay with a view to reinforcing long-term investment signals. To attract investment, support schemes for RESs need to (i) be stable, (ii) offer a long-term market outlook and (iii) find a balance between least-cost RES at scale and nurturing technological innovation. The long-term investment outlook should be reinforced through the 2023–2024 NECP process, which can reveal national ambitions regarding RES investments including, for example, volumes of auctions measured against the pace of progress required to achieve climate neutrality by 2050.

The topic of bioenergy is discussed in Section 9.5 (see enabling condition "Keep biomass demand within sustainable limits").

Although the European Commission endorsed system integration as a strategic direction in 2020, the EU still lacks long-term planning for a transformation of the energy system as a whole. Policy support is needed to boost direct electrification, digitalisation and non-fossil flexibility options. These mitigation options require distribution system operators (DSOs) and regulators to adapt fast. Direct electrification should be prioritised over indirect electrification (e.g. hydrogen) to avoid conversion losses.

Needs. Cost-effective decarbonisation requires energy system integration through RES-based electrification and digitalisation. The share of electricity in the EU's energy use needs to double by 2040, which means the recent trend needs to be reversed. By 2030, the flexibility needs of the EU electricity system will more than double from today's level. To meet them, demand-side response, grid expansion and innovation, storage and dispatchable generation need to be upscaled. Distribution system operations play a key role in this process, but the network operators and regulators need to adapt fast.

Gaps. Despite the endorsement of the system integration as a strategic direction by the European Commission in 2020, the EU still does not plan and operate the energy system as a whole **(implementation gap)**, as pointed out by the Advisory Board in its previous contribution on decarbonised and resilient EU energy infrastructure (ESABCC, 2023c). This risks locking in options that are not viable beyond 2030 as the EU moves towards a decarbonised energy system. Carbon lock-ins increase long-term mitigation costs and delay the net zero transition. Digitalisation of the energy sector was embedded in an EU action plan in October 2022 and is synergetic with existing and new EU policies (e.g. the RED III, the EED, the EPBD, the Net-Zero Industry Act) that aim at encouraging direct electrification, demand response, and district heating and cooling. EU policies so far have not sufficiently activated new players (e.g. aggregators, active consumers), the roles of transmission and distribution system operators and regulatory authorities, and dynamic pricing and business models (e.g. virtual power plants). The impact of the new laws including the electricity market reform in terms of upscaling demand response and storage is still uncertain. The EU's massive policy support to the hydrogen value chain does not sufficiently reflect the techno-economic limits of hydrogen and its role in the integrated and decarbonised energy systems **(policy gap)**.

Recommendation E5. The EU should improve energy system integration through better energy infrastructure planning and development and through urgently delivering on new policies to bring about direct electrification and non-fossil flexibilities in line with the energy efficiency first principle.

Recommendation E6. EU policies should better target hydrogen deployment, prioritising well-defined uses that cannot be directly electrified, notably in industrial processes (see Chapter 5 'Industry') and fuels for some modes of transport (mostly aviation and shipping; see Chapter 6 'Transport').

EU policies support CCU/CCS without a strategy for targeting their deployment to applications that have no of very limited other mitigation options.

Needs. Fossil fuel phase-out is a priority for the decarbonisation of EU energy systems. By 2050, CCU/CCS needs to play only a limited role in energy supply. This is because of the limitations of CCU/CCS such as its capital intensity and impacts on the energy system. The value chain of CCU/CCS across the EU is not yet mature and needs to be developed only where non-fossil alternatives are not viable.

Gaps. Several EU policies support CCU/CCS, including CO_2 infrastructure (e.g. REPowerEU plan, hydrogen strategy, TEN-E Regulation, Innovation Fund, Net-Zero Industry Act proposal, State aid rules), without targeting their deployment to applications with no or limited other mitigation options. Residual emissions (e.g. in agriculture or industry) that motivate the use of carbon capture and storage (CCS) are currently not defined at the EU or Member State level **(policy gap)**.

Recommendation E7. Carbon capture and utilisation or storage are less efficient or have higher sustainability risks compared to other mitigation pathways such as renewable energy deployment. EU policies in support of the CCU/CCS should be better targeted towards applications with no or very limited other mitigation options (see Chapter 5 'Industry' and Chapter 9 'Land use, land use change and forestry').

Progress in development and roll-out of innovative energy technologies is too slow to unlock the decarbonisation of the EU energy supply. To remain a front runner in innovative energy technologies, the EU has to increase its efforts in research, development and market scale-up of innovative renewable energy and flexibility sources.

Needs. The EU needs to improve support of research and innovation, and accelerate market scale-up of innovative renewable energy technologies. Other technologies such as concentrated solar power, geothermal energy and innovative storage concepts could contribute significantly more to EU energy supply if innovation hurdles and inadequate value chains were addressed.

Gaps. Despite the strategic policy direction towards the market upscaling of innovative renewable energy technologies, they show slow progress in market roll-out because of immature markets and inadequate value chains involving high upfront costs and significant technical risks, among other reasons.

Recommendation E8. The EU should review its allocation of research and development (R & D) spending to technologies, considering their expected and potential future contributions to the energy mix. This can also include support to build up value chains and workforce skills (see Chapter 13 'Innovation' and Chapter 15 'Labour, skills, and capacity building').

The largest sources of CH_4 emissions from the energy sector were subject to a major EU policy gap until the agreement on the EU regulation on CH_4 emissions from the energy sector in November 2023. The new regulation is a step in the right direction, but the actual ambition of the new rules is yet to be defined. The EU should also consider expanding the EU ETS to fugitive emissions from domestic fossil fuel operations, and in parallel introduce a border adjustment mechanism for upstream GHG emissions from fossil fuel imports.

Needs. By 2050 at the latest, the EU needs to eliminate fugitive CH_4 emissions from coal and fossil gas operations and from biomass combustion, which are the largest sources of energy-related CH_4 emissions. Fugitive CH_4 emissions are currently not systematically measured and can continue many years after oil, gas or coal operations have ceased. Until recently, fugitive CH_4 emissions in the energy sector have not been addressed by EU policies. The new EU regulation on CH_4 emissions from the energy sector aims to address this gap and could become a crucial instrument in EU energy supply decarbonisation. At the time of writing of this report, no agreed legislative text had been published, however. The regulation's scope also covers non-EU operators exporting fossil fuels to the EU. In this regard, the new law offers an opportunity for the EU to support global decarbonisation efforts.

Gaps. The new EU regulation on CH_4 emissions in the energy sector requires monitoring, reporting and verification measures to be put in place only by 2027, and maximum CH_4 intensity values by 2030. The ambition of the applicable thresholds, including the minimum detection limits and the maximum CH_4 intensity values, will depend on the implementing acts to be adopted by the European Commission. This indicates a delay and ambition uncertainties in EU policies on reducing energy-related CH_4 emissions. The regulation does not put a price on leaking upstream emissions and does not align with similar international initiatives **(policy gap)**.

Recommendation E9. The EU should address upstream emissions from fossil fuel extraction and handling, both domestically and related to imported fossil fuels imported into the EU. Building on the Methane Regulation, it should consider expanding the EU ETS to fugitive emissions from domestic fossil fuel operations, and in parallel introduce a border adjustment mechanism for upstream GHG emissions from fossil fuel imports. Pricing upstream emissions from fossil fuels would also contribute to the required phase-out of fossil fuels in the EU.

4.1 Scope and sectoral assessment framework

Scope

This chapter focuses on the energy supply sector, which includes electricity and (public) heat production, and fossil fuel extraction, processing (e.g. refining), transport and distribution (including fugitive emissions).

The interplay between energy supply and demand is a key factor in the clean energy transition, as demand-side responses can enable greater renewable energy penetration and more efficient energy uses. Therefore, the policy consistency assessment in the chapter goes beyond energy supply, and also considers broader aspects of energy demand. The demand for energy in end use sectors and specific policies to address this are further elaborated on in the dedicated chapters (see Chapter 5 'Industry', Chapter 6 'Transport' and Chapter 7 'Buildings').

Greenhouse gas emission reductions required in the energy supply sector to reach climate neutrality

According to the European Commission's policy scenarios underpinning the 2050 climate neutrality objective, the energy supply sector will need to achieve near-zero GHG emissions by 2050 (zero emissions in electricity, > 90 % reductions in other supply sectors), before considering negative emission technologies. The use of fossil fuels for public electricity and heat generation would need to be almost fully phased out by 2040, resulting in zero emissions from those activities by that date at the latest. (EC, 2018a, EC, 2020h). This is also consistent with the IPCC scenarios, which see the energy supply sector reach net zero emissions well before other sectors of the economy on the path to climate neutrality by 2050 (IPCC, 2022g).

Assessment framework for the energy supply sector

Outcomes. Two main outcomes are considered for the assessment: reduced GHG emissions from energy supply, and reduced energy demand.

Mitigation levers. To achieve these outcomes, six main mitigation levers were identified based on IPCC AR6 and other scientific literature.

- **Energy efficiency.** Bring down energy sector needs, including energy conversion and distribution losses, through fossil fuel phase-out, deployment of RESs and direct electrification. Beyond energy supply, energy efficiency depends on end use sectors and their efficient consumption of energy in sufficient quantities.
- **Fossil fuel phase-out.** Substantially lower the use of fossil fuels compared with today by decommissioning of coal, gas and oil facilities, and limited carbon abatement/removal in specific cases. Given the low demand for oil in the energy sector (less than 5 % in 2021 according to (Eurostat, 2023b), the phase-out of oil is addressed in sectoral analyses in Chapters 5–7.
- **Fast roll-out of renewable energy at scale.** Significantly increase and accelerate deployment of RESs, mainly wind and solar PV, but also dispatchable non-biomass renewables. Bioenergy deployment, subject to stringent sustainability criteria and the energy efficiency first principle, also contributes to a net zero energy system.
- **System integration.** Coordinated planning and operation of the energy system as a whole, across multiple energy carriers, infrastructures and consumption sectors (European Commission,) should focus on (i) zero-carbon flexibility solutions, such as storage and advanced control tools, and (ii) direct electrification of end uses, including light-duty transport, space heating and cooking.

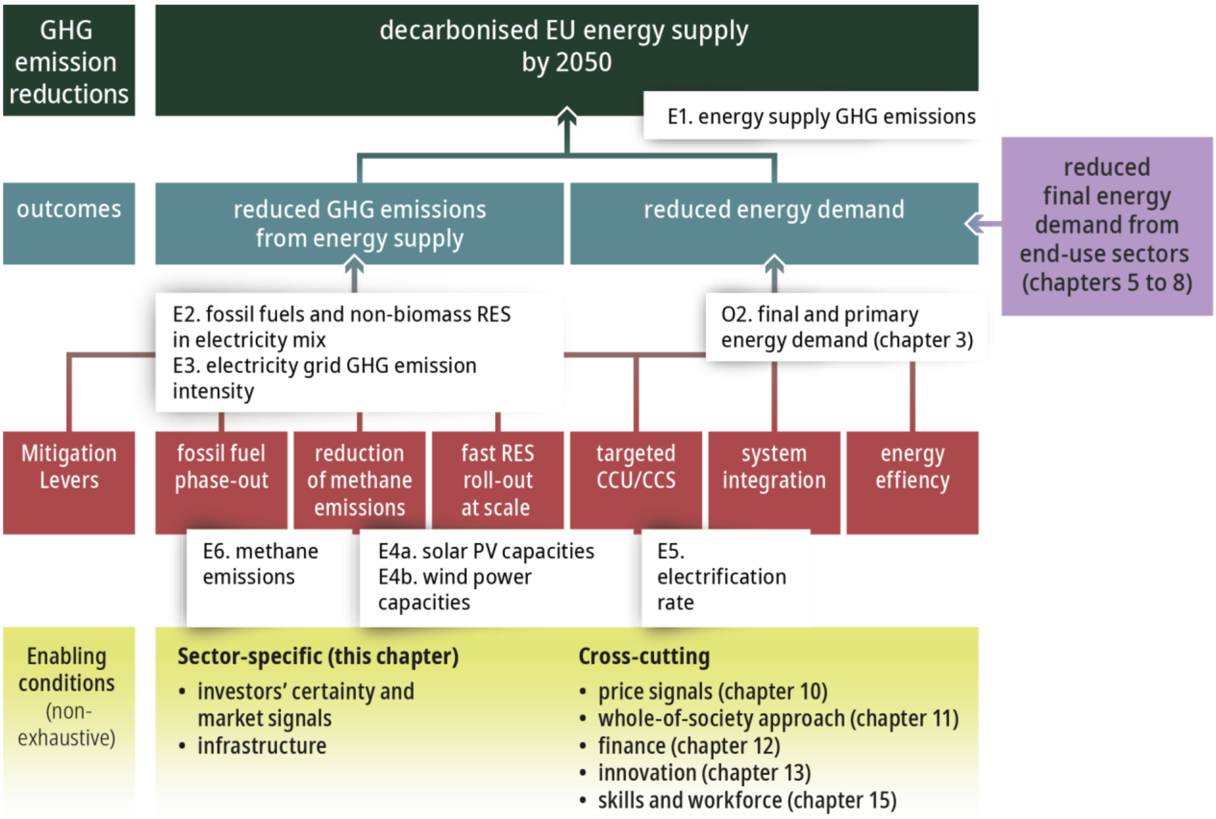
— **Targeted carbon capture and utilisation/storage.** Apply CCU/CCS in a number of industrial processes and the fossil fuel electricity sector where non-fossil mitigation options have been exhausted, based on a scientifically led definition of residual emissions.
— **Reduction of CH_4 emissions.** CH_4 mitigation options in energy supply include leak detection and repair in fossil gas operations, and CH_4 recovery.

Enabling conditions. In addition, seven enabling conditions have been identified as key to at least one of the mitigation levers described above. Two sector-specific enabling conditions are addressed in this chapter.

— **Infrastructure.** Energy system planning should include identifying net zero projects, scaled-up investment in electricity grids at all voltage levels, and faster issuing of permits for renewable energy infrastructure within the bounds of sustainability.
— **Market signals.** Regulatory certainty, long-term investment signals and well-functioning wholesale and retail markets can stimulate the expansion of variable energy sources and their integration with non-fossil flexibility solutions.

Some other cross-cutting enabling conditions, which are discussed in other chapters of this report (price signals, public engagement and a just transition, finance, innovation and a skilled workforce) are also relevant to the energy supply sector, as shown in Figure 12. This figure also shows the indicators (shown in the white boxes) that were selected to track progress in the energy supply sector.

Figure 12 Assessment framework for the energy supply sector

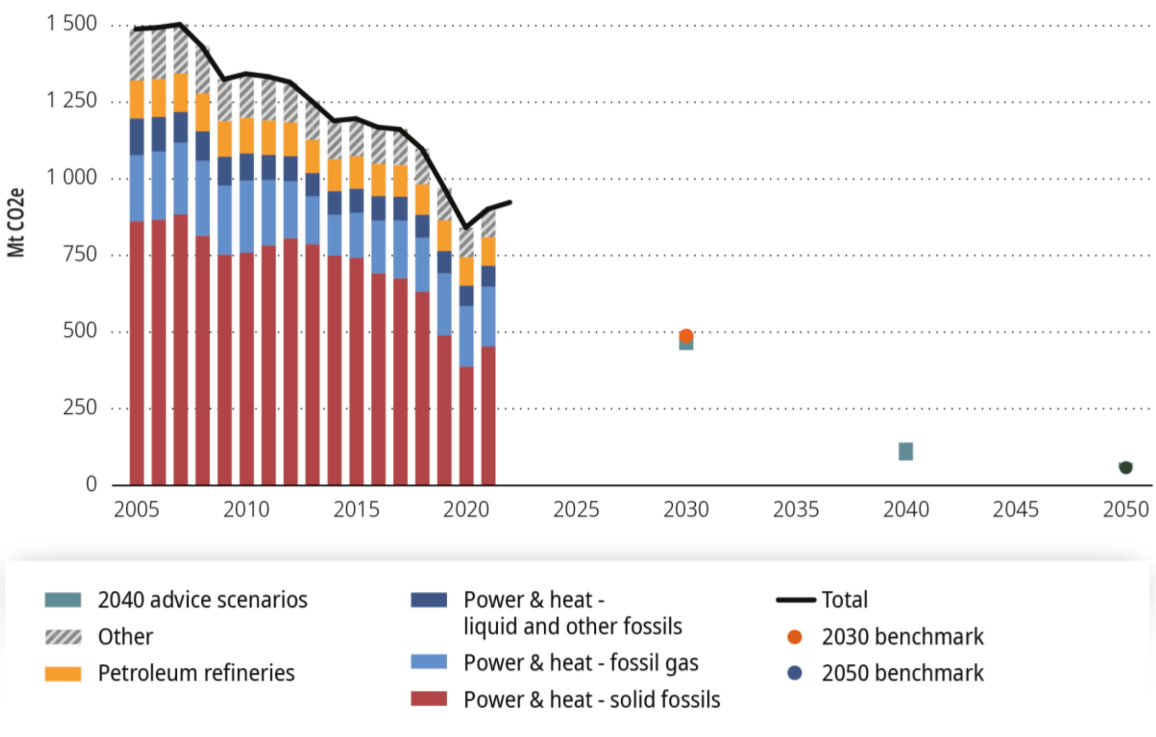


Source: Advisory Board (2024).

4.2 Emission reduction progress

The energy supply sector reduced its GHG emissions by 565 Mt CO_2e (– 38 % or – 33 Mt CO_2e per year) between 2005 and 2022 (see Figure 13). Between 2005 and 2020, there was a decrease of 648 Mt CO_2e (– 43 % or – 43 Mt CO_2e per year), followed by a rebound in GHG emissions in 2021 (+ 60 Mt CO_2e) and 2022 (+ 22 Mt CO_2e). The reduction until 2021 was mainly achieved by reduced coal use for electricity and heat production (– 407 Mt CO_2e, 70 % of the total decrease), with smaller emission reductions in other parts of the energy supply sector. The use of coal for electricity generation was mainly replaced by solar and wind electricity, and to a lesser extent by increased biomass use. If the average annual reduction experienced between 2005 and 2022 in the energy supply sector (– 33 Mt CO_2e per year) is maintained, the energy supply contribution will be sufficient to ensure net zero emissions by 2050. However, because the sector must decarbonise faster than other sectors, an acceleration of emission reductions to on average 54 Mt CO_2e per year (or by a factor of 1.6 compared with 2005–2022) is required to reach the 2030 benchmark. In pathways consistent with the 90–95 % objective recommended by the Advisory Board, the rate of reductions will then need to remain between 35 and 41 Mt CO_2e per year in 2031–2040.

Figure 13 Indicator E1 – overall progress in reducing GHG emissions in the energy supply sector



Notes: Historic emissions up to 2021 from the EU GHG inventory, with 2022 data based on proxy date reported by Member States to the EEA. Historic emissions include all GHG emissions from energy industries (CRF category 1.A.1) and fugitive emissions from fuels (CRF category 1.B). The 'other' category includes emissions from mining, fuel production other than petroleum refining, and gas distribution. The 2030 benchmark is based on the Fit for 55 MIX scenario and includes CO_2 emissions from electricity, heat and the "energy branch" and CH_4 emissions from energy use. The 2040 advice range is based on the scenarios which underpin the Advisory Board's 2040 advice. The 2050 benchmark is based on the 1.5TECH scenario of the in-depth analysis accompanying a Clean Planet for all (recalibrated for EU27 based on 2015 data), and includes all GHG emissions from electricity production, refineries and energy-related fugitive emissions.

Sources: GHG inventories (EEA, 2023f), Fit for 55 MIX scenario (EC, 2021v), Advisory Board 2040 advice scenarios (ESABCC, 2023b), in-depth analysis accompanying a Clean Planet for All (EC, 2018e).

4.3 Outcomes 1 and 2: decarbonised energy supply and reduced energy demand

Lever: energy efficiency

The EU target for final energy demand reduction is fit for net zero, but attention should be paid to energy intensity and emission intensity of energy supply as well as common metrics and understanding of energy efficiency concepts and benefits.

As described in Section 3.2, additional efforts are needed to achieve the legal objective of reducing the EU's final energy consumption to maximum 8 874 TWh in 2030.

The EU's energy demand is driven by many factors, including seasonal temperature changes, price signals and the structure of the EU economy. The flagship EU policy instrument driving energy demand reduction is the EED (EU, 2012), revised in 2023, which sets out EU energy efficiency targets for 2030. The agreed targets are final energy consumption of no more than 740 Mtoe (8 606 TWh) and primary energy consumption of no more than 960 Mtoe (11 165 TWh) at the EU level in 2030, which translates into a 40 % reduction in final energy consumption relative to the 2007 modelling projections for 2030(EU, 2023e). The new target is in line with the energy demand projections in the 2040 scenarios assessed by the Advisory Board (ESABCC, 2023b), and the Advisory Board therefore considers it to be fit for net zero.

In terms of final energy demand savings, the EED sets out energy efficiency obligation schemes, a flagship instrument in support of the EU energy efficiency target so far (EC, 2021g). The EU Member States should achieve cumulative end use energy savings up to 2030, with annual savings of at least 0.8 % of final energy consumption by the end of 2023, increasing gradually to 1.9 % from 2028 (EU, 2023e). This measure focuses on final energy consumption, and 'can be designed in a variety of ways to meet national needs, and to fit within very different policy mixes' (Fawcett et al., 2019). The success of final energy demand savings depends on the public's acceptance of ambition levels and its adoption of the saving measures they trigger (Fawcett et al., 2019; IPCC, 2022g; Wagner et al., 2020).

Regarding both primary and final energy consumption, delivery of the 2030 energy efficiency target will benefit from the application of the energy efficiency first principle (see Box 2). That principle was introduced to the EU policy framework in 2015 (EC, 2015b) and reiterated in the European Climate Law, with limited impact so far because, among other reasons, the stakeholders do not understand how to translate it into concrete action across the sectors (EC, 2021g). As Von Malmborg (2023) concludes, the 'energy efficiency first principle is constantly disputed in a struggle for interpretation, meaning and implementation'. This issue also affects pan-European energy system planning in support of infrastructure investment decisions; so far, that planning has not been sufficiently driven by the energy efficiency first principle (ESABCC, 2023c).

Box 2 Definition of energy efficiency first principle

The **energy efficiency first principle** in EU policy framework means 'taking utmost account in energy planning, and in policy and investment decisions, of alternative cost-efficient energy efficiency measures to make energy demand and energy supply more efficient, in particular by means of cost-effective end-use energy savings, demand response initiatives and more efficient conversion, transmission and distribution of energy, whilst still achieving the objectives of those decisions' according to Article 2 of the Governance Regulation (EU, 2018e).

It is therefore a good sign that the principle is clarified and its application encouraged under the revised EED (EU, 2023e). However, Article 3 of the revised EED, which aims to operationalise the energy efficiency principle, sets a very high investment value threshold (EUR 100 million) to trigger the assessment of energy efficiency solutions including demand-side resources and system flexibilities. In practice, major infrastructure projects may be split into smaller investments below the threshold set; see, for instance, information on projects of common interest (PCI) available through the PCI Transparency Platform (EC and CINEA, 2023).

Putting the energy efficiency first principle into practice is stifled by lack of a common understanding of energy efficiency-related concepts and measurements, including the diversity of scientific observations, for example in terms of energy conversion efficiency of biofuel generation (Van Den Oever et al., 2022; IPCC, 2022g). It is generally difficult 'to define and measure' efficiency, which can be understood as a ratio between primary and final energy, between economic growth and energy consumption, or between energy savings and lower energy consumption (Dunlop and Völker, 2023). Misinterpretations and the lack of a harmonised approach have weakened annual monitoring of progress under the EU energy efficiency policies so far. Standardising of calculation methodologies as well as defining baselines and the savings additionality have challenged the implementation of the EED; so has assessing of behavioural effects (Renders et al., 2021).

Energy efficiency improvement towards 2030 depends on policy, on public awareness of the measurement and on governance (see also Chapters 11 'Whole-of-society approach' and 14 'Climate governance'). In this respect, experience from the EU gas demand reduction measure offers valuable insight. As an exceptional EU-led policy instrument fostering energy savings, it was put in place in response to fossil gas supply disruptions triggered by the Russian invasion of Ukraine. The European gas demand reduction plan communication (EC, 2022n), followed by the Council regulation on coordinated demand reduction measures for gas (EU, 2022b), set a voluntary (mandatory in emergencies) 15 % target for reducing Member States' gas consumption between summer 2022 and spring 2023 (with the average consumption between 2017 and 2022 as a baseline). The target has been extended to end of March 2024 (Council of the EU, 2023b). Modelling contributions, taking account of the disruption caused by the Russian invasion of Ukraine, highlights the benefit of EU energy demand reduction measures (10 % from transport and buildings sectors were assumed) for both the economy and the environment of the EU in the long run, including its potential to reverse the current headwinds facing the EU economy (Liu et al., 2023).

Lever: coal and fossil gas phase-out

Coal in energy supply decreases, but fossil gas decline is too slow

As described in Section 3.2, the phase-out of fossil fuels in the overall energy mix (across all sectors) needs to double by 2030 and even triple thereafter (compared with 2005–2021) to be consistent with the European Commission's scenarios underpinning the EU climate objectives.

Figure 14 displays the historical and benchmark shares of fossil-based and RES in EU electricity generation. The fossil fuel share has fallen from 52 % in 2005 to 36 % in 2021, while the renewable electricity share (excluding from biomass) has increased from 14 % to 32 %. In the 5 years from 2017 to 2021, the share of fossil fuels fell by 1.7 pp per year on average, while the share of renewables rose by 1.7 pp ([10]). Looking ahead, meeting the EU's climate goals for 2030 and 2050 (as represented by the Fit

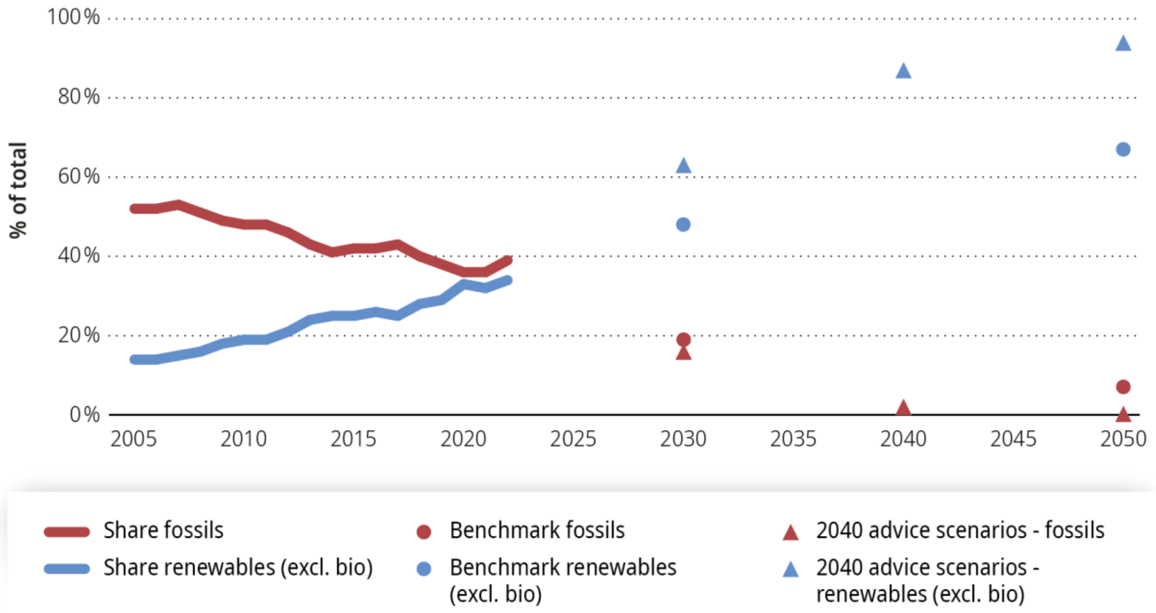
([10]) The assessment of recent trends in these indicators excludes 2022 because in that year output from hydroelectric and nuclear plants was exceptionally low owing to a combination of hot, dry weather and technical outages (IEA, 2023h). The resultant increase in fossil fuel generation (from coal) is not expected to be repeated as plant operations return to normal and the capacity of other renewables continues to expand.

for 55 MIX scenario (EC, 2021v)) implies slightly accelerating the annual decline in fossil fuel share (to – 1.9 pp up to 2030) and accelerating the increase in renewable energy share (to + 1.8 pp) in the EU's electricity mix. However, this would need to happen in the context of increasing electricity demand, and therefore the deployment of renewable generation capacity would need to increase considerably (see indicator E4 below).

Based on the scenarios considered by the Advisory Board in the context of its advice on the 2040 target, wind and solar PV will account for 79–82 % of the electricity mix in 2040. The use of fossil fuels, notably coal and fossil gas, for public electricity and heat generation will be almost phased out in 2040, with the remaining emissions abated through carbon capture or CDR. The 2040 advice range refers to the final electricity consumption from the six scenarios assessed in the Advisory Board's 2040 advice that achieved 2040 emission reductions of 90–95 % while remaining within identified environmental risk levels.

In the scenarios from the Advisory Board's advice on an EU 2040 target and accompanying GHG budget, the acceleration to 2030 is more rapid compared with the benchmark, with the renewable share 16 pp. higher (and fossil share 2 pp. lower). The scenarios from the Advisory Board report also see continued rapid deployment of renewable generation beyond 2030, with its share reaching 88 % by 2040 and 95 % by 2050 (compared with 71 % in the Fit for 55 MIX scenario). By contrast, the fossil fuel share in 2040 falls to 1 % in the Advisory Board report scenarios, compared with a 13 % share in the European Commission's Fit for 55 benchmark.

Figure 14 Indicator E2 – shares of fossil-based and renewable energy sources (excluding biomass) in the total electricity mix

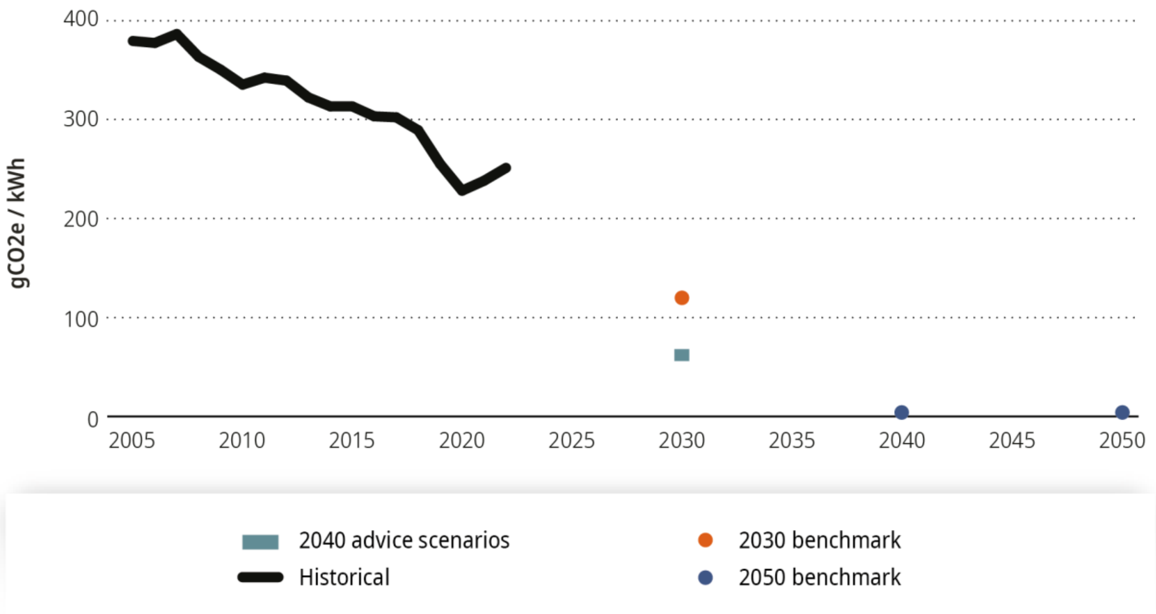


Notes: Historic data refers to gross electricity generation reported in the Eurostat energy balances. The 2030 benchmark and breakdown are based on the Fit for 55 MIX scenario. The 2050 benchmarks are based on the MIX Scenario from the Climate Target Plan impact assessment (see figure 46). For 2040, the benchmark refers to the High renewable energy iconic pathway of the Advisory Board's 2040 advice.

Sources: Eurostat energy balances (2023b), Climate Target Plan impact assessment (EC, 2020s), Fit for 55 MIX scenario (EC, 2021v), Advisory Board 2040 advice (ESABCC, 2023b).

The average grid GHG intensity (shown in Figure 15) declined steadily from 2005, until a rebound in 2021 and 2022 due to a combination of factors including record low volumes of hydro and nuclear electricity generation (ESABCC, 2023a). As a result, the decarbonisation rate of the electricity grid averaged 0 g CO_2e per kilowatt-hours (kWh) in 2018–2022. It needs to accelerate to 6 g CO_2/kWh in 2023–2030 to be consistent with the scenarios underpinning the Fit For 55 package. This decarbonisation rate (which is an increase from before 2015) needs to be maintained while increasing overall electricity consumption due to the electrification of end use sectors. The scenarios assessed in the Advisory Board's advice on an EU 2040 target envisage both a faster decarbonisation rate (21–23 g CO_2/kWh) and more electricity consumption than the Fit For 55 benchmark. Under both of the European Commission's scenarios that underpin the climate neutrality objective, like the scenarios underpinning the Advisory Board's 2040 advice, the electricity sector should already be fully decarbonised by 2040.

Figure 15 Indicator E3 – average intensity of greenhouse gas emissions from electricity grids



Notes: 2030 benchmark is based on the Fit for 55 MIX scenario. 2050 benchmark based on the 1.5TECH and 1.5LIFE scenarios from the in-depth analysis accompanying a Clean Planet for all (recalibrated for EU27), *excluding* negative emissions from carbon removal technologies. 2040 advice range based on the 6 scenarios that underpin the Advisory Board's 2040 advice. In these cases, negative emissions from carbon removal technologies are *included*, but are not a major contributor to the scenarios' near-zero GHG intensity in 2040. Both the 2040 range and the 2050 benchmark are close to 0 (below 5gCO_2e/kWh) as of 2040 (the 2040 range data point is "hidden" by the 2050 benchmark marker).

Sources: EEA (2023j), Fit for 55 MIX scenario (EC, 2021v), in-depth analysis accompanying a Clean Planet for all (EC, 2018e), Advisory Board 2040 advice scenarios (ESABCC, 2023b)

So far, coal phase-out commitments at the national level have not been sufficiently supported by EU policies.

Twenty-one EU Member States are currently participating in a governmental initiative called the Powering Past Coal Alliance (PPCA), established in 2017 (PPCA, 2017), which encourages its EU members to phase out coal by 2030 at the latest. However, early evidence from the crises induced by the COVID-19 pandemic and the Russian invasion of Ukraine indicates that policymakers tend to support incumbent energy industries to increase energy security (Zakeri et al., 2022). Moreover, not all EU Member States had a clear pre-war commitment to phasing out coal (IPCC, 2022g); there are still a few that do not envisage their coal power plants closing before 2050. The lack of a clear commitment is not consistent with the EU's net zero target.

The EU Member States commitment to phasing out coal in energy supply can be accompanied by transition measures including phase-out roadmaps, divestment strategies, compensation mechanisms for early power plant closures, labour market measures for coal workers and substantial support for structural change in coal-mining regions (IPCC, 2022g; Jakob et al., 2020; Rosenbloom et al., 2020). The EU's efforts in this area will benefit from continued and reinforced carbon pricing under the EU ETS, the revised energy taxation directive (ETD; see also Chapter 10 'Pricing emissions and rewarding removals') and support under the just transition programmes that encourage public support for coal phase-out policies and increase the pressure on policymakers for swift and definitive action (see Chapter 11 'Whole-of-society approach' and Chapter 14 'Climate governance'). In addition, the revisions of the EU industrial emissions directive (EC, 2022t) and the European Pollutant Release and Transfer Register regulation (EC, 2022z) are an opportunity to increase EU policy coherence, notably between pollution reduction and climate policy instruments. While the installations prompted by the industrial emissions directive account for around 40 % of EU GHG emissions and there are strong interconnections between climate change and pollution (EEA, 2022k), the EU's industrial emission policy under the directive currently makes an incoherent contribution to the EU's climate objectives. It does not sufficiently exploit the synergies between depollution and decarbonisation; in other words, it does not build on the increasing interlinkages between climate policy measures, such as carbon pricing and energy efficiency targets, or on industrial policy measures such as the best available techniques mandated under the industrial emissions directive (EC, 2022h).

The EU's stance on the role of fossil gas is ambiguous, leading to costly infrastructural and institutional lock-ins, and delayed fossil fuel phase-out.

Locking fossil gas into the EU's energy infrastructure and business operations perpetuates GHG emissions and implies additional costs linked to stranded assets, energy imports and carbon capture infrastructure (IPCC, 2022g) ([11]). Despite the vulnerabilities linked to the negative impacts of fossil gas on climate change and energy independence, the role of fossil gas in EU energy systems has still not been clearly addressed at the EU level.

The EU **State aid rules** authorise new investment in fossil gas as long as it is CCU/CCS ready, which means it could be qualified as low-carbon gas in the future (see Chapter 12 'Finance and investments'). They recognise fossil gas's role in a transitional period (EC, 2022ab), which confirms the ambiguous stance of the EU, torn between the need for rapid fossil fuel phase-out and the costs of stranded fossil gas assets and business models, underpinned by newly signed long-term import contracts. In addition, fossil fuel subsidies continue being channelled through the Temporary Crisis and Transition Framework. Adopted in response to the energy crises, the Temporary Crisis Framework of March 2022, and its successor the Temporary Crisis and Transition Framework of March 2023, allow Member States to shield fossil fuel power plant operations and energy-intensive companies from the high and volatile energy prices. Despite its supposedly temporary and crisis-led nature, the framework provisions keep being extended, allowing vast public support inconsistent with energy transition. Beyond the fossil fuel subsidy concern, the Temporary Crisis and Transition Framework includes also very positive opening for more public investment towards net-zero economy (see Section12.4). Member States' fiscal choices, some of which qualify as state aid (see e.g. Nowag et al. (2021), leading to **fossil fuel subsidies** more than

([11]) As pointed out by Seto et al (2016): 'Carbon lock-in is a special case of path dependency, which is common in the evolution of complex systems. However, carbon lock-in is particularly prone to entrenchment given the large capital costs, long infrastructure lifetimes, and interrelationships between the socioeconomic and technical systems involved. Further, the urgency of efforts to avoid dangerous climate change exacerbates the liability of even small lock-in risks'.

doubled between 2021 and 2022 to reach at least EUR 123 billion, and fossil gas subsidies tripled (to EUR 46 billion in 2022; EC, 2023) (see also Section 12.3).

The above ambiguity regarding the fossil fuel phase-out is also demonstrated under the **Taxonomy Regulation** and its delegated acts (EU, 2022a). They allow energy generation from fossil gas to be labelled as a sustainable activity owing to its transitional capacity 'to accelerate the shift from more polluting activities, such as coal generation, towards a climate-neutral future, mostly based on renewable energy sources'. The use of fossil gas to generate electricity or heat is compliant with the taxonomy criteria as long as it replaces other fossil fuels and meets specific emission and efficiency thresholds. These thresholds are too high, however, potentially leading to exaggerated capacity additions, given that electricity generation from such plants should be marginal in the decarbonised energy systems, even if emissions can be captured through CCU/CCS (ESABCC, 2023b) (see also Section 12.6).

Another example is the revised **TEN-E Regulation**, which, despite its stated target of discontinuing support to fossil fuels, allows new fossil gas investment – for instance, in repurposed infrastructure blending fossil gas with hydrogen or biomethane as a transitional activity – until the end of 2029. Electrolysers producing hydrogen from fossil gas can be eligible for the status of PCI / project of mutual interest as long as they meet GHG emission thresholds, which can be achieved through CCU/CCS. They represent a risk in terms of the EU's path to net zero, linked to the low maturity of CCU/CCS projects and the lack of coordination in their deployment to abate fossil gas emissions in energy supply.

The proposed recast of the **Gas Directive** (EC, 2021ag), under discussion at the time of writing of this report, sends a generally positive signal that the new EU policies aim to phase out fossil gas, including a time limit for the duration of long-term contracts for unabated fossil gas (2049, or earlier for willing Member States) ([12]). This overall policy direction is, however, called into question by the specific proposed EU measures that allow up to 5 % hydrogen blended with fossil gas to flow through cross-border infrastructure under Article 20 of the proposed recast of the gas regulation (EC, 2021ag), and lenient criteria for low-carbon hydrogen, that is, hydrogen produced from non-renewable sources with at least 70 % GHG emission reduction (European Parliament, 2023a). These measures risk extending the fossil fuel business case, with costly lock-in effects.

Moreover, regarding fossil gas emissions, the above EU laws and plans to upscale deployment of so-called low-carbon gases (i.e. gases not produced from RES but producing 70 % less GHG emissions than fossil gas across their full life cycle (EC, 2021ag)) are not consistent with carbon neutrality. Moreover, the connection between fossil gas installations, and actual CCU/CCS deployment is currently weak (see the targeted CCU/CCS lever below). The lack of robust connection between fossil gas installations and abatement projects can lead to a **slowdown of energy transition** because of ill-identified investment priorities and carbon **lock-in effects**. Moreover, there has been little progress in defining, identifying and prioritising carbon capture or CDR in those application areas for which alternative emission reductions, e.g. through fuel switching or decommissioning, are not viable (Buck et al., 2023; Lund et al., 2023); see 'Lever: targeted carbon capture and utilisation/storage') below.

In this context, the EU's policy would be more effective if it focused on **phasing out fossil fuel deployment** rather than fossil fuel emissions (e.g. through CCU/CCS). It is therefore regrettable that the EU policy framework does not openly address the shift in operations in the fossil gas sector towards the phase-down of traditional activities (Szabo, 2022), including the impacts of a decreasing customer base on gas system operators. While protection of fossil gas customers from rising tariffs is proposed by the

([12]) The EU Member States' short-term energy security considerations triggered in 2021 have resulted in new liquefied natural gas infrastructure being built and planned (EC, 2023bb) and long-term fossil gas contracts signed between the Member States and global suppliers.

European Parliament (European Parliament, 2023a), a systematic approach to the decline of the fossil gas economy and the rise of new business models is absent. This in turn has impacts ranging from local decision-making on the demand side (e.g. homeowners choosing between a gas boiler and a heat pump) to supply-side geopolitical considerations and contracting. Notably, the EU needs a new vision to underpin fossil fuel phase-out roadmaps and divestment strategies, in line with Article 10 of the European Climate Law, which puts forward voluntary sectoral roadmaps towards climate neutrality (EU, 2021c), and considering regulatory approaches to repurposing and decommissioning fossil gas infrastructure (ACER, 2022a), as well as other measures also outlined in the discussion of coal at the beginning of this subsection.

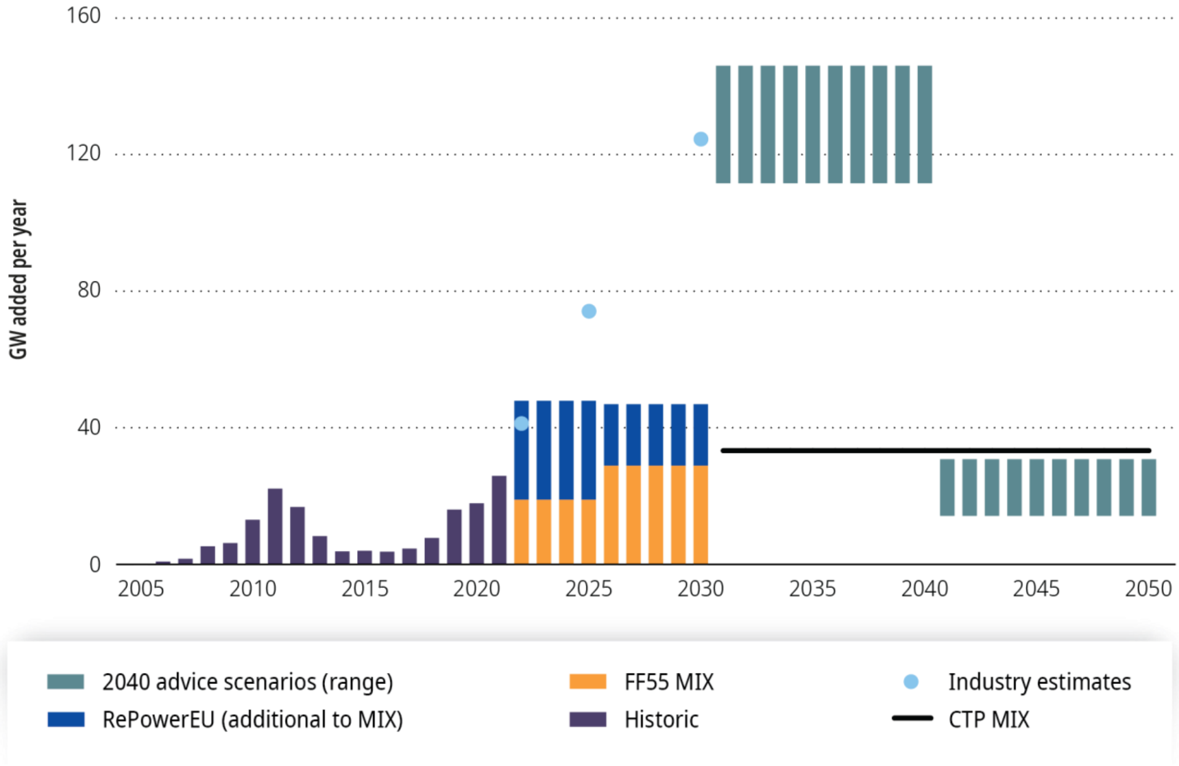
Lever: fast roll-out of renewable energy sources at scale

Solar PV and wind need to scale up massively across the EU and lead to a decarbonised electricity system by 2040 at the latest. Further progress remains challenging because of changing investment landscapes, inadequate infrastructure planning and development, and workforce and supply chain shortages.

Solar PV represented around 6% of renewable energy supply and 1% of gross final energy consumption in the EU in 2021 (EEA, 2023n). However, its annual installation rate has been rising since 2015 and is expected to continue. In 2018–2022, on average 22 GW of capacity was added each year, with a clear upward trend within that period, driven in particular by distributed solar installation, that is, by homes and businesses rather than at utility scale (IEA, 2023h). The current installed solar PV capacity of 160 GW across the EU needs to nearly quadruple to reach the REPowerEU target of 600 GW by 2030 (EC, 2022p). As Figure 16 suggests, installation of solar PV capacity is generally on track with pathways that were thought consistent with delivering climate neutrality in older scenarios, particularly if the acceleration observed in recent years continues into the future. The faster deployment of this technology provides an opportunity to either increase the EU's rate of decarbonisation or compensate for slower development of other mitigation options. Forward-looking scenarios have also tended to revise solar PV capacity upwards over time, which in part explains why the more recent scenarios (such as the European Commission's REPowerEU scenario and selected scenarios from the Advisory Board's recent advice on an EU 2040 target) have higher capacities than earlier estimates (such as the Fit for 55 MIX scenario and the 1.5TECH scenario in 'a Clean Planet for all') ([13]).

([13]) Other explanations for higher PV estimates include REPowerEU's emphasis on the need to reduce reliance on imported fossil gas, and the Advisory Board's emphasis on reducing emissions by 2040 (to 90–95 % below the 1990 level) rather than aiming for a slower path towards climate neutrality by 2050.

Figure 16 Indicator E4a – annual solar PV capacity additions



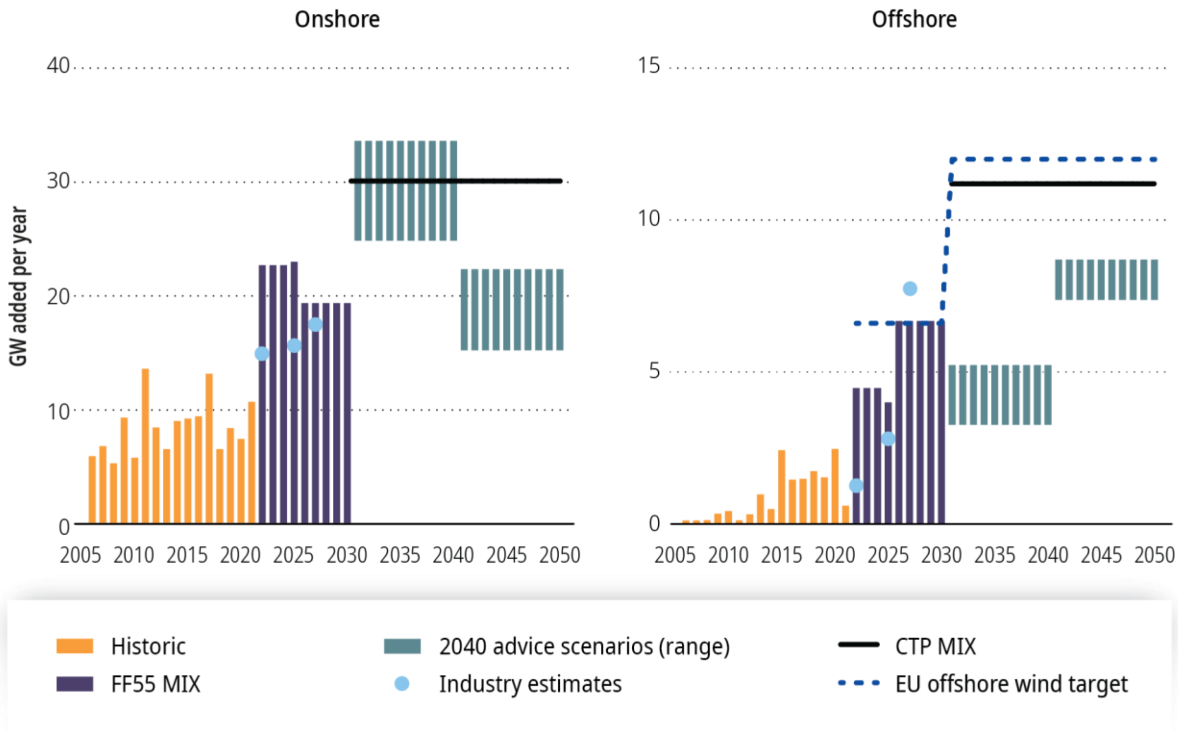
Notes: Historic annual additions based on solar production capacity data from Eurostat (nrg_inf_epcrw). The 2030 benchmarks are based on the European Commission's Fit for 55 MIX and REPowerEU scenarios for solar PV. Post-2030, the bars show the average annual additions needed to reach the total capacity foreseen in the Advisory Board's 2040 advice. Diamonds show the estimated annual additions in selected years from the medium outlook scenarios of SolarPower Europe.

Sources: Eurostat (2023d), REPowerEU staff working document (EC, 2022p), Advisory Board 2040 advice (ESABCC, 2023b), SolarPower Europe EU market outlook 2022-2026 (SolarPower Europe, 2022a).

Wind represented around 16% of the renewable energy supply and 3% of gross final energy consumption in the EU in 2021 (EEA, 2023n). Wind electricity has been increasing at a rate of over 5 % annually in recent years, with 19 GW added in 2022, mostly onshore (EEA, 2023p). Unlike solar PV, new capacities in wind have been added at a slower pace recently (see figure 17); this has been attributed to serious bottlenecks, primarily linked to the issuing of permits and changing investment landscapes. While the pace of annual capacity additions in wind shows signs of recovery, projected capacity this decade appears set to remain below the level envisaged by the Fit for 55 and REPowerEU scenarios.

Figure 17 illustrates that the installed wind capacity across the EU, currently 236 GW, needs to more than double to reach the REPowerEU target of 510 GW by 2030. The installed offshore wind capacity (16.3 GW EU-wide in 2022) needs to nearly quadruple to reach 60 GW in 2030 as set out in the EU strategy on offshore renewable energy (EC, 2020d), and to grow even more to reach the recently agreed political target of about 111 GW of offshore renewable generation capacity in each of the EU's five sea basins by 2030 (EC, 2023an). This would be in line with the latest EU policy direction under REPowerEU, which emphasises the benefits of offshore wind, referring to its higher public acceptability than onshore wind (EC, 2022m). Nevertheless, in the short term, onshore wind is expected to account for three quarters of new wind capacity additions in the EU (WindEurope, 2023).

Figure 17 Indicators E4b and E4c – annual wind electricity capacity additions



Notes: Historic annual additions based on wind production capacity data from Eurostat. 2030 benchmarks are based on the European Commission's Fit for 55 MIX scenario (available data for REPowerEU does not distinguish between onshore and offshore wind). Post-2030, lines show the average annual additions in the Climate Target Plan MIX scenario and Offshore Renewable Energy Strategy, while bars show the average annual additions needed to reach the total capacity foreseen in the Advisory Board's 2040 advice. Diamonds show the estimated annual additions in selected years from the outlook scenarios of WindEurope.

Sources: Eurostat (2023d), Fit for 55 MIX scenario (EC, 2021v), Climate Target Plan impact assessment (EC, 2020s), Offshore Renewable Energy Strategy (EC, 2020d). Advisory Board 2040 advice (ESABCC, 2023b), WindEurope market outlook 2023-2027 (WindEurope, 2023).

Progress in PV and wind deployment remains challenging because of changing investment landscapes, inadequate infrastructure planning and development, inadequate spatial planning, and workforce and supply chain shortages.

The EU policy framework identifies solar PV and wind energy as priority energy sources. Since 2009 they have been promoted mostly under the consecutive renewable energy directives. The Renewable Energy Directive that is currently in force (RED II) (EU, 2018b) recognises that 'the promotion of the use of renewable energy in the electricity sector, the heating and cooling sector and the transport sector are effective tools, together with energy efficiency measures, for reducing GHG emissions in the [EU] and the [EU]'s energy dependence' (RED II, recital 4, EC, 2021e). Through renewable energy directives, the EU established the 2020 and 2030 binding targets for the minimum share of renewables in the energy mix. The recently agreed target of 42.5 % RES share in EU energy mix is welcome and needs to support early decarbonisation of the EU electricity systems, which is a key milestone in the projected net zero pathways. RepowerEU targets for wind and solar PV are higher than those assumed under Fit for 55 scenarios, which is a good thing from climate mitigation and energy security perspectives. To account for the increased targets, the EU's overall long-term investment signals and strategic planning, including modelling in support of decision-making (e.g. PV and wind value chains), still needs to be adjusted to the required deployment of PV and wind, and growth of the industry (Haegel et al., 2023; IEA, 2022g).

To address the specific wind industry hurdles, the European Commission tabled a European wind power action plan in October 2023 (EC, 2023s). It aims to address some of the key **bottlenecks** impeding the fast roll-out of wind power that can be attributed to infrastructure, investors' certainty and market signals, public engagement, workforce and supply chains. Barriers to deployment can also be identified in the solar PV sector, and should be addressed as well (see Section 4.4 below and Chapters 14 'Climate governance' and 15 'Labour, skills and capacity building').

EU policies to promote biomethane risk extending the use of fossil fuels, delaying electrification and lead to higher fugitive emissions.

The REPowerEU plan (EC, 2022m) has the ambition to increase the production and use of biomethane tenfold (compared to 2021) to reach 35 billion cubic metres per year by 2030. However, this has potentially negative impacts in terms of extended use of fossil fuels (e.g. through blending of biomethane with fossil gas, and dedicated infrastructure investment) and stalled electrification. Constraints on large-scale local availability of sustainable biomethane feedstock, together with transport and fugitive emissions, can lead to high emissions of biomethane along the value chain (Bakkaloglu et al., 2022; ICCT et al., 2021). The EU legislation in force, the REPowerEU plan (EC, 2022m), do not sufficiently address these risks. Neither do the European Commission proposals for a regulation on methane emissions reduction in the energy sector (EC, 2021af) or the gas package proposals (EC, 2021ag, 2021ab). For instance, CH_4 emissions from biomethane are not covered by the regulation on methane emissions reduction in the energy sector (Council of the EU, 2023a).

A broader assessment of bioenergy use and related policies is included in Section 9.5. An assessment of EU policies on transport biofuels is included in Chapter 6 'Transport'.

For the EU to remain the front runner in innovative renewable energy technologies that will enable more effective pathways to carbon neutrality, a concerted effort of research, development and market scale-up is required.

Some renewable energy technologies, e.g. ocean energy (wave and tidal), concentrated solar power, geothermal energy and other new and innovative RESs, currently contribute only marginally to the overall EU renewable energy mix. This may present untapped potential that could possibly contribute to the future energy system, including through dispatchable load contribution, which is needed for wind and PV system integration (IEA, 2023i). Geothermal technologies, for example, can be efficient in decarbonising heating and cooling systems (IPCC, 2022g).

Innovative RES are currently supported under the EU policy framework, including the RED III, EU research and infrastructure funding and the EU's offshore renewable energy strategy (EC, 2020d). Barriers to their scale-up persist, however, including immature markets, high upfront costs and significant technical risks (IPCC, 2022g). Market scale-up of innovative renewable technologies developed with EU support, such as through Horizon programmes, is currently too slow to put the EU on the path to climate neutrality (see also Chapter 12 'Finance and investments'). For instance, only about 10 % of the total R & D expenditure in the EU goes to the energy sector, or 0.02 % of the EU's gross domestic product (GDP), and most of it goes to incumbent energy sources such as fossil fuels and nuclear power (IEA, 2022c). As further explained in Chapter 13 'Innovation', significant scale-up in R & D spending in support of RESs is urgently needed for the EU to achieve its climate neutrality objectives.

The European Commission's strategic ambition to have 1 GW of installed ocean energy capacity by 2030 and 40 GW by 2050, driven by the EU's technological leadership in this field (EC, 2020d), could support the overall progress in decarbonising the EU's energy system. The slow progress in the implementation of the EU's offshore renewable energy strategy, however, results in low levels of ocean energy being deployed and industrial leadership in ocean energy shifting to non-EU jurisdictions (Ocean Energy Europe, 2023; Ramos et al., 2021).

In this context it is positive that offshore renewable and geothermal energy technologies feature among the strategic net zero technologies in the European Commission's proposal for a framework of measures to strengthen Europe's ecosystem for manufacturing net zero technology products, that is, the Net-Zero Industry Act proposal (EC, 2023ao). The EU should strive to remain the front runner in innovative renewable energy technologies that will enable more effective pathways to carbon neutrality, through a concerted effort of research, development and market scale-up.

Box 3 Nuclear power

In 2021 around 25 % of the EU's electricity demand was met by nuclear power plants located in 13 EU Member States. Nuclear electricity generation in the EU has been generally decreasing since 2006. In 2022 nuclear power plant output decreased to unprecedented levels as a result of drought and technical issues [– 18 % compared with 2021, according to EEA, (2023)]. Based on the MIX policy scenario in the climate target plan, nuclear power could account for about 15 % of the EU's overall electricity generation in 2030 and 10 % in 2050 (EC, 2020s).

In its recent advice on aligning policy responses to rising energy prices with the long-term climate neutrality objective (ESABCC, 2023a), the Advisory Board acknowledged that delaying the closure of existing nuclear reactors can be a supportive tool to ensure additional low-carbon energy supply in the short term if it is cost-effective and if safety can be sufficiently guaranteed. Given the long lead times of new nuclear power plants (10 to 15 years), a further expansion of this technology cannot be expected to contribute to achieving the EU's 2030 climate targets. Furthermore, social acceptability remains an issue in several countries. In terms of the potential contribution of nuclear power to the 2050 climate neutrality target, climate change impacts on the EU's future energy security should be considered and weighed against risk factors and other impacts. In 2022 a wide and persistent lack of precipitation in combination with heatwaves affected several regions in Europe. This in turn led to historically low hydropower outputs, and reduced generation by thermal power stations – including nuclear reactors – due to a lack of cooling water (Toreti et al., 2022). In addition, low water levels in some of the EU's main waterways disrupted fuel supplies to coal-fired power plants (Gillespie and Sorge, 2022). These events show that climate change – which makes extreme weather events such as drought more frequent and intense – requires a rethinking of the drivers of and solutions for the EU's energy security in the future, including technologies that have in the past been considered highly reliable.

Lever: system integration

Despite the endorsement of system integration as a strategic direction by the European Commission in 2020, the EU still lacks coordination in its planning and operation of the energy system as a whole. While policymaking focuses on upscaling low-carbon fuels, including hydrogen, it does not sufficiently target them to priority sectors. Other pillars of the EU's energy system integration strategy such as digitalisation, energy efficiency and distributed resources need further policy and implementation support.

System integration is defined by the European Commission in the dedicated strategy (EC, 2020l) as the coordinated planning and operation of the energy system 'as a whole', across multiple energy carriers, infrastructures and consumption sectors. There are six pillars of the European Commission's energy system integration strategy:

— a more circular energy system, with energy efficiency first at its core,
— accelerated electrification of energy demand, building on a largely renewables-based electricity system,
— more renewable and low-carbon fuels, including hydrogen, for priority sectors,
— energy markets more fit for decarbonisation and distributed resources,
— more integrated energy infrastructure,
— a digitalised energy system and a supportive innovation framework.

New EU policies and funding support have been directed to the **hydrogen** economy, which plays a central role in all recent European Commission energy strategies (EC, 2023q, 2022m, 2020c). New fuels and energy carriers such as hydrogen appear in all climate target plan policy scenarios in significant quantities after 2030 and are crucial to achieving climate neutrality by 2050. However, the EU's targeting of hydrogen to priority sectors, as part of the EU's energy system integration strategy, is not progressing fast enough.

Key policies from the European Commission include the EU hydrogen strategy (EC, 2020c), the REPowerEU plan (EC, 2022m), the proposals for a revised regulation and directive (EC, 2021al, 2021m) addressing the internal markets for renewable and fossil gases and for hydrogen (the 'gas package'), and the revised TEN-E Regulation (EU, 2022e). The European Commission has set out the rules enabling hydrogen to be treated as a RES under the RED III (EU, 2023f). It has also tabled a proposal to set up an EU Hydrogen Bank (EC, 2023r). The proposed electricity market design reform may define the role of hydrogen in EU energy systems: notably its potential as an energy carrier for non-electrified uses and as a flexibility source in electricity markets.

The currently limited hydrogen market (8 Mt in 2022; EC, 2023) in the EU is dominated by unabated fossil gas-based hydrogen for the refining and ammonia industries. According to the European Commission, 'hydrogen may provide an alternative fuel for transport, heating and industry where direct electrification might face challenges' (EC, 2020a). The REPowerEU plan envisages a ramp-up in production of renewable hydrogen from nearly zero in 2022 to 20.6 Mt (about 680 TWh, half domestic and half imported) by 2030. The MIX policy scenario sees a ramp-up of the installed electrolyser capacity to 12–13 GW by 2030, 40–70 GW in 2035 and 528–581 GW in 2050. Hydrogen and, to a smaller extent, its derivatives are expected to account for 71 % of all renewable and low-carbon gases in 2050.

To enable hydrogen uptake, five supply corridors totalling about 28 000 km are planned to be created by 2030 as a 'European hydrogen backbone'. By 2040, the backbone is expected to grow to almost 53 000 km, consisting of about 60 % repurposed infrastructure and 40 % new hydrogen pipelines. The European Commission expects the total investment needed to produce, transport and consume 20.6 Mt of renewable hydrogen and its derivatives by 2030 to be in the range of EUR 835 billion to

EUR 971 billion. Within the EU the estimated costs include EUR 200 billion to EUR 300 billion for additional renewable electricity production, EUR 50 billion to EUR 75 billion for electrolysers, EUR 28 billion to EUR 38 billion for EU-internal pipelines, EUR 6 billion to EUR 11 billion for storage and EUR 1.2 billion for upscaling electrolyser-manufacturing capacities (EC, 2023r). The European Commission estimates that 150–210 GW of additional renewable capacity to generate electricity at low cost is needed to make renewable hydrogen competitive with its fossil alternatives (EC, 2023r).

The IPCC highlights that hydrogen production processes (power to gas and vice versa) and hydrogen storage can bring short- and long-term flexibility to the electricity system, replacing fossil gas-based electricity generation in this respect. However, the economic benefits of flexible power-to-gas plants, energy storage and other flexibility options will depend on the locations of variable RESs, storage sites, gas, hydrogen and electricity networks. Electricity use in producing hydrogen for storage (power to gas) and its subsequent reconversion to electricity is very resource-intensive because of the low round-trip efficiency of the process. The use of fossil gas in the production of hydrogen will only be feasible if it involves carbon capture and storage (CCS) or CDR (IPCC, 2022g).

Hydrogen from fossil gas with CCU/CCS (sometimes still referred to as 'blue' hydrogen, and termed 'low-carbon' hydrogen in recent EU policy documents) is associated with higher GHG emission intensity than fossil gas combustion, notably because of fugitive CH_4 emissions associated with the increased demand for fossil gas driven by CCS applications (Howarth and Jacobson, 2021; Novotny, 2023); see also the levers 'reduction of methane emissions' and 'Lever: targeted carbon capture and utilisation/storage' below.

Regarding non-electrified uses, such as heating buildings, 'delivered cost of heat from hydrogen would be much higher than the cost of delivering heat from heat pumps, which could also be used for cooling. Repurposing gas grids for pure hydrogen networks will also require system modifications such as replacement of piping and replacement of gas boilers and cooking appliances … with safety and performance concern'. Scenarios assessed by the IPCC show a 'very modest role for hydrogen in buildings by 2050' (IPCC, 2022b).

Overall, there are remaining challenges around hydrogen-based energy carriers. Economically and environmentally viable options, including efficient hydrogen transport, storage and conversion technologies, are currently not widely available but may become so in the future thanks to, among other things, further research and market scale-up. **Targeted hydrogen deployment** could provide a practical safeguard in support of the EU's energy transition. Priority should be given to well-defined uses that cannot be electrified, notably in industrial processes and fuels for some transport modes. Blending fossil gas with hydrogen and using fossil gas in the production of hydrogen should be avoided, considering the risks of infrastructural carbon lock-ins, risks of CH_4 leakages (see 'Lever: reduction of methane emissions' below) and limited CCU/CCS availability (see 'reduction of remaining emissions' below) in line with the energy efficiency first principle.

Moreover, other aspects of the EU energy system integration are less advanced. This weakness can be attributed to, among other things, the methodologies and assumptions behind the pan-European energy infrastructure planning and development (see also Section 4.4). The key scenarios underpinning the identification of EU energy infrastructure gaps and priority projects have been found to be misaligned with the EU's climate neutrality objective and do not incorporate future climate projections (ESABCC, 2022b). They underestimate the potential of integrated energy infrastructure, including electrification driven by energy efficiency first, and innovative flexibility options such as digitally enabled demand response (ESABCC, 2023c, 2022b).

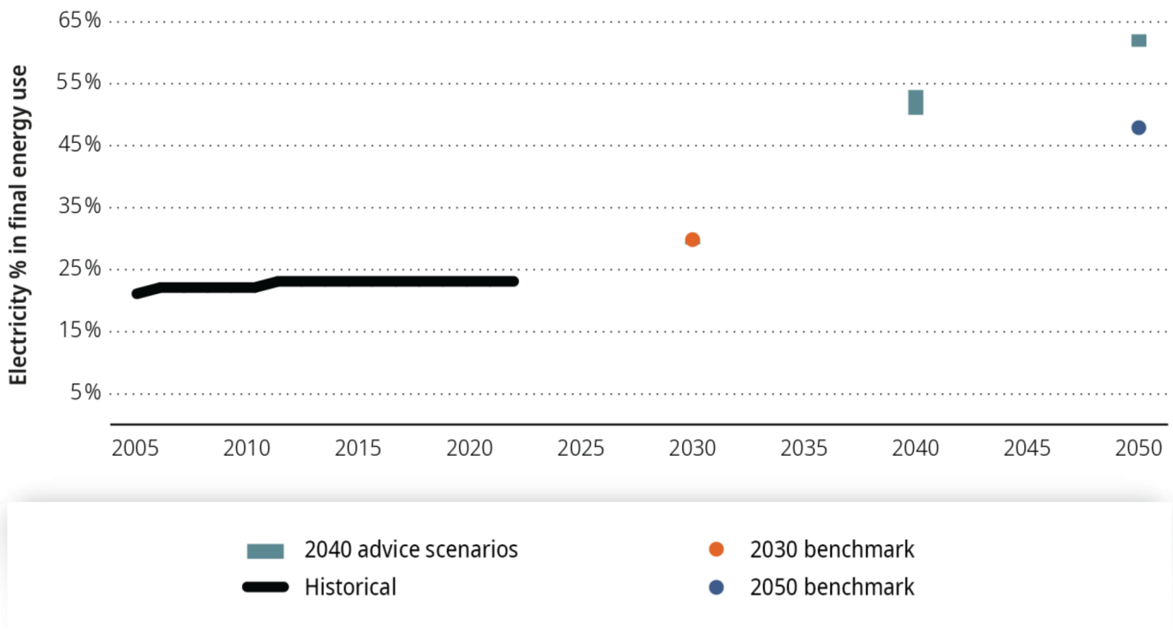
Accelerated electrification of energy demand is not yet on track to reach the EU's climate objectives.

The share of electricity in the EU's total final energy use has increased slightly from 21 % in 2005 to 23 % in 2021. In the most recent 5-year period for which data is available (2017–2021), the share even decreased slightly (see Figure 18).

Electrification needs to increase considerably, to align with the trajectories towards overall climate neutrality by 2050. The electrification of end use is one of the key levers to achieve the EU's climate targets for 2030 and 2050. In the European Commission's scenarios that underpin these targets, electricity represents at least 30 % of final energy demand by 2030, and almost 50 % by 2050. The increasing share under these scenarios is driven by the uptake of heat pumps in buildings, the electrification of industrial processes and the further electrification of transport, while other forms of electricity use would see reductions due to energy efficiency improvements.

Electrification is also a key feature of all pathways assessed in the Advisory Board's 2040 advice. Electricity reaches 50% of final energy demand by 2040 and 60% by 2050 in the pathways that achieve a 90-95% emissions reduction, while remaining within specified environmental risk levels. Pathways with similar emissions reduction but lower electrification rates were found to rely more heavily on bioenergy or carbon removal (through CCUS technology or expansion of the land sink (ESABCC, 2023b).

Figure 18 Indicator E5 – electrification rate (share of electricity in final energy use)



Notes: Historic share is calculated as the share of electricity in final energy use based on the Eurostat energy balances. The 2030 benchmark is based on the Fit for 55 MIX scenario. The 2050 benchmark is based on the MIX Scenario from the Climate Target Plan impact assessment (see figure 37). The 2040 advice range based on the 6 scenarios that underpin the Advisory Board's 2040 advice.

Sources: Eurostat energy balances (2023b), Climate Target Plan impact assessment (EC, 2020s), Fit for 55 MIX scenario (EC, 2021v), Advisory Board 2040 advice scenarios (ESABCC, 2023b).

Electrification can be direct (e.g. through heat pumps or electric vehicles) or indirect (e.g. through hydrogen or synthetic fuels), but it usually means replacing fossil fuel applications (Haegel et al., 2023). Direct and indirect electrification can increase the flexibility of the EU electricity system, which is increasingly reliant on variable wind and solar PV energy production. However, indirect electrification through, for example, production of renewable hydrogen comes with energy losses during conversion process, and hence reduces overall efficiency of energy supply (IPCC, 2022g; JRC, 2022a).

By 2030, the EU electricity system will need more than double the flexibility it has today. Distribution system operations play a key role in meeting them, but DSOs and regulators need to adapt fast.

The recent EEA and ACER (2023) report shows that by 2030, an increase by 240 % of variable renewable energy generation compared with 2021 levels, corresponding to three main target-reaching scenarios of the EU Climate Target Plan (EC, 2021w) will require more than the doubling of the flexibility needs existing in 2021 across the EU electricity system ([14]). Several solutions that provide the required flexibility in highly electrified systems include cross-border grid links, demand-side management, storage, dispatchable generation and grid efficiency. At the heart of many of these solutions is the distribution system.

The operation of the many distribution systems is diversely regulated across Europe, providing highly different investment environments. Distribution system operations have been subject to relatively little direct involvement at the EU level so far, apart from the EU unbundling and consumer protection rules. This is changing, as the Fit for 55 legal changes and the REPowerEU plan put distribution networks in the spotlight (EC, 2022m). Closer EU cooperation in this area is timely, as DSOs share increasing uncertainties due to the integration of distributed energy resources, increasing investment needs, and opportunities in the form of **flexibility services** that they could facilitate. As with the transmission assets, shifting the operating paradigm of DSOs should encourage regulators to reflect on how to adapt so that they identify missing solutions and encourage flexibility services as a cost-efficient investment. For instance, there is growing evidence that the regulatory framework is often positively tilted towards capital expenses rather than operating expenses, which may discourage flexibility services (Ruiz et al., 2023). Moreover, the system needs study conducted under the TYNDP insufficiently grasps the potential benefits of **demand-side response**, as it is based on the premise that 'only a small portion of consumers, or no consumers at all, will be flexible in the future' (ACER, 2023a). This observation could explain the fact that, despite a substantial roll-out of smart meters in the residential sector across the EU (54 % of households had smart meters in 2022 according to ACER and CEER (2022), demand-side response still plays a marginal role in wholesale electricity markets and ancillary services (ACER, 2022; ACER and CEER, 2022). This is despite the fact that, following its inclusion in the electricity regulation, demand-side response is emerging as potentially the cheapest technology to ensure that systems are reliable (ACER, 2022b).

([14]) Over 2015–2021, the average daily, weekly and annual flexibility needs were 157 TWh, 128 TWh and 130 TWh, respectively. In 2030, when variable renewable energyinstalled capacity should be at least 3.4 times higher than in 2021, daily, weekly and annual flexibility needs are estimated to reach 362 TWh, 242 TWh, and 168 TWh, respectively. Essentially, for daily, weekly and annual flexibility needs this means an increase of 138 % (2.4-fold increase), 77 % (1.8-fold increase) and 28 % (1.3-fold increase), compared to the situation in 2021' (ACER and CEER, 2022).

EU policies for energy system digitalisation and non-fossil sources of flexibility require urgent, target-driven implementation.

Implementation of **the EU action plan on digitalisation of energy system** (EC, 2022k) can help mostly zero-carbon flexible energy resources, such as bidirectional charging of electric vehicles, virtual power plants and energy communities, participate in the wholesale markets. The European Commission expects these solutions to satisfy 90 % of the flexibility needs in the EU's electricity grids by 2050, namely 580 GW (EC, 2022k).

The action plan's delivery depends on the EU Member States overcoming multiple policy, technological and behavioural barriers, some of which could be tackled by the EU policymakers in the upcoming revision of the ETD (Voulis et al., 2019) by encouraging **energy efficiency first** demand response and sector coupling.

Moreover, in the **Net-Zero Industry Act** proposal (EC, 2023ao), the European Commission puts forward an expansion of the EU's 'manufacturing capacity for energy efficient technologies, such as heat pumps and smart grid technologies, that help the EU reduce and control its energy consumption' (EC, 2023ao). This is a very positive development, as the proposal announces a step change in EU policies at the electricity distribution level, which is where connecting prosumers and managing the demand side increase system flexibility and lead to better energy system integration.

In March 2023 the European Commission issued its **recommendations on energy storage** (EU, 2023a), which, among other things, encourage EU Member States and system operators to identify their flexibility needs and create an inducive framework for storage. This is an important development from a system integration perspective, especially as different storage solutions have different material and carbon footprints and different timescales (short, medium and long terms).

The revised **TEN-E Regulation** (EU, 2022e) covers cross-border electricity links, which are key flexibility solutions for the EU by 2030 and beyond (JRC, 2023b). It also covers smart grid projects that can become PCI.

The **RED II** (EU, 2018b) assists renewable self-consumers, including their aggregation and storage systems, and requires DSOs to assess the potential of district heating or cooling to provide system services, including demand response and storing of excess electricity from renewable sources. The **RED III** (EU, 2023f) introduces indicative storage and demand-side flexibility targets and defines co-located energy storage projects. While the new provisions are a step change in terms of zero-carbon flexibility frameworks, the EU's experience suggests that such indicative targets may not be sufficient to drive fast transformational change.

The **electricity market design** reform proposal (EC, 2023ar) puts forward objectives to deliver on (among other things) electricity system flexibility needs through low-carbon solutions and new support schemes for non-fossil flexibility through demand-side response and storage.

Lever: reduction of methane emissions

The largest sources of CH_4 emissions from energy sector have been subject to a major EU policy gap until the adoption of the EU regulation on CH_4 emissions from the energy sector. The new EU regulation is a step in the right direction, but the actual ambition of the new rules is yet to be defined. The EU should also extend the EU ETS to cover CH_4 emissions from the energy sector and align its policy in this area with the US measures under the Inflation Reduction Act, while encouraging other jurisdictions to tackle CH_4 emissions from the energy sector.

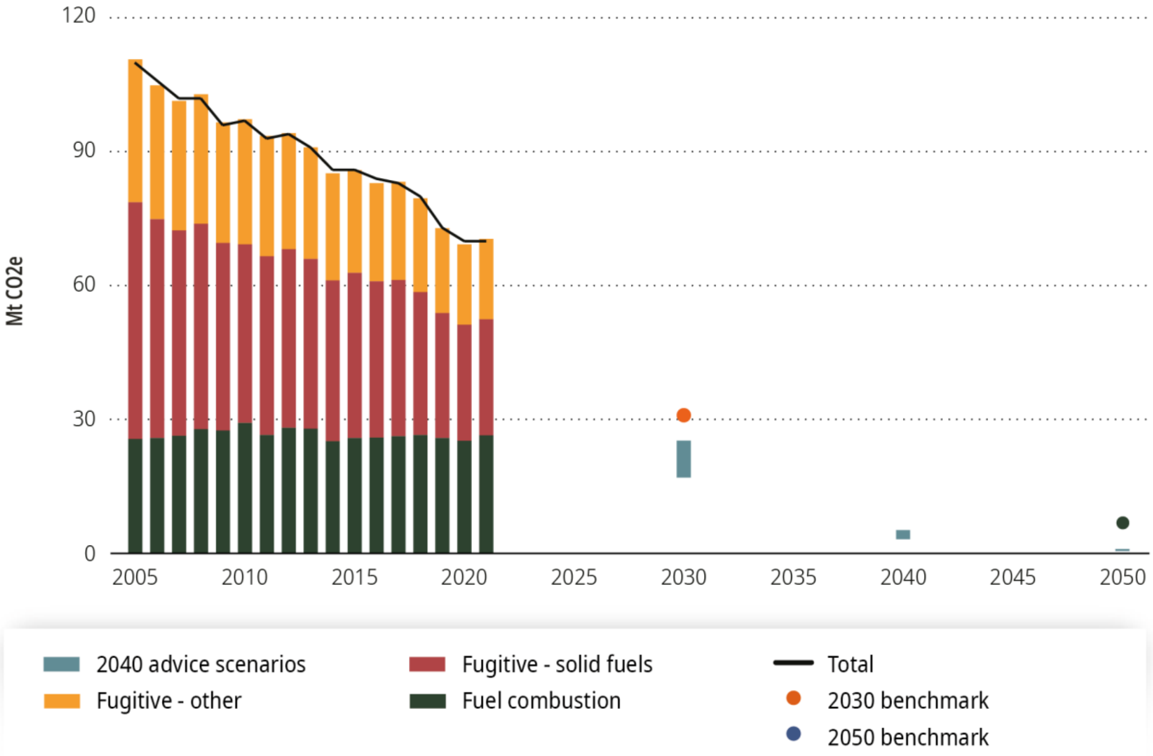
CH_4 is a potent GHG with high global warming potential (IPCC, 2007b). The energy supply sector is the third-biggest source of CH_4 emissions in the EU (11 % of total), after agriculture (55 % of total) and waste (23 %). The largest sources of CH_4 in the energy sector in 2021, as shown in Figure 19, are fugitive emissions from coal mining and handling (37 %), fossil gas operations (25 %) and emissions from biomass combustion in the residential sector (17 %) (EEA, 2022f). Fugitive emissions have fallen by an average of 3 Mt CO_2e per year since 2005, while emissions related to combustion have remained stable. However, fugitive emissions are currently not systematically measured and can continue many years after oil, gas or coal operations have ceased (EEA, 2022f). Moreover, the reporting of CH_4 emissions from closed or abandoned coal mines in the EU has not been reliable to date (ECA, 2022a).

Fugitive emissions from gas pipelines and bioenergy make it difficult to reach the EU's net zero target by deploying fossil gas in combination with carbon capture (EC, 2020c) and biomethane. Remaining emissions from continued use of fossil fuels, including fossil gas with CCU/CCS-based hydrogen, and from bioenergy include large amounts of fugitive emissions (IEA, 2023g). CH_4 leaks occur not only in the EU but also outside it, linked to EU fossil gas imports.

Nevertheless, the European Commission's analysis considered that fugitive emissions in the energy sector can be largely eliminated by 2050 (EC, 2018d). The analysis identifies 8 Mt CO_2e of potential mitigation in the production, transmission and distribution of oil and fossil gas. However, the mitigation potential from decreasing fuel consumption is much greater, with the 1.5LIFE scenario in 'A clean planet for all' estimating a reduction of 15 Mt CO_2e (the difference in 2050 between the baseline and the 1.5LIFE scenarios, excluding the 8 Mt CO_2e of supply-side mitigation). Global CH_4 emission reductions of 45 % by 2030, according to United Nations Environment Programme and the Climate and Clean Air Coalition, could avoid nearly 0.3 °C of global warming by 2045 (UNEP and CCAC, 2021).

While until 2024 there has been no specific policy aimed at eliminating CH_4 emissions from energy supply at the EU level, the EU has been a leading partner in the Global Methane Pledge signed at the 26th Conference of the Parties (COP26) in November 2021 (UNFCCC, 2021). By joining the pledge, countries commit to collectively reduce CH_4 emissions by at least 30 % below 2020 levels by 2030. The pledge was followed up with the Energy Pathway in June 2022, in which the EU committed to 'endeavour to reduce the methane emissions from the entire value chain of oil and gas production and consumption, including by promoting appropriate international monitoring, reporting, and verification standards; by providing technical assistance and investment for methane emission reduction along the fossil fuel value chain; and by supporting lower-GHG emissions oil and gas production and consumption' (EC, 2022r). Further policy progress in regulating CH_4 emissions is enabled by increasingly reliable data thanks to, among others, the EU's Copernicus Earth observation system (Copernicus and ECMWF, 2023).

Figure 19 Indicator E6 – energy-related methane emissions



Notes: Historic data refers to CH_4 emissions from fuel combustion (CRF category I.A) and fugitive emissions (CRF category I.B) reported in the EU GHG inventory. 2030 benchmark refers to the same emissions scope under the Fit for 55 MIX scenario. 2050 benchmark is based on the 1.5LIFE scenario from the in-depth analysis accompanying a Clean Planet for All (see table 3, recalibrated for EU27 based on 2015 emissions). 2040 advice range is based on the scenarios which underpin the Advisory Board's 2040 advice, calculated as total CH_4 emissions less those from agriculture, land use and waste.

Sources: GHG inventories (EEA, 2023f), Fit for 55 MIX scenario (EC, 2021v), in-depth analysis accompanying A Clean Planet for All (EC, 2018e), Advisory Board 2040 advice scenarios (ESABCC, 2023b).

In this context, the new EU regulation on CH_4 emissions from the energy sector (EC, 2021af), which was agreed by the EU co-legislators at the end of 2023 (Council of the EU, 2023a), is set to become a crucial instrument in decarbonising the EU's energy supply. The regulation introduces new requirements for the oil, gas and coal sectors to measure, report and verify CH_4 emissions and to put in place emission mitigation measures, including detecting and repairing CH_4 leaks and limiting venting and flaring. The regulation also puts forward global monitoring tools to ensure transparency on CH_4 emissions from imports of oil, gas and coal into the EU. Given that the EU imports fossil fuels, the act will apply to both EU and non-EU operations. The European Commission's implementing acts will be essential, as they will define, among other things, the maximum CH_4 intensity values and minimum detection limits. Administrative penalties for infringing the regulation, including non-compliance with the set thresholds, will apply. The power to impose penalties lies with the Member States (Council of the EU, 2023a).

The new regulation could therefore be a first step to expanding the scope of the EU ETS to upstream emissions in the energy sector. In the future, a financial charge equal to the price level of the EU ETS could be levied on fossil fuel imports exceeding the EU CH_4 standards. This would de facto establish a border adjustment mechanism on upstream emissions in the energy sector (Clausing et al., 2023). In addition, the EU continues to strive for an internationally coherent approach, concerting its actions with other major policy initiatives to regulate energy-related CH_4 emissions, notably the 'Methane Emissions

Reduction Program' and 'Royalties on All Extracted Methane' under the US Inflation Reduction Act (CRS, 2022), and incentivising non-EU countries to implement adequate oil and gas regulations.

The new rules on monitoring, reporting and verification measures will only bind exporters to the EU starting from 2027, and maximum CH_4 intensity values will apply from 2030. The agreed regulation's impact will be most prominent when it comes to new contracts signed between EU importers and non-EU suppliers of fossil fuels; the parties under existing contracts are only encouraged to 'do their best' (Council of the EU, 2023a). Given the urgent need to reduce CH_4 emissions along the fuel value chain and the long-term nature of fuel import contracts, the implementation delays indicate an ambition gap under the new regulation and are a reminder of the risks and costs of contractual lock-ins.

Lever: targeted carbon capture and utilisation/storage

EU policies support CCU/CCS without targeting deployment to applications with no other mitigation option.

Fossil fuel phase-out in the EU should be the priority of decarbonising the EU's energy systems. It also necessitates identifying and defining those uses of fossil fuels that cannot be replaced by renewables.

The EU policies address remaining emissions by promoting CCU/CCS. In 2009 the EU put in place a directive on the geological storage of CO_2, called the CCS directive (EU, 2009a). Activities listed in Annex I of the EU ETS Directive, including in energy supply, are exempted from surrendering allowances for CO_2 that is captured and geologically stored in line with the CCS directive (Article 12 of the EU ETS Directive). Emissions related to the transport and storage of CO_2 are also covered by the CCS directive to ensure all emissions remain covered. With the latest revision, the exemption from surrendering allowances has been extended to CO_2 that is captured and used in such a way that it becomes permanently chemically bound in a product so that it does not enter the atmosphere under normal use, including any normal activity taking place after the end of the life of the product (EU, 2023c). Combined with the observed increases in the EU ETS allowance price since 2018, this provides a considerable financial incentive for CCU/CCS.

Carbon capture is also a key technology in the EU hydrogen strategy (EC, 2020c) and the EU energy sector integration strategy (EC, 2020l). Capital-intensive infrastructure required for CCU/CCS, including CO_2 transport networks, is supported under the revised TEN-E Regulation (EU, 2022e). Moreover, national investment in CCU/CCS technologies, including for power plants, is compatible with EU State aid rules (EC, 2022i).

The EU funds CCU/CCS through, among other means, the Innovation Fund (EC, 2023al), the Horizon Europe programme and the Connecting Europe Facility. CCU/CCS projects supported under the Innovation Fund can originate from electricity and heat generation facilities as well as energy-intensive industries. The proposal for the Net-Zero Industry Act aims to address some core drivers of investments in net zero technology manufacturing, which include fossil gas-based hydrogen with CCU/CCS. It also includes a binding target for EU carbon storage: the annual injection capacity should reach at least 50 Mt CO_2 by 2030 (EC, 2023ao).

Other specific EU policies have been put in place to incentivise the demand for – and therefore development of – CCU-based fuels, including specific fuel mandates under ReFuelEUAviation, the GHG intensity objective under FuelEU maritime and the general objective of reducing the GHG intensity of transport fuels under the RED III (see Chapter 6 'Transport').

The European Commission is planning to publish a dedicated EU strategy for CC(U)S deployment by the end of 2023, which aims to cover industrial carbon management through the transport, use and storage of CO_2 (EC, 2023d).

Several techno-economic aspects of CCU/CCS deployment guide our assessment of the above EU policies in terms of their consistency with climate neutrality.

- Firstly, the contribution of CCU/CCS to the decarbonisation of energy supply depends on costly investment, so that the highest possible rate of carbon emissions can be captured. The standard rate of 90 % observed so far is much lower than the technically feasible rate of over 99 % (Bolscher et al., 2019; Brandl et al., 2021; Holz et al., 2021; IEAGHG, 2019). In practice, projects supported with EU funds, for example the Innovation Fund, are not required to meet the 90 % capture threshold (CINEA, EC, 2023), which leads to remaining ('residual') emissions.
- Secondly, fugitive CH4 emissions are associated with the increased demand for fossil gas driven by CCS applications (see 'Lever: system integration' and 'Lever: reduction of methane emissions' above).
- Thirdly, facilities equipped with CCU/CCS are more energy intensive and may increase cooling water usage significantly compared with their unabated counterparts (IEA, 2023a; IPCC, 2022g).
- Fourthly, there is an inverse correlation between the level of CCU/CCS deployment in energy generation and the need to expand electricity transmission. As explained by Holz et al., 2021, 'as coal- and gas-fired power plants using CCS are located at existing electricity nodes, there is less reinforcement needs for the grid when this type of generation contributes to the supply of electricity than in the case where renewable deployment is larger'.
- Fifthly, only limited long-term geological storage capacity for CO2 is accessible so far across the EU. The mismatch between capture and storage capacity and the failure of coordination in Europe are growing (EC, 2023ao; Simon et al., 2022). The lack of a thorough CCU/CCS value chain identification and mapping has been highlighted in a recent contribution by the JRC (EC JRC et al., 2022).
- Sixthly, EU and national governments will be in charge of developing infrastructure for the transport and storage of CO2, including financing, issuing permits and regulating liabilities (IPCC, 2022g). CO2 infrastructure will be required to provide industrial installations with access to new, low-emission energy carriers and feedstocks (e.g. electricity, low-emission hydrogen) and CO2 storage sites. The need for new infrastructure can be limited through the geographical clustering of industrial activities ((Chiappinelli et al., 2021; Wyns and Khandekar, 2020)
- Finally, studies indicate that CCS has relatively little advantage over a system without CCS in terms of energy system costs (Holz et al., 2021; IPCC, 2022g); further insight into the system costs and benefits of CCU/CCS applications could be part of the TYNDP process (ESABCC, 2023c).

Residual emissions are currently not well defined at the EU or Member State level. Recent studies indicating that without standards for what can be reasonably deemed residual emissions the achievement of the EU's 2050 climate neutrality target is at risk (Buck et al., 2023; Lund et al., 2023).

It is therefore key for EU policymaking to consider the above policy and socioeconomic aspects, the benefits of other mitigation options in line with the energy efficiency first principle, and the limited availability and uncertainties inherent to CCU/CCS and sustainable CDR (Krause et al., 2020; Rogelj et al., 2021). Swift policy correction in this area can avoid the risks linked to the path dependence of EU energy innovation funding and institutional design (see e.g. Meckling et al., 2022). EU policies should target CCU/CCS at priority applications with no alternatives, that is, sectors unable to achieve net zero emissions without CCU/CCS (see e.g. European University Institute., 2022).

4.4 Enabling conditions

Enabling condition: infrastructure

Growth in the share of solar and wind in the EU's electricity mix depends on their rapid integration into electricity grids (IPCC, 2022g) which remains a key challenge in the EU. Connection delays, congestion management work and the costs of curtailing renewable energy because of inadequate electricity grid infrastructure remain considerable and are expected to grow (see for example EC, 2020; ENTSO-E, 2022; Kryszk et al., 2023). This is largely due to administrative and grid aspects of increasingly complex system planning and management. For instance, the permit-granting process for large renewable energy projects can take up to 9 years in some EU Member States (EC, 2022a). According to a study by the European Commission, administrative and grid issues already make up about 46 % of all identified barriers and this share is expected to rise in the future (EC, 2022a). In this light, for electricity network, renewable energy generation, and storage investment to grow more quickly we identify the following EU policy directions.

Faster permits for renewable energy sources

Renewables acceleration areas and other new rules for faster issuing of permits for RESs should go hand in hand with other environmental policies. Project developers and local policymakers can increase fairness and avoid opposition by embracing early and carefully designed public and stakeholder engagement processes.

The numerous barriers to issuing permits for renewable energy infrastructure projects are well identified in institutional and academic literature (EC et al., 2022; IEA, 2023i; Kitzing et al., 2021; Schumacher, 2019). Permission and administrative procedures enabling renewable energy projects have recently entered the centre stage of EU energy policy. The key EU policy instruments in place to address them are the RED II and III, and the European Commission recommendation on speeding up permit-granting procedures for renewable energy projects and facilitating power purchase agreements (EC, 2022d). In May 2022 the European Commission proposed an urgent amendment to the RED II, targeted at speeding up permit procedures as part of the REPowerEU plan (EC, 2022p). While the amendment process is still ongoing, in December 2022 the Council of the EU adopted an emergency regulation laying down a framework to accelerate the deployment of renewable energy (EU, 2022c). It established temporary rules to accelerate the permit-granting process for RESs, especially solar, storage, repowering assets and heat pumps. The emergency rules include a clause on overriding public interest that aims to accelerate the granting of permits, and so do the recently adopted RED III (EU, 2023f) and the European wind power action plan (EC, 2023s).

The RED III (EU, 2023f) increases the ambition to facilitate issuing permits for renewable energy infrastructure projects through (among other means) the introduction of renewables acceleration areas, shortening lead times for issuing permits and extending the overriding public interest clause beyond the temporary framework. In the meantime, technical assistance from the RRF supports EU Member States in reforming their administrations that grant renewables permits (European Commission, 2022e; see also 'investors' certainty and market signals' subsection). EU lawmakers should provide clear guidance on when the above measures are to be effectively implemented; according to the IEA, ambiguity in this respect risks further delays in renewables deployment (IEA, 2023i).

It is paramount that these policies do not compromise on other environmental policy objectives, notably biodiversity protection. Accordingly, the designation of renewables acceleration areas under the RED III needs to be subject to technology-specific environmental impact assessments, and to safeguarding the balance between nature restoration and the siting choices for net zero infrastructure development. Moreover, locally rooted public engagement plays a pivotal role in accelerating RES roll-out. As pointed out by Kirkegaard et al. (2023) in the context of wind energy projects, 'success … heavily depends on how society engages with the development of wind power infrastructure'. Project developers and local policymakers can increase fairness and avoid opposition by embracing early and carefully designed engagement processes following good practice described by institutions, practitioners and scientists (see e.g. EC, 2022d; RGI, 2023; Segreto et al., 2020). These processes can enrich local project planning and execution, including technology choices, by means of co-design and cooperation (e.g., Kirkegaard et al., 2023). Nevertheless, despite good practices being available, the public is often excluded from decision-making in climate matters (Citizens' Observatory for Green Deal Financing, 2023; EPRS, 2023). This weakness partly explains the European Commission's observation that 'the lack of public acceptance of renewable energy projects is another significant barrier to their implementation in many Member States' (EC, 2022d). It is therefore welcome that, in its recommendation on speeding up permit-granting procedures for renewable energy projects and facilitating power purchase agreements (EC, 2022d), the European Commission provides Member States with guidance on good practices in public engagement and encourages them to facilitate participation by citizens, energy companies and local communities, for example by passing the benefits to local communities and simplifying granting permits for renewable energy communities.

Identification of missing projects for a decarbonised electricity system

Energy regulators do not focus sufficiently on identifying cost-efficient but currently missing solutions, including anticipatory investments.

Most electricity transmission projects are regulated. National regulatory frameworks within EU Member States provide the same return to all electricity transmission infrastructure projects in the country, irrespective of their individual risk profile or impact (ACER, 2023b) The EU policy framework recognises different, often high, risk profiles of energy infrastructure projects needed to achieve EU climate targets; for example, projects of cross-border importance, such as most offshore grids. The EU regulation on guidelines for trans-European energy infrastructure – the TEN-E Regulation as recently revised (EU, 2022e) – allows favourable regulatory treatment of such projects, for instance faster issuing of permits and financial incentives. However, some project categories falling under the TEN-E Regulation, such as storage and hydrogen, are often unregulated, so the national regulatory authorities may not have any power to grant them favourable treatment (ACER, 2023b). Risk management aspects of investment in regulated and unregulated assets are an emerging concern for rapid decarbonisation of the EU's electricity grid. ACER has recently suggested that, to improve the incentives framework, regulators' focus should be shifted from project risk mitigation or compensation for transmission system operators to prioritising the identification of cost-efficient but currently missing solutions (ACER, 2023b). Such missing solutions could be identified as part of the TYNDP.

Investment in electricity grids at all voltage levels

EU electricity grid investment needs to increase by a factor of 1.5 from current levels, with a big part of new investment directed towards distribution (low- and medium-voltage) grids.

The observed average investments between 2017 and 2021 are about EUR 40 billion to EUR 45 billion per year (ETIP Wind et al., 2021; IEA, 2022c). According to the REPowerEU plan, an additional EUR 29 billion (ca. EUR 3.6 billion per year) of electricity grid investment is needed by 2030 'on top of what is needed to realise the objectives of the Fit for 55 proposals' (EC, 2022m). The estimates of needs for Fit for 55 range from an additional EUR 2.2 billion per year in the MIX-50 scenario to EUR 7.7 billion per year in MIX and EUR 9.6 billion per year in ALLBNK (EC, 2020p). The European Commission estimates put forward in October 2022 as part of the communication 'Digitalising the energy system – EU action plan' indicate that at least EUR 58.4 billion per year of electricity grid investment is needed between 2020 and 2030 (EC, 2022k).Based on this, it can be assumed that, to meet the EU's 2030 climate objectives, investment in the EU's electricity grid needs to increase by a factor of 1.5 from current levels. However, this assumption should be considered with care, as the estimated ranges of current and needed investment levels in EU electricity grids vary significantly, and call for more consistent and reliable data. There is a consensus, however, about the need to significantly ramp up investment in electricity networks across the EU, with a big part of new investment directed towards distribution (low- and medium-voltage) grids (see for example Prettico et al., 2021; EC, 2022c).

EU-wide system planning aligned with EU climate targets

The TYNDP is not yet in line with the EU's 2050 climate neutrality objective.

The EU internal energy market policy requires the European networks of transmission system operators for electricity and for gas to develop TYNDPs. As a European electricity and gas grid infrastructure investment roadmap, the TYNDP will link, support and complement national grid development plans and will be connected to the national energy and climate action plans. The TYNDP will inform today's energy infrastructure investment decisions, and hence play a pivotal role in the EU's path to its 2050 climate neutrality target. The TYNDP process does not sufficiently address the transformational changes and rapid reductions in GHG emissions that are necessary to achieve the EU's climate neutrality and climate resilience targets by 2050 (ESABCC, 2022b). This observation pertains to the entire TYNDP process, in particular the scenario development, system needs assessment and cost–benefit analysis, as well as the subsequent selection of PCI and projects of mutual interest. To address this weakness, the Advisory Board recommends that priority be systematically given to full decarbonisation, energy efficiency and infrastructure resilience to changing climate, in particular through rapid and widespread electrification combined with demand-side flexibility (ESABCC, 2023c).

Enabling condition: investors' certainty and market signals

The EU's internal energy market is the most interconnected energy market worldwide. There is abundant scholarly literature explaining the fundamentals of its functioning (see for example Meeus, 2020). Well-functioning wholesale and retail markets lead to lower prices for consumers and enable investment in energy systems decarbonisation (see for example IEA, 2022d). The recent fall in wind and solar PV deployment costs as well as geopolitical disruptions in the energy markets have led the EU Member States to revisit the premises of the current legal framework of the internal energy market. The planned market reforms (EC, 2023ar) will go hand in hand with the EU ETS as well as energy taxation and capacity remuneration mechanisms.

While the political negotiations on the EU's electricity market reform (EC, 2023ar) are ongoing, recent academic contributions (EEA and ACER, 2023b; European University Institute, 2022; Glachant, 2022; Grubb et al., 2022; IEA, 2022d) agree that (among other things) the uptake of innovative zero-carbon energy solutions should be encouraged through market design changes (e.g. higher temporal granularity), grid congestion should be tackled and capacity remuneration mechanisms should be reformed.

Capacity mechanisms

The EU can reduce its reliance on fossil fuels to ensure reliability of the energy system by favouring non-fossil resources such as demand-side response and storage to ensure adequate supply.

An opportunity to phase out fossil fuel subsidies becomes evident when scrutinising the existing rules governing so-called capacity mechanisms, which remunerate availability of energy generators to ensure energy system reliability. Energy system reliability can be defined as resource adequacy in which the demand for and supply of energy are always in balance. Capacity mechanisms deployed across the EU aim to ensure that electricity supply is sufficient during peak periods by remunerating producers for the availability of resources. In practice, so far most capacity mechanisms in the EU remunerate fossil fuel thermal generation plants (70 % of contracted capacity in 2022; ACER, 2022). These translate to substantial fossil fuel subsidies given that in 2021 the total incurred or projected costs of capacity mechanisms in the EU reached nearly EUR 5 billion and they are expected to increase to nearly EUR 7 billion in 2023 (ACER, 2022b).

While their overall design is at the discretion of EU Member States, capacity mechanisms must comply with the principles set out in the electricity regulation (EU 2019/943). They must also be in line with the EU's internal market rules, and the state aid rules in particular (regarding state aid, see also Chapters 12 'Finance and investments' and 14 'Climate governance'). Until their revision in 2022, the state aid guidelines for energy and environment did relatively little to encourage capacity mechanisms to remunerate other sources of resource adequacy than fossil fuels (Hancher and Maria Salerno, 2021a; Nowag et al., 2021). A general overhaul of the current rules may be expected under the electricity market reform, creating an opportunity for the EU to encourage non-fossil adequacy resources such as demand-side response and storage.

Supply chains

Vulnerabilities in the EU's supply chains for renewable energy and electrification put the transition in many sectors at risk. Recent EU policies aim to address this challenge by boosting domestic manufacturing and promoting the reuse of secondary raw materials.

The EU's transition to climate neutrality entails energy and material supply substitution processes, which rely on secure supply chains of raw materials and technical components of clean technologies. These substitution processes and material reliance have profound impacts on, and are impacted by, global trade and geopolitics (EC, 2023be; Lowe and Drummond, 2022). The supply chain disruptions due to the COVID-19 pandemic and the Russian invasion of Ukraine illustrated Europe's vulnerabilities in this regard (Accenture, 2022; WindEurope and Eurofer, 2023).

In 2022 the REPowerEU plan called for 'action on the supply side to create the capacity and framework to roll out and produce renewables' (EC, 2022m). It focuses on strengthening supply chains for solar, wind and heat pump technologies. In this vein, the EU co-legislators work on future EU regulation to diversify and monitor the EU's imports of critical raw materials in order to reduce strategic dependencies, and to improve sustainability and circularity within supply chains (EC, 2023as); see also Chapter 5 'Industry'. Resilient and transparent wind industry supply chains, and de-risking financial exposure linked to supply disruptions are also in the focus of the EU wind power action plan (EC, 2023s). These policy initiatives make a very promising contribution to EU energy supply decarbonisation.

4.5 Summary tables

Table 4 Progress summary – energy supply

Indicator	Reference period	Historical progress	Required up to 2030		Required in 2031–2050
E1: GHG emissions	2005–2022	– 33 Mt CO_2e/yr	– 55 Mt CO_2e/yr		– 24 Mt CO_2e/yr
E2: electricity generation mix					
E2a: % of fossils	2017–2021	– 1.7 pp/yr	– 1.9 pp/yr		– 0.6 pp/yr
E2b: % of non-bio renewables	2017–2021	+ 1.7 pp/yr	+ 1.8 pp/yr		+ 0.9 pp/yr
E3: electricity GHG intensity	2018–2022	– 10 g CO_2e/kWh/yr	– 16 g CO_2e/kWh/yr		– 12 g CO_2e/kWh/yr ([a])
E4: renewables capacity deployment					
E4a: solar PV	2018–2022	+ 22 GW/yr	+ 25 GW/yr Fit for 55	+ 48 GW/yr REPowerEU	+ 34 GW/yr
E4b: onshore wind	2018–2022	+ 10 GW/yr	+ 21 GW/yr		+ 30 GW/yr
E4c: offshore wind	2018–2022	+ 1.5 GW/yr	+ 6 GW/yr		+ 11 GW/yr
E5: electrification rate	2017–2021	– 0.04 pp/yr	+ 0.9 pp/yr		+ 0.9 pp/yr
E6: energy-related methane emissions	2017–2021	– 3 Mt CO_2e/yr	– 4 Mt CO_2e/yr		– 1 Mt CO_2e/yr

Legend

On track	The required change ([b]) is ≤ 1.
Almost on track	The required change ([b]) is between 1 and 1.5.
Somewhat off track	The required change ([b]) is between 1.5 and 2.
Considerably off track	The required change ([b]) is ≥ 2.
Wrong direction	The required change ([b]) is < 0.

([a]) Required in 2031–2040 in order to reach near- zero GHG intensity by 2040.

([b]) See Section 2.2 for more details on how the required change is calculated.

Table 5 Policy consistency summary - energy supply

Policy inconsistencies	– Not all EU policies are consistent regarding the role of fossil gas in future energy systems (e.g. the TEN-E Regulation, the proposed Gas Directive and regulation, State aid rules and the EU Taxonomy).
Policy gaps	– The EU's massive policy support to the hydrogen value chain does not sufficiently reflect the techno-economic limits of hydrogen and its role in integrated and decarbonised energy systems. – Residual emissions (from so-called hard-to-abate sectors) are currently not defined at the EU or Member State level. – Fugitive CH_4 emissions in the energy sector have not been addressed by EU policies (dedicated regulation in the lawmaking process). – The electricity market reform including support to non-fossil electricity system flexibility sources (e.g. demand response) and the RES value chain reinforcement (Net-Zero Industry Act) are in the lawmaking process.
Ambition gaps	– The EED reinforces the application of the energy efficiency first principle but sets a very high threshold, which means that many relevant projects are exempt from assessment of energy efficiency solutions, including demand-side resources and system flexibilities.
Implementation gaps	– Diverse understandings and measurements of energy efficiency and its multiple benefits under the EED and energy retrofit investment schemes have led to insufficient operationalisation of the energy efficiency first principle so far. – The EU still lacks planning and operation of the energy system as a whole. – Market upscaling of innovative renewable energy technologies is making slow progress.

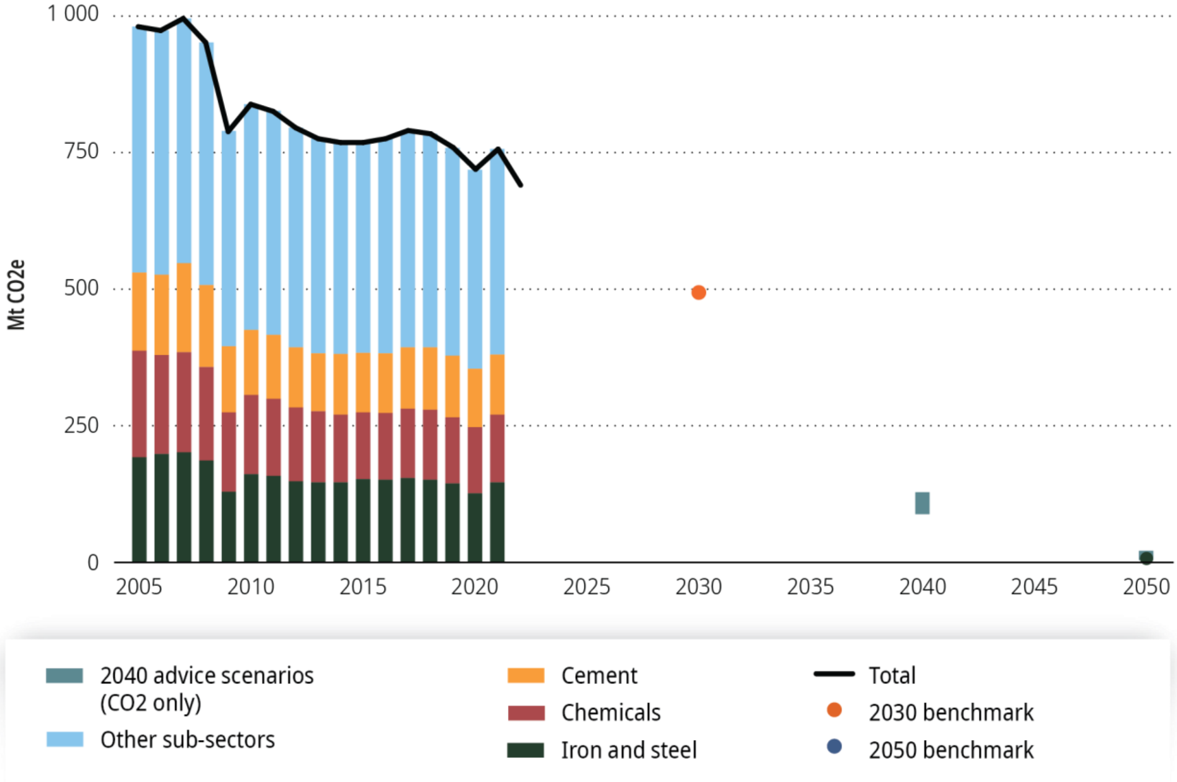
5 Industry

Key messages

Industrial GHG emissions reduced by 30 % in 2005–2022, partially driven by lowered production in emission-intensive industries. Achieving climate neutrality requires a transition to new, zero-emission technologies in combination with lowered demand for GHG-intensive materials.

The industry sector reduced its GHG emissions by 30 % in 2005–2022 (see Figure 20), while its gross added value increased by 33 %. In GHG-intensive sectors (iron and steel, cement, and chemicals), reductions were mainly driven by lowered production, while their use levels and GHG intensities ([15]) remained relatively stable. The increase in gross value added, in combination with declining production levels in GHG-intensive industries, suggests a shift of activities to less GHG-intensive subsectors.

Figure 20 Indicator I1 – overall progress in reducing industrial GHG emissions



Source: see Figure 23 for detailed sources and notes.

The average annual reduction in 2005–2022 (by 17 Mt CO_2e per year) needs to accelerate (to 24 Mt CO_2e per year in 2023–2030 and 21 Mt CO_2e per year in 2031–2050) to be consistent with the trajectories towards the overall 2030 and 2050 reduction objectives. A steeper reduction rate would be required to achieve the recommended 90–95 % GHG emission reductions by 2040. Achieving deep reductions in industry while avoiding carbon leakage to outside the EU requires a transition towards low- and zero-

([15]) The GHG intensities of steel, cement and chemicals are also dependent on the production mix and quality grade (e.g. steel alloy grades, clinker content in cements, share of finer chemicals in the total production mix). For lack of available data, the Advisory Board was not able to assess the impact of this on the observed GHG intensities.

emission industrial production technologies in combination with lowered demand for GHG-intensive materials. Such technologies are currently under development, and several pilot and demonstration projects have been launched in recent years, bringing the sector closer to faster emission reductions.

More action is needed to accelerate the transition towards a circular economy and curb demand for GHG-intensive materials.

Needs. Demand for GHG-intensive materials can be limited through an overall reduction in product demand (e.g. by increasing lifetimes and repairability), increased material efficiency and enhanced material circularity. This would allow faster emission reductions at overall lower costs, while reducing pressures on expanding renewable electricity, hydrogen and CCS infrastructures, as well as waste handling. Policies that could support such demand-side measures include product standards, price policies (e.g. a carbon price that is passed along the value chain) and waste policies. So far, the EU has made very little progress in increasing the circular use of materials, and demand for key GHG-intensive materials (steel, cement and base organic chemicals) has remained relatively stable.

Gaps. Demand management and material efficiency have until recently remained largely unaddressed by EU policies. The 2015 circular economy action plan (CEAP 1) and the strategy on plastics mainly targeted recycling, with little focus on solutions upstream in the waste hierarchy **(policy gap)**. Similarly, the Ecodesign Directive has been mainly focused on energy efficiency and, whereas product circularity has been added in recent years, its scope remained limited to energy products **(policy gap)**. Recent policies are steps in addressing this gap, including the 2019 Directive on Single Use Plastics and CEAP 2 which has a broader scope than CEAP 1 (including product design, durability, repairability, reusability and recyclability). Although a clear improvement, the effectiveness of the latter will depend on the specific actions included in the plan, most of which have only been adopted recently (e.g. the Ecodesign for Sustainable Products Regulation) or still under negotiation (e.g. the End-of-life vehicles Regulation).

In parallel, high levels of free allocation to industry in combination with the lack of a carbon price on imports, as well as the exclusion of the waste sector under the EU ETS, have undermined the incentive for such demand-side measures **(ambition and policy gaps)**. The most recent revision of the EU ETS partially addresses this gap by gradually shifting from free allocation to a CBAM for specific sectors as a carbon leakage prevention measure, and the potential inclusion of the waste sector as of 2028 (while taking into account the potential diversion of waste to landfill or exports to third countries). See also Chapter 10 ‘Pricing emissions and rewarding removals’.

Recommendation I1. The Advisory Board recommends that EU co-legislators complete the legislative decision process on the various actions under the CEAP 2 without watering down the provisions, in order to accelerate the transition towards a circular EU economy, which would contribute to climate neutrality.

Recommendation I2. The EU should further develop alternatives to free allocation for addressing the risk of carbon leakage. The European Commission should, among other things, monitor the introduction of the CBAM, with a view to expanding it to more products and sectors, as envisaged in the CBAM regulation (see also Chapter 10 ‘Pricing emissions and rewarding removals’). In addition to relying on price signals, it would be prudent to explore other policy measures to support the demand management and efficiency of materials, such as through spatial planning (see also Section 7.5), standards or public procurement.

Dedicated policies are needed to help low-emission industrial technologies reach full maturity ([16])**.**

Needs. So far, limited progress has been made in reducing the GHG intensity of key GHG-intensive materials (iron and steel, cement, and chemicals), and achieving deep reductions by 2050 in these subsectors will require a large-scale shift towards new, low-emission production processes. Promising production technologies are currently under development but have not yet reached full maturity. These include, among others, hydrogen direct reduction of iron ore, CCS for cement, and electrification, hydrogen and sourcing of non-fossil carbon in the chemicals industry. Their development and deployment will need to be accelerated and scaled up. Dedicated policies are required to support new low-emission technologies throughout each stage of their development. For other industrial sectors, emissions are mainly related to heat production, which can be reduced through direct electrification, complemented with other forms of renewable heat (e.g. based on hydrogen and biomass). In all cases, the transition to a low-emission industry depends on sufficient access to decarbonised electricity, hydrogen and – for sectors with high process emissions, such as cement – CCS infrastructure (see also Chapter 4 ‘Energy supply’).

Gaps. Past EU policies have been mainly focused on supporting basic R & D (e.g. Horizon Europe), pilots and demonstration (NER 300 and the Innovation Fund) and the large-scale diffusion of mature technologies (the EU ETS), but dedicated policies to support early deployment / market formation have been largely absent **(policy gap)** (see also Chapter 13 ‘Innovation’, and particularly Section 13.3). Recent (proposed) EU policies aim to address this gap, including by providing direct financial support ((carbon) contracts for difference or fixed premium contracts under the Innovation Fund), and by creating lead markets (planned mandatory green public procurement requirements and the proposed Ecodesign for Sustainable Products Regulation under CEAP 2). Given how recent these new policies are, the Advisory Board has not yet been able to assess their (expected) effectiveness.

Recommendation I3. Dedicated EU policies should (continue to) provide support for the development and deployment of new, low-emission industrial technologies at each stage of their development. The new support mechanisms under the Innovation Fund and the various initiatives under the CEAP 2 should be implemented and closely monitored to ensure they provide adequate support for the early deployment of such technologies.

5.1 Scope and sectoral assessment framework

Scope

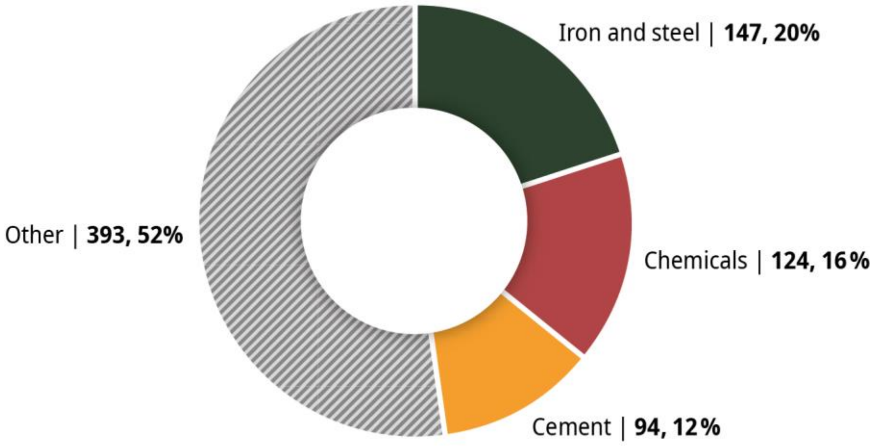
This chapter covers both the energy- and process-related GHG emissions from the EU industrial sector (CRF categories I.A.2 and 2 in the GHG inventories). It includes F-gases and emissions from construction activities but excludes emissions from petroleum refining and fossil fuel extraction (which are included in Chapter 4 ‘Energy supply’). Emissions from waste treatment are not included in the emission data, but some waste-related policies are included in the policy consistency assessment, given their links with the circular economy.

The industrial sector is a heterogeneous group of subsectors, each of which has its own characteristics. Whereas this chapter covers the entire industrial sector, a particular focus is put on the top three emitting

([16]) Full maturity is assumed to be reached when such technologies reach technology readiness level 9: ‘actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)’ (EC, 2014).

subsectors (iron and steel, cement and chemicals), which jointly accounted for almost half of total industrial GHG emissions in the EU in 2021 (see Figure 21).

Figure 21 Industrial GHG emissions in 2021 per subsector (Mt CO_2e and % of total)



Notes: GHG emissions for iron and steel are based on the 2023 EU GHG inventory, and includes both energy- (CRF category 1.A.2.a) and process emissions (CRF category 2.C.1) but excludes emissions from blast furnace gases which are combusted for electricity production, which is instead reported under the 'energy supply' sector (CRF category 1.A.1) in the GHG inventory. GHG emissions for chemicals include both energy- (CRF category 1.A.2.c) and process emissions (CRF category 2.B). GHG emissions for cement are based on verified EU ETS data accessed via the EEA EU ETS data viewer (installations with main activity code 29). These emissions are slightly underestimated as they don't include installations without in-house clinker production. 'Other sectors' is calculated as the difference between total industrial emissions (CRF categories 1.A.2 and 2) and the emissions of iron and steel, cement, and chemicals.

Sources: GHG inventories (EEA, 2023f), EEA EU ETS data viewer (EEA, 2023g)

Greenhouse gas emission reductions required in the industry sector to reach climate neutrality

Under the 1.5TECH and 1.5LIFE scenarios of the European Commission's in-depth analysis accompanying the 2018 LTS 'A clean planet for all' (EC, 2018e), industrial CO_2 emissions are expected to reduce by almost 90 % by 2050 compared to 2005. Under the more recent 2020 Climate Target Plan impact assessment (EC, 2020s) , total industrial GHG emissions are expected to reduce by 90–93 % by 2050 compared to 2005. Nevertheless, some limited residual emissions would remain in 2050 (65–95 Mt CO_2e.), which need to be counterbalanced by emission removals either within or outside the industrial sector to achieve overall climate neutrality. This is also in line with the latest IPCC AR6 Illustrative Mitigation Pathways, which see deep reductions but still a certain level of residual industrial GHG emissions in most scenarios by 2050 (IPCC, 2022h).

Assessment framework for the industry sector

The selection of outcomes, mitigation levers and enabling conditions is primarily based on the industry chapter (chapter 11 of the contribution of Working Group III) of IPCC AR6 (IPCC, 2022h).

Outcomes. IPCC AR6 has identified six major mitigation pathways (see levers below) for the industry sector that could reduce emissions by reducing overall demand for GHG-intensive materials, and by decarbonising industrial production processes (IPCC, 2022h). Based on this, the following two outcomes were identified as a basis for tracking progress and policy consistency in the industry sector:

— **lowering demand** for GHG-intensive materials,
— a shift towards **low-carbon industrial production processes**.

Mitigation levers. To achieve these outcomes, six main mitigation levers were identified, which largely correspond with the six main mitigation pathways of IPCC AR6. A split was made between marginal efficiency improvements and fuel switches within existing production processes, on one hand, and the switch to new, climate-friendly production processes, on the other hand. The selected levers are as follows.

— An overall **reduction in product demand** can be achieved through smarter system design, sufficiency measures (e.g. more compact housing, and fewer and more compact vehicles, both of which are also linked with spatial planning at the urban and territorial scales; see also Section 7.5), the sharing economy and enhanced product lifetimes (through higher durability and repairability).
— A further reduction in demand for GHG-intensive materials can be achieved through **material efficiency** (e.g. lightweighting, 3D printing, near-net shaping and avoiding over-dimensioning) and **material substitution** (e.g. substitution of supplementary cementitious materials for clinker-based cement).
— A high level of **material circularity** at end of life can be achieved through a higher level of repurposing and high-quality recycling, facilitated by product design, appropriate waste sorting and collection, and adequate recycling capacities.
— Continued **energy efficiency improvements** and **fuel switches (including electrification)** within existing production processes can contribute to further reducing emissions in the short to medium term without major changes required to industrial infrastructure.
— In some subsectors – including major emitters such as the iron and steel and chemicals sectors – the potential for further efficiency improvements and fuel switches within existing production processes is limited. For these sectors, **a shift towards new, climate-friendly production processes** will be needed to achieve deep GHG emission reductions.
— The application of end-of-pipe **carbon capture** combined with geological storage (**CCS**) or utilisation (**CCU**) will be required for industrial processes that have no alternative mitigation option (e.g. cement production, in which 60 % of total emissions relate to unavoidable CO_2 emissions from calcium carbonate decomposition).

The first three levers are also often referred to as circular economy measures.

Enabling conditions. In addition, six enablers were identified that could support the six levers. These enablers are based on the key policy approaches and strategies identified by IPCC AR6, complemented by insights from other studies on industrial decarbonisation.

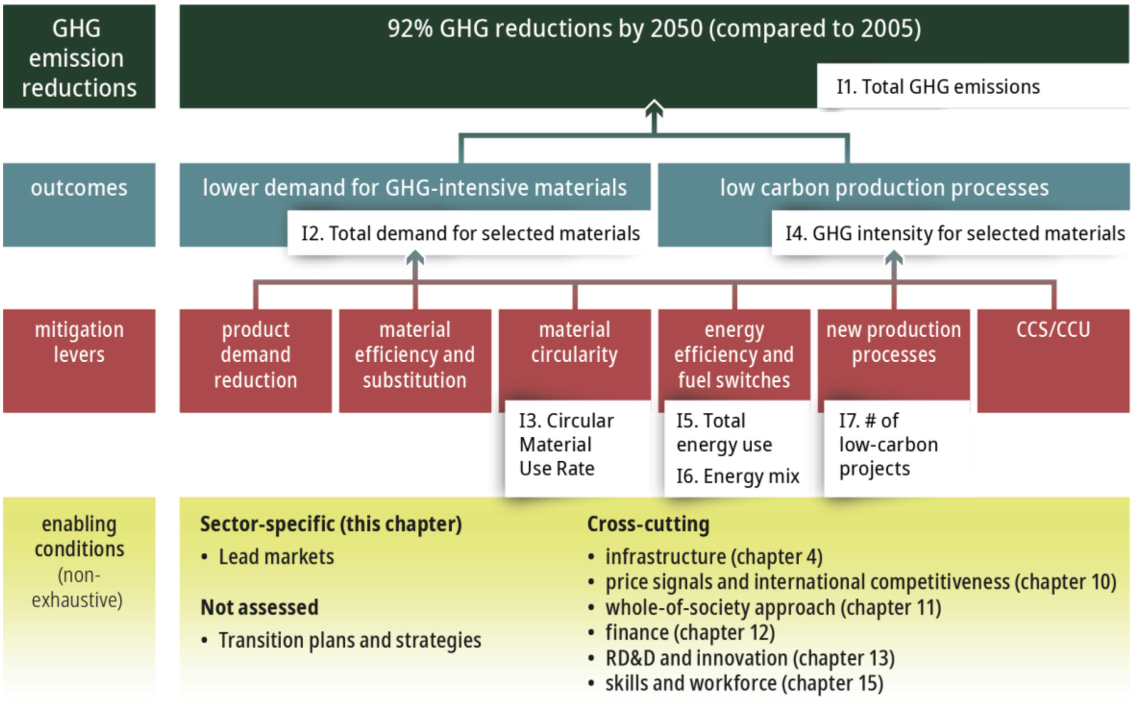
— **Price signals** – e.g. by means of carbon-pricing policies – can steer both consumer's choices and industrial producers' investment and operational decisions (see also Chapter 10 'Pricing emissions and rewarding removals').
— **Transition plans and strategies** are needed to coordinate the different policy domains affecting the industrial sector, and to guide policy design and investments.
— **RD & D and innovation** are necessary to enable the development and improvement of new technologies that can facilitate further emission reductions.
— **Lead markets** (or market pull) and **financial support** are considered highly effective (or even a prerequisite) to allow new technologies to bridge the gap between first commercialisation and large-scale deployment.
— **Infrastructure** planning, financing and construction will be required to provide industrial installations with an adequate supply of new, low-emission energy carriers and feedstocks (e.g. electricity, hydrogen) and CO_2 storage sites. Given the overlap with the energy supply sector, this

enabling condition is assessed in Chapter 4 'Energy supply'. The need for new infrastructure can be limited through the geographical clustering of industrial activities, which would also facilitate the exchange and valorisation of by-products between different installations (Chiappinelli et al., 2021; Wyns and Khandekar, 2019).

— **International competitiveness** needs to be safeguarded to ensure that EU GHG emission reductions are achieved by real emission reductions and not merely by displacing industrial activities to areas outside the EU (carbon leakage), and to attract the required investments in new climate-friendly production technologies and infrastructures.

Some other cross-cutting enabling conditions, which are discussed in other chapters of this report (whole-of-society approach, finance and a skilled workforce), are also relevant to the industry sector, as shown in Figure 22. This figure also shows the indicators (shown in the white boxes) that were selected to track progress in the industry sector.

Figure 22 Assessment framework for the industry sector



Source: Advisory Board (2024).

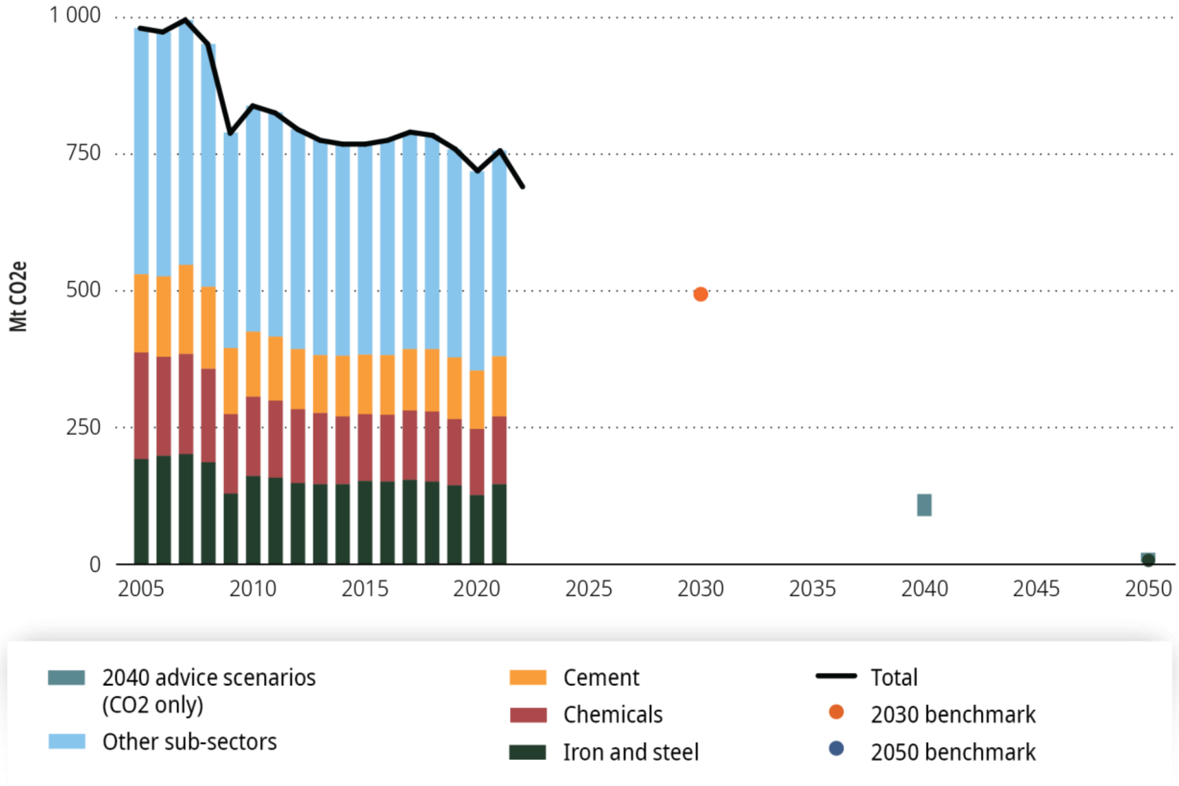
5.2 Emission reduction progress

Total industrial GHG emissions decreased by 30 % in 2005–2022 (see Figure 23). The sharpest reduction occurred in 2007–2010, mainly because of production decreases in the iron and steel and cement sectors in the context of the economic crisis and N_2O abatement measures in the chemicals industry (EEA, 2023f; EEA ETC/CM, 2022). After that, the pace of reductions slowed until 2020. A period of volatility then followed the COVID-19 pandemic, when emissions dropped, then partially rebounded in 2021, and fell again in 2022 amid high energy prices and curtailed production levels (ESABCC, 2023a). While emissions decreased, the gross value added of EU industry increased by 33 % in real terms from 2005 to 2021 (Eurostat, 2023m). When considering specific industrial subsectors, considerable reductions occurred in

2005–2021 in the iron and steel sector (– 24 %), the chemicals sector (– 36 %) and the cement sector (– 23 %), with less steep reductions in other industrial subsectors (– 16 %) (see Figure 23).

The average annual reduction in 2005–2022 (– 17 Mt CO_2e per year) needs to accelerate to – 24 Mt CO_2e per year in 2023–2030 and – 19 Mt CO_2e per year in 2031–2050 to be consistent with the trajectories towards the overall 2030 and 2050 reduction objectives. A steeper reduction rate would be required to achieve the recommended 90–95 % GHG emission reductions by 2040.

Figure 23 Indicator I1 – overall progress in reducing industrial GHG emissions.



Notes: Historic GHG emissions based on the EU GHG inventory and verified EU ETS data (see figure 21 for more info, including on the split between different sub-sectors). The 2030 benchmark is based on the European Commission's Fit for 55 MIX scenario, as the sum of industrial energy-related CO_2 emissions, non-LULUCF non-energy CO_2 emissions, and non-CO_2 emissions from industry, AC & refrigeration and 'other sectors'. The 2050 benchmark is based on the MIX scenario from the Climate Target Plan impact assessment (see figures 9 and 65), and includes industrial energy and process CO_2 and non-CO_2 emissions. The 2040 advice range is based on the scenarios which underpin the Advisory Board's 2040 advice, and includes CO_2 emissions only.

Sources: GHG inventories (EEA, 2023f), EEA EU ETS data viewer (EEA, 2023g), Fit for 55 MIX scenario (EC, 2021v), Climate Target Plan impact assessment (EC, 2020s), Advisory Board 2040 advice scenarios (ESABCC, 2023b).

5.3 Outcome 1: lower demand for greenhouse gas-intensive materials

Demand-side measures have substantial potential to reduce GHG emissions while providing several other co-benefits.

The GHG reduction potential of measures that reduce the demand for GHG-intensive materials could be substantial. A 2020 report by the International Resource Panel found that material efficiency measures could reduce the life cycle GHG emissions of residential buildings and passenger vehicles by 35 % and 40 % respectively by 2050 compared with a scenario that only pursues supply-side mitigation measures (IRP, 2020). Two reports by Material Economics came to similar conclusions and found that increased material efficiency and high-quality material recirculation could reduce emissions from major industrial sectors in the EU by more than half. Most of the required measures would be at relatively low cost (< EUR 50/t CO_2e) or even profitable, provided that specific barriers are removed (Material Economics, 2019, 2018). Furthermore, these measures would not only reduce GHG emissions but also contribute to mitigating biodiversity loss and pollution, whereas a GHG reduction strategy solely focused on supply-side measures might worsen other environmental problems such as biodiversity loss, pollution and waste (Potoćnik and Teixeira, 2022).

Slow progress has been made so far in curtailing material demand and increasing material circularity.

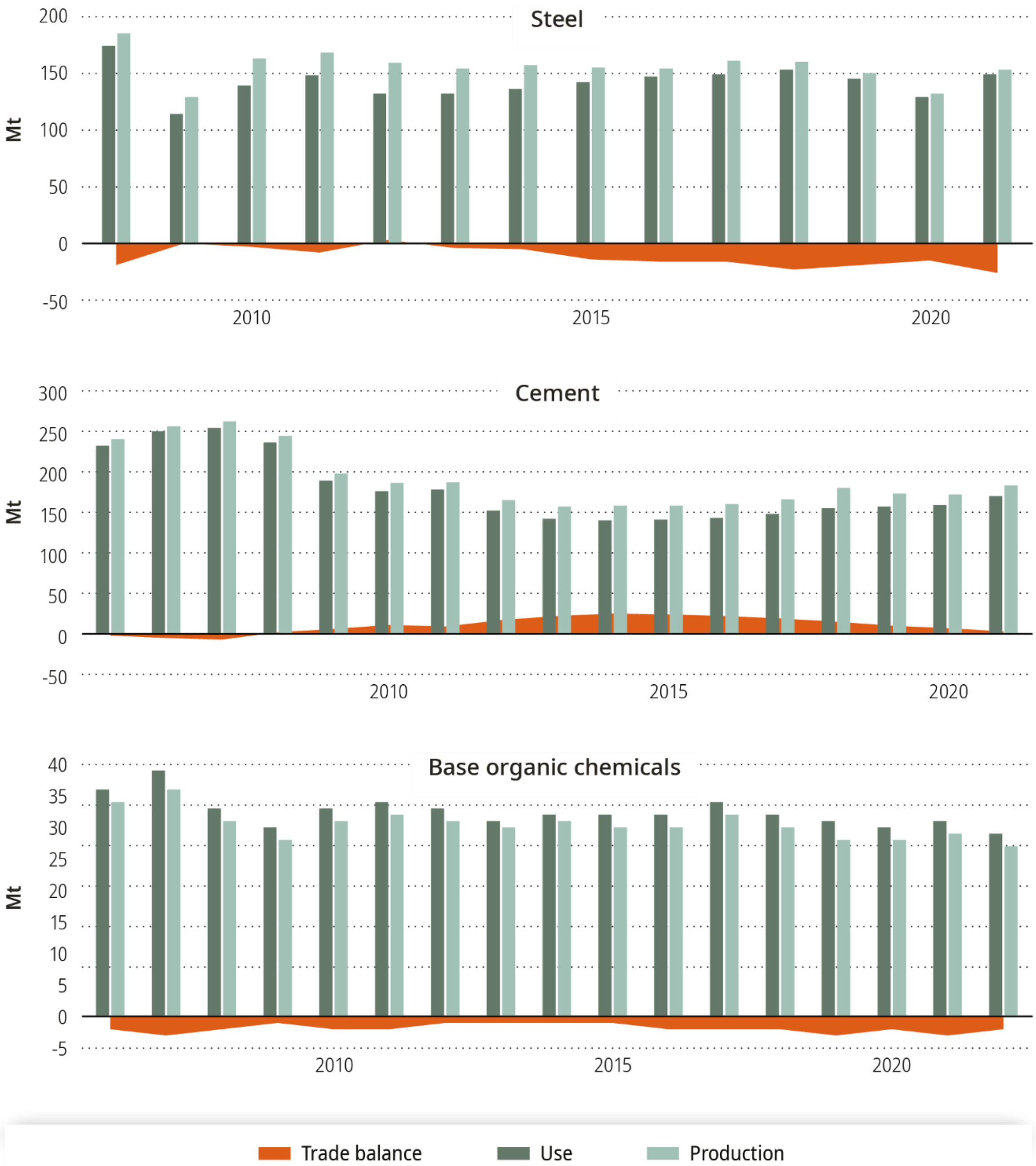
Figure 24 shows estimates of the use and production of steel, cement and chemicals in the EU, illustrating a pattern that largely follows economic cycles. The demand for these GHG-intensive materials decreased in 2008–2009 in the context of the economic crisis, and, although it has recovered somewhat since 2015, overall demand has been relatively stable in recent years. Production of steel, cement and base organic chemicals have followed similar cyclical trends, although there are some differences in the change in trade balance. For example, growth in steel demand in recent years has largely been met by increased imports, leading to the development of a negative trade balance. For cement, this trade balance has become positive, while the negative trade balance for chemicals has largely remained stable.

There is no publicly available data on the use and production of GHG-intensive industrial products under the European Commission's scenarios that underpin the EU climate objectives, and therefore no benchmark for this indicator was set. However, the EU's 8th EAP does include a legally binding (but unquantified) broader objective to 'significantly reduce the EU's material and use footprint by 2030' (EC, 2022q), which might also require a reduction in the overall use of GHG-intensive materials.

The circular material use rate represents the share of recycled materials in the total amount of materials used by the EU economy and is therefore a good proxy indicator of the circularity of an economy. As Figure 25 illustrates, the rate has been increasing very slowly in recent years; it went from 10.8 % in 2010 to 11.7 % in 2021.

The European Commission has announced its ambition to double the circular material use rate by 2030 (EC, 2020g). This would require a more than a tenfold increase in the recently observed average annual rate of change by (from on average + 0.1 pp per year in 2017–2021 to on average + 1.3 pp per year in 2021–2030). Given the scale of the required acceleration, this will probably need a combination of increasing recycling and declining overall material demand.

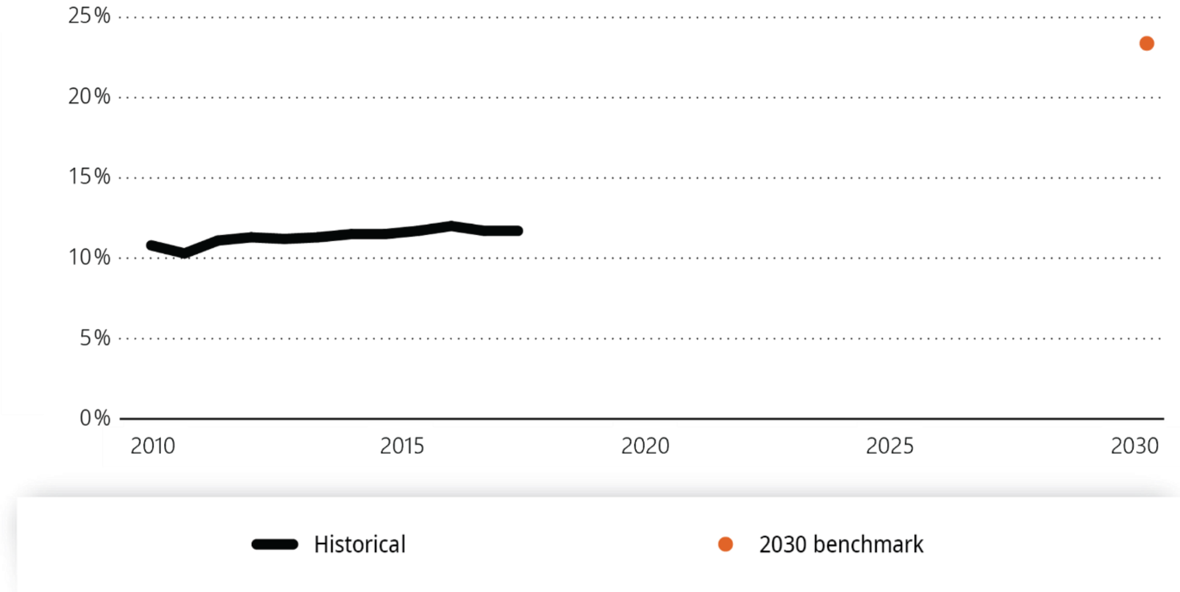
Figure 24 Indicator I2 – production, use and trade balance of steel, cement and base organic chemicals



Notes: Steel production and use data is from Eurofer's annual activity report. Production refers to crude steel outputs, whereas use refers to apparent steel consumption (which includes steel that is stocked and not used immediately). The steel trade balance (exports minus imports) is based on data from Eurostat (DS-059268). The trade balance does not fully reflect the balance between production and use, which is partially due to material losses between crude steel output and total finished steel production (with the latter being lower than total steel use since 2015, which is consistent with the observed negative trade balance). Cement production and use received by mail from Cembureau, trade data based on Eurostat (DS-059268). Base organic chemicals data on production, import and export estimated based on Eurostat (DS-056120), use calculated as production + import – export.

Sources: Eurofer annual activity report (Eurofer, 2022), Eurostat (2023c, 2023d)

Figure 25 Indicator I3 – circular material use rate in the EU



Sources: Eurostat (2023a) (historic), Circular Economy Action Plan 2 (EC, 2020g) (benchmark).

Improvements to the EU circular economy policy framework are still under development.

In the period to 2020, EU policies to decarbonise the industry sector mainly focused on supply-side solutions to address negative consequences of production, neglecting demand-side options (Pantzar and Suljada, 2020). Efforts to address the demand side have long been limited to voluntary information provision (e.g. on eco-labels) and voluntary green public procurement. However, the impact of such voluntary approaches is likely to remain limited unless combined with other, stronger policies such as pricing policies (e.g. carbon pricing) or regulations (EEA, 2022h; Pantzar and Suljada, 2020; SAPEA, 2020). The uptake of green public procurement practices in EU Member States has also been limited (Axelsson et al., 2023; Sapir et al., 2022).

In 2015, the European Commission launched CEAP 1, which included 54 specific actions (EC, 2015a). However, these measures have not been effective at curbing demand for GHG-intensive materials (see indicator I2) or at increasing the circularity of materials (see indicator I3). One of the major shortcomings that have been identified is the focus on waste management at the end of life of products rather than product system design and lifetime decisions, which determine much of a product's environmental impact (Friant et al., 2020; IRP, 2020; Watkins and Meysner, 2022; ECA, 2023a).

Similarly, the Ecodesign Directive (2009/125/EC) largely focuses on energy efficiency, although other dimensions such as product durability and repairability have been added over time (Barkhausen et al., 2022). Nevertheless, its scope remains limited, covering mainly energy-related products. A broader range of product standards covering recyclability has been identified as necessary to reverse the growing variety of composites, alloys and additives that prevent high-quality, closed-loop recycling of GHG-intensive materials (Chiappinelli et al., 2021; Neuhoff et al., 2019).

Finally, the lack of consistent price signals has been identified as a barrier to a more circular economy and an overall reduction in demand for materials. Inconsistencies include the exclusion of waste treatment from the EU ETS and the free allocation of allowances to GHG-intensive industry as a means to prevent carbon leakage in combination with a lack of carbon pricing on imported materials (see Chapter 10 'Pricing emissions and rewarding removals').

In more recent years, several steps were taken to address these gaps. In 2019, the EU adopted the Single-Use Plastics Directive (EU, 2019a), which introduced measures to reduce the use of 10 single-use items made from plastics. These include bans on those items where sustainable alternatives are easily available and affordable. This could also contribute to GHG emission reductions, as alternatives have, or can have, a substantially lower carbon footprint (– 75 % for bioplastics, ≥ 85 % for multi-use items (Di Paolo et al., 2022)).

The European Commission also launched CEAP 2 under the European Green Deal, including 35 additional actions (of which about half are legislative) to boost the circular economy (EC, 2020g). At the time of the publication of this report, most of these proposals have already been published by the European Commission but the legislative process is still ongoing. CEAP 2 takes on a broader approach towards the circular economy than CEAP 1, extending the focus of its actions to areas upstream in the waste hierarchy, such as product design, durability, repairability, reusability and recyclability. Furthermore, as about half of the actions under the plan are legally binding measures, it shows an increasing recognition of the need to use legally binding measures to strengthen the transition towards a circular economy. Finally, it also aims to improve the monitoring framework to track progress on the transition towards a circular economy (Johansson, 2021; Pantzar and Suljada, 2020; Watkins and Meysner, 2022). Although the plan itself is not binding on Member States, achieving its objectives will require ambitious and effective policies at the national and subnational levels. Several legislative proposals under CEAP 2 will become binding at the national level, including the Ecodesign for Sustainable Products Regulation (EC, 2022v), the revision of the Construction Products Regulation (EC, 2022x), the revision of the Vehicle End-of-life Directive (EC, 2023at), the revision of the Packaging and Packaging Waste Regulation (EC, 2022y), and the revision of the EU Waste Framework Directive (EC, 2023aq). These proposals are currently still in the legislative process or have been adopted only recently (see Table 3), and a detailed assessment of their consistency with the EU's climate objectives goes beyond the scope of this report.

Circularity also plays an important role in alleviating supply chain challenges, which have recently affected EU net zero industries and risk complicating the EU's transition to climate neutrality. The challenge stems from, among other factors, the high concentration of strategic minerals and supply chains in a few countries, and in particular China, which dominates supply chains of key critical materials (e.g. copper, lithium, nickel, cobalt and rare earth minerals) and net zero technologies (e.g. solar PV and batteries) (ECA, 2023d; IEA, 2023j, 2022f). Such concentration raises concerns that geopolitical factors could disrupt the supply chain required for the net zero transition (IPCC, 2022g). The combination of the EU's limited own extraction, processing and production capacities, high dependence on imports from a limited number of trading partners, strong incentives in other regions of the world to attract investments in battery supply chains and projected strong increases in demand globally makes it particularly vulnerable to supply chain disruptions (ECA, 2023d; IEA, 2023j). The EU policy framework is currently responding to this challenge: the EU raw materials initiative launched in 2008, led to the adoption of Critical Raw Materials Resilience roadmap in 2020 (EC, 2020j), including the EU list of critical raw materials. The REPowerEU plan announced increased EU innovation funding to 'reduce materials consumption, enhance recyclability of renewable energy equipment and substitute critical raw materials' (EC, 2022p) in line with CEAP 2. In 2023, as part of its Green Deal Industrial Plan, in response to the US Inflation Reduction Act it proposed a Critical Raw Materials Act (EC, 2023ac) and Net-Zero Industry Act (EC, 2023ao), which contain objectives aimed at boosting the EU's domestic supply chains for critical raw materials and its manufacturing of strategic net zero technologies respectively. Both proposals are currently still in the legislative process (see Table 3), and a detailed assessment of their consistency with the EU's climate objectives goes beyond the scope of this report.

The revision of the EU ETS Directive in combination with the CBAM Regulation (EU, 2023c, 2023n) is expected to result in better internalisation of the carbon cost in end use products, which supports the different mitigation levers to reduce demand for GHG-intensive industrial products. However, as this is only introduced gradually and for specific sectors, the EU ETS does not yet ensure that the climate cost of producing a product is fully reflected in the product's price. That may potentially result in overconsumption. In addition, the revised EU ETS Directive requires the European Commission to assess the extension of the system to waste incineration by 2026, with a view to including it as of 2028 (see Chapter 10 'Pricing emissions and rewarding removals' for more details). This assessment should consider, among other topics, the potential diversion of waste towards landfill or increased exports to non-EU countries, which would lead to higher overall emissions (EU, 2023c).

5.4 Outcome 2: low-emission production processes

Progress on decarbonising industrial production is slow. New technologies are under development.

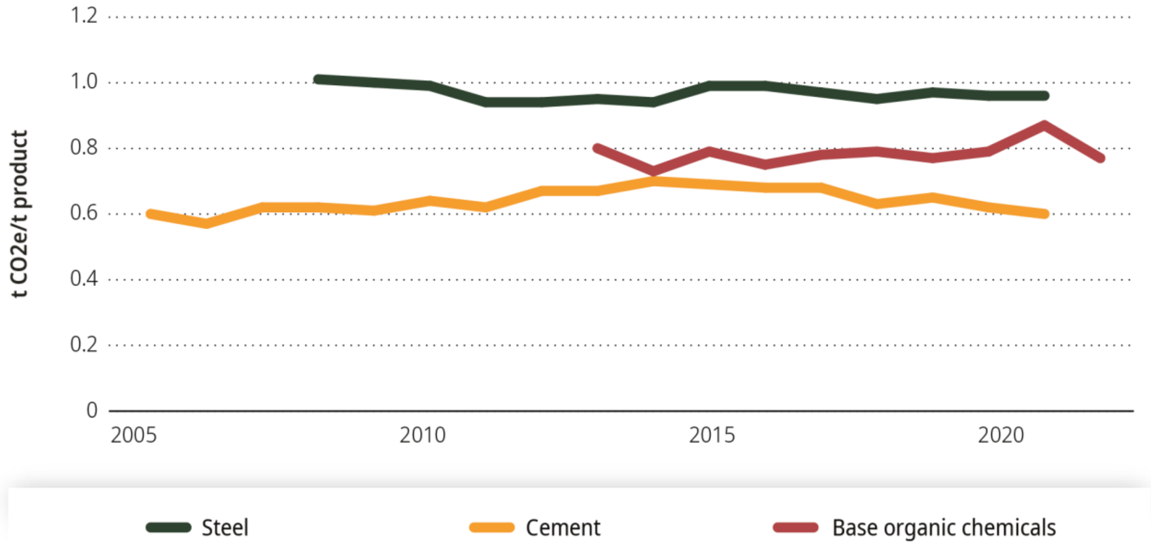
Estimates suggest that the GHG intensity of the selected GHG-intensive materials (steel, cement and chemicals) in the EU has been relatively stable or even slightly increasing, and observed trends in total emissions have been driven mainly by changes in production levels rather than reductions in emission intensity (see Figure 26).

— The emission intensity of steel production decreased slightly (– 5 %) between 2008 and 2021. The 21 % decrease in total GHG emissions was thus mainly driven by lower production levels, rather than decarbonisation of the production process.
— The emission intensity of (clinker-based) cement increased slightly in 2005–2015 before starting to decline again. By 2021, the emission intensity was at the same level as 2005, whereas total GHG emissions reduced by 23 % in the same period as a result of lower production levels. Whereas this assessment only accounts for the emission intensity of clinker-based cements, the sector has developed its own GHG-monitoring methodology, which also considers the replacement of clinker-based cement with supplementary cementitious materials. Using this methodology, the sector reports that the gross emission intensity of cementitious products in the EU decreased from 0.65 t CO_2e per tonne of cementitious product in 2005 to 0.61 t CO_2e per tonne in 2020 (Cembureau, 2023).
— A similar picture emerges for base organic chemicals. A slight reduction in the average GHG intensity (– 5 % in 2013–2022) only contributed about one third of the decrease in total emissions (– 14 %), with reduced production levels accounting for the large majority of emission reductions.

Final energy use in EU industry (shown in Figure 27) decreased in 2007–2010 in the context of the economic crisis but has remained relatively stable since (between 2 700 and 2 800 TWh per year). In the most recent 5-year period (2017–2021), there was even a slight increase in final energy use (on average + 0.8 TWh per year), although it is expected that 2022 data will show a considerable drop in final energy use linked to product curtailment due to the energy crisis (ESABCC, 2023a).

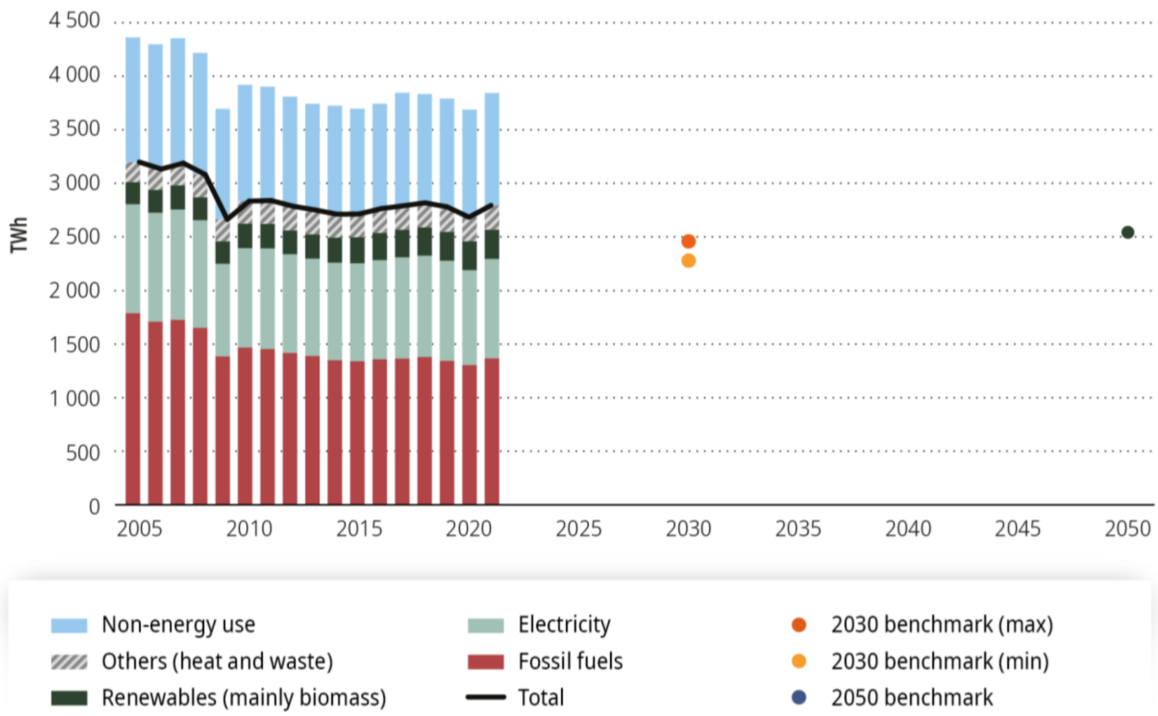
Under the European Commission's scenarios that underpin the EU's climate objectives, industrial energy use would need to reduce by on average 38 TWh per year up to 2030 (– 57 TWh per year under REPowerEU), which requires a reversal of recently observed trends.

Figure 26 Indicator I4 – GHG intensity of steel, cement and base organic chemicals in the EU



Notes: Advisory Board's estimates based on sectoral GHG emissions (see sources and notes under Figure 23) and production data (see sources and notes under Figure 24) for the iron and steel, cement, and base organic chemicals sectors.

Figure 27 Indicator I5 – final industrial energy use



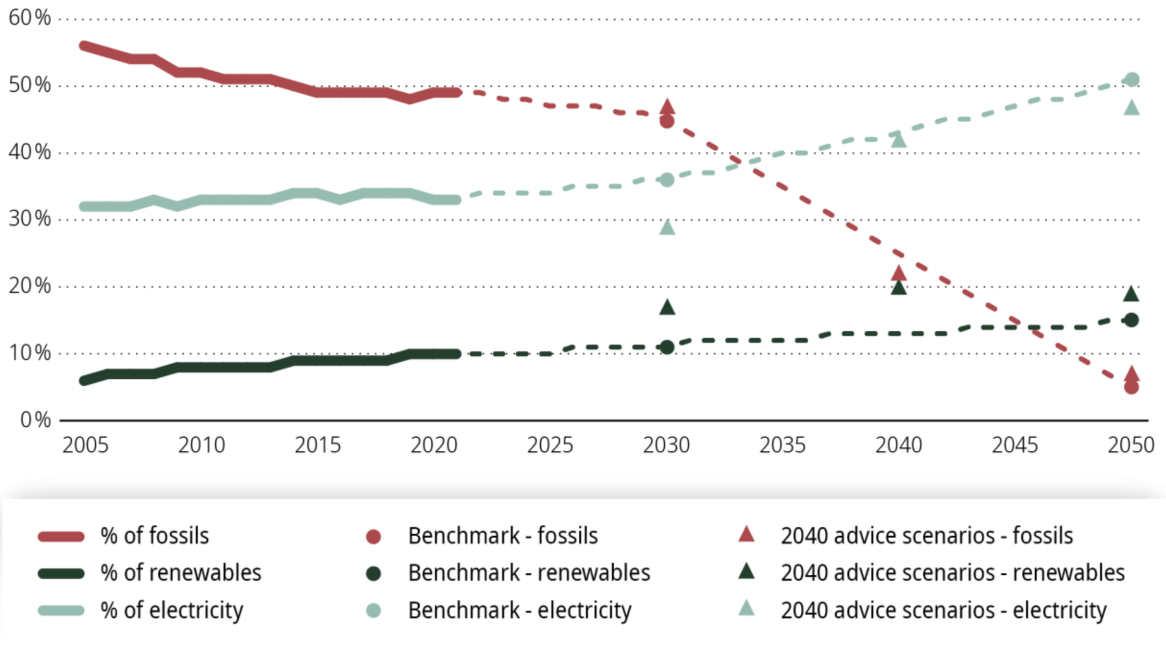
Notes: The max and min 2030 benchmarks based on the Fit for 55 MIX scenario and REPowerEU scenario respectively. The 2050 benchmark is based on the MIX scenario from the Climate Target Plan impact assessment (see Figure 67). All values were converted from kilotonnes of oil-equivalent to TWh.

Sources: Eurostat energy balances (2023b), Fit for 55 MIX scenario (EC, 2021v), REPowerEU staff working document (EC, 2022p), Climate Target Plan impact assessment (EC, 2020s).

In relative terms, the share of fossil fuels in final industrial energy use has been slightly declining, from 56 % in 2005 to 49 % in 2021, as shown in Figure 28. This was mainly replaced by (predominantly bio-based) renewable energy (from 6 % in 2005 to 10 % in 2021) and to a lesser extent electricity (from 32 % in 2005 to 33 % in 2021). However, the phase-out of fossil fuels has stalled in recent years, with their share stable at 49 % since 2015.

To be consistent with the European Commission's scenarios that underpin the EU climate objectives, the use of fossil fuels needs to be further reduced by 2030 and almost completely phased out by 2050. On the other hand, the uptake of renewables (other than renewable electricity) needs to double (from + 0.1 pp per year in 2017–2021 to + 0.2 pp per year until 2050), and the declining trend in the share of electricity (on average – 0.1 pp per year in 2017–2021) needs to be reversed (+ 0.3 pp per year until 2030; + 0.7 pp per year until 2050).

Figure 28 Indicator I6 – relative shares of fossil fuels, renewables and electricity in industrial final energy use (excluding non-energy use)



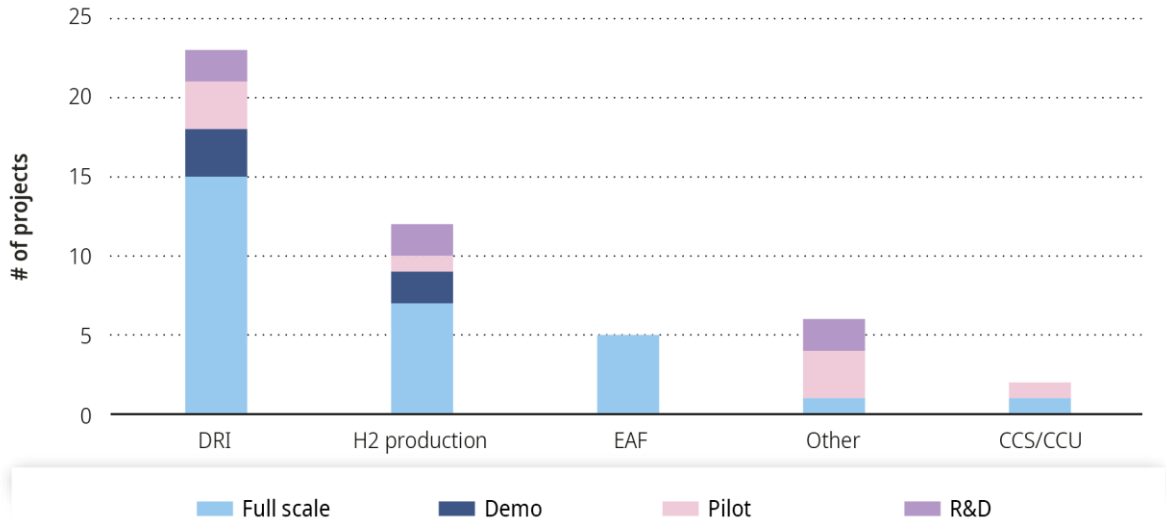
Notes: 2030 and 2050 benchmarks are based on the MIX scenario from the Climate Target Plan impact assessment (see figure 67). The 2040 advice values are based on the scenarios which underpin the Advisory Board's 2040 advice. The linear trajectories are shown to increase the readability of the figure, but do not imply that the Advisory Board recommends a linear trajectory towards the benchmarks.

Sources: Eurostat energy balances (2023b), Climate Target Plan impact assessment (EC, 2020s), Advisory Board 2040 advice scenarios (ESABCC, 2023b).

Although incremental efficiency improvements and fuel switches remain important to further bring down industrial GHG emissions, achieving deep reductions (> 90 %) by 2050 will require a shift towards new, low-emission industrial production processes. Several new technologies are currently under development in the various subsectors, but most of them have not yet reached commercial maturity. These include, among others, hydrogen direct reduction of iron ore, carbon capture for cement, and electrification, hydrogen and sourcing of non-fossil carbon in the chemicals industry.

Over the last few years, projects have emerged in the EU steel sector to research, develop and test low-emission and low-carbon production technologies. According to the Green Steel Tracker (summarised in Figure 29) on 15 September 2023, 48 such projects were currently in development, of which more than half (28) related to full-scale industrial production plants (LeadIT, n.d.). Most of these projects are focused on the direct reduction of iron production route (23 direct reduction of iron projects + 12 projects to provide these with the required hydrogen), either by means of hydrogen or using fossil gas as a transitional fuel. Only two projects relate to carbon capture, which until recent years had been considered a key mitigation pathway for the steel sector.

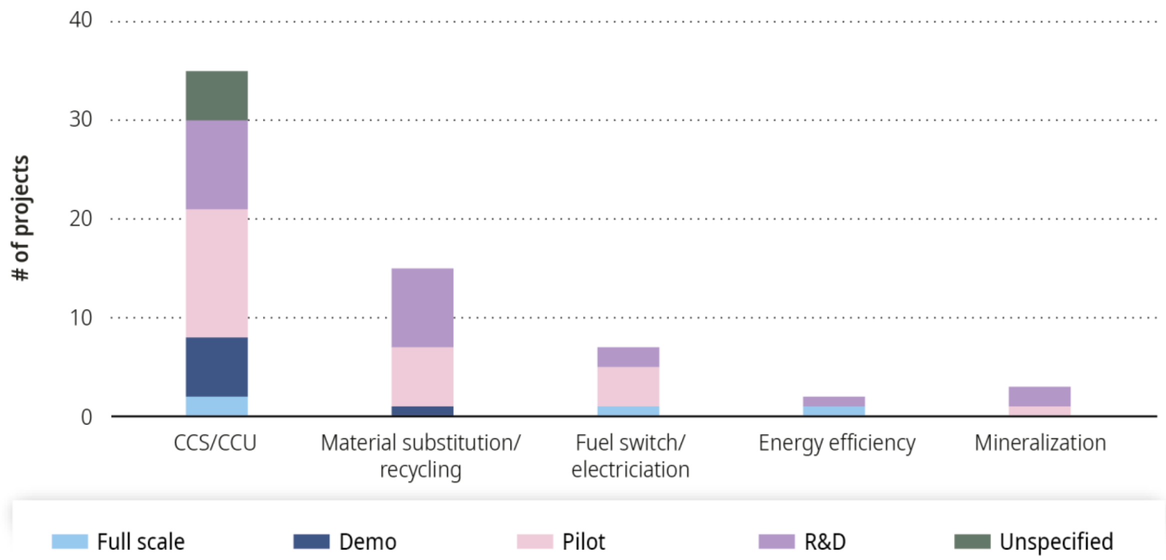
Figure 29 Indicator I7a – low-carbon projects in the steel sector by technology group and project scale



Source: Green Steel Tracker database (LeadIT, forthcoming).

The cement sector in the EU has reported 63 low-carbon projects currently under development or in operation in the EU, as shown in Figure 30. However, in contrast to the steel sector, only a small minority of these relate to full-scale projects, whereas most of the projects are still in the R & D (22) or pilot (24) phase. In terms of mitigation routes, more than half of the projects relate to carbon capture, reflecting the limited options for reducing the sector's high share of process emissions.

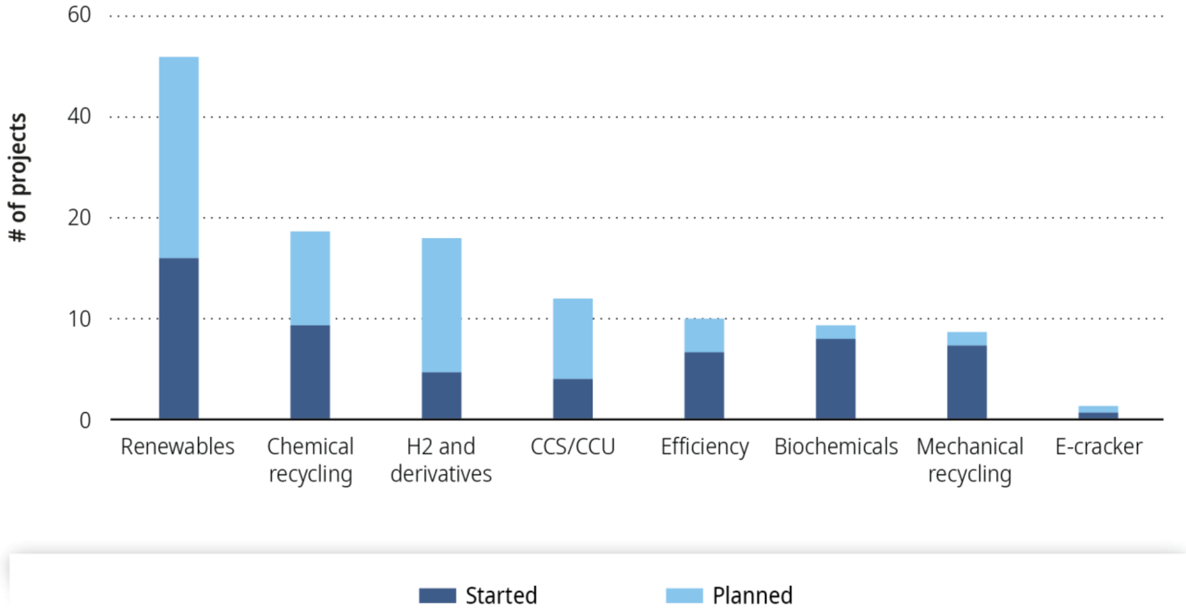
Figure 30 Indicator I7b – number of low-carbon projects in the cement sector by technology group and project scale



Source: Cembureau's online map of innovation projects (Cembureau, n.d.).

The chemical sector has reported 85 low-carbon projects that have already started in the EU, with another 86 currently planned ([17]), as shown in Figure 31. These projects cover a wide range of technologies, reflecting the different mitigation options available to the chemicals sector. The bulk of the projects relate to renewable energy, but these include many on-site solar PV parks, which are likely to contribute only a small share of those sites' energy needs. Chemical and mechanical recycling is also well represented, as are projects related to the use of low-emission hydrogen (and derivates) and the application of CCS/CCU technologies. Electric cracking is only being pursued by two projects. The sector overview does not provide consolidated information regarding the scale of the various projects, unlike the steel and cement sectors.

Figure 31 Indicator I7c – number of low-carbon projects in the chemicals sector by technology group and status



Source: CEFIC's online map of low-carbon technology projects (CEFIC, n.d.).

Dedicated policies are needed to accelerate the development and deployment of low-emission technologies.

Since 2005, the EU ETS has been the EU's flagship policy to reduce GHG emissions and spur low-carbon technologies in the industrial sector. Although the latest revision has substantially reinforced the system, there are justifications for combining it with complementary measures to bring forward and reduce the cost of immature technologies, which often face a competitive disadvantage, as society is currently locked in GHG-intensive technologies in terms of infrastructure, institutions and markets (see Section 10.2). This provides a justification for combining carbon pricing with a range of complementary policies to support new low-emission technologies, throughout each step of their development (R & D, prototype, pilot or demonstration, early deployment or market formation, and maturity and diffusion).

In the past, the EU has actively supported the early stages through dedicated research programmes (e.g. Horizon 2020 and Horizon Europe). Since its revision in 2018 and more recently in 2023, the EU ETS is

([17]) Projects related to renewable power purchasing agreements and the installation of combined heat and power units were not included in the overview.

also expected to become more effective in supporting the pilot and demonstration phase (through the Innovation Fund) as well as the diffusion of low-emission technologies once they reach full maturity (via a stronger carbon price signal). In addition, several measures are taken at the EU level to reinforce the EU electricity grid and develop infrastructure for hydrogen and CO_2 (see Chapter 4 'Energy supply' for more details), which are important enabling conditions for the deployment of low-emission industrial technologies. However, until recently, dedicated policies to support technologies in the phase of early deployment/market formation have been largely lacking or ineffective due to their voluntary nature and limited implementation at the national level (as described in more detail later in this section). Such policies are important for technologies to improve their reliability and cost-competitiveness through learning effects (Chiappinelli et al., 2021; Material Economics, 2022; Neuhoff et al., 2019; Nilsson et al., 2021; Vogl et al., 2021; Wyns and Khandekar, 2019).

The creation of lead markets allows innovations to be tailored to customer needs, to gain experience and therefore to improve quality, reliability and cost-competitiveness (Neuhoff et al., 2019). There are several options to create such lead markets, such as green public procurement, labels and product standards (Chiappinelli et al., 2021; Neuhoff et al., 2019; Nilsson et al., 2021; Sapir et al., 2022). However, Vogl et al. (2021) have cautioned about the limited effectiveness and practical complexity of lead markets in the context of decarbonising the steel sector, while recognising they can help to reduce the required subsidy volumes and aid the global diffusion of new production methodologies (as they would also incentivise EU importers to reduce their GHG intensity). Vogl et al. therefore conclude that direct financial support mechanisms such as carbon contracts for difference (CCfDs; see later in this section) are a more effective approach to supporting green steel production, in case the EU ETS does not create sufficient incentives. Policies to create lead markets can still be warranted, to serve other policy goals such as creating international demand for green steel and thereby driving climate action in non-EU countries.

Until recently, there have been few EU policies that aim to create lead markets for climate-friendly industrial products. New and revised policies under the European Green Deal include several measures which could address this.

As public procurement accounts for around 15 % of the EU's GDP, green public procurement could be an effective tool to create demand for low-emission materials (Axelsson et al., 2023; Sapir et al., 2022). The EU directive on public procurement (EU, 2014) allows the (voluntary) inclusion of green criteria in public procurement processes, and in 2022 the European Commission provided a list of good practices to encourage their use. However, so far their application remains rare, at less than 5 % of all public procurement contracts. The main barriers identified are their voluntary nature, public authorities' preference for short-term lowest-cost options, limited know-how and lack of established environmental criteria/assessment methodologies, lack of coordination between different ministries at the national level, and lack of a monitoring and reporting mechanism to track progress on green public procurement practices (Axelsson et al., 2023; Sapir et al., 2022). Under CEAP 2, the European Commission is planning to tackle these issues by proposing minimum mandatory green public procurement criteria and targets in sectoral legislation, phase in compulsory reporting to monitor the uptake of green public procurement, and continue supporting capacity building and sharing of best practices (EC, 2020g). Green public procurement obligations are included amongst others in the proposed Ecodesign for Sustainable Products Regulation, the proposed revision of the Construction Products Regulation, and the proposed Packaging and Packaging Waste Regulation. Whereas these planned policies seem to address most of the barriers identified, their effectiveness will depend on their final form and implementation in the coming years.

A second group of tools to create lead markets are labels that nudge climate-aware consumers into low-carbon choices, and product standards that regulate the GHG intensity of produced materials. So far, EU labelling and standardisation requirements have been mainly focused on safety, functionality and – in some cases – energy efficiency, and their potential to create demand for low-carbon products has remained largely unused (Chiappinelli et al., 2021; Neuhoff et al., 2019; Wyns and Khandekar, 2020). The sustainable products initiative under CEAP 2 aims to increase the circularity and reduce the climate impact of products sold in the EU, with priority given to high-impact intermediary products such as steel, cement and chemicals. This would be operationalised through the proposed Ecodesign for Sustainable Products Regulation (EC, 2022v) – which would replace the Ecodesign Directive (EU, 2009b). Once adopted, it would have to be elaborated in secondary legislation with specific rules for specific product groups. A preliminary study by the JRC identified a shortlist of intermediary products, including GHG-intensive products such as steel and chemicals, but excluding plastics and construction products (including cement), as these would be covered by other legislative initiatives (JRC, 2023a). One of these initiatives is the proposed revision of the Construction Products Regulation (EC, 2022x), which sets a range of minimum requirements that construction products sold on the EU market need to adhere to, including a requirement to "address – in accordance with the state of the art – minimising whole-life-cycle greenhouse gas emissions". Given the broad and generally defined criteria in the proposed Ecodesign for Sustainable Products Regulation and proposed revision of the Construction Products Regulation, their effectiveness in creating lead markets for low carbon industrial products is difficult to assess *ex ante* and will largely depend on the outcome of the legislative process and subsequent implementation.

In addition to creating lead markets, new technologies could be supported by direct financial support by the EU and its Member States, which could cover investment or operational costs. CCfDs have been recommended to provide operational support for three reasons: firstly, they make it possible to provide adequate levels of support for new, low-carbon, but more costly technologies, without the need to increase the carbon price for the entire economy. Secondly, they increase investor certainty by providing a predictable, long-term level of support, which would also reduce financing costs ([18]). Finally, they reduce public expenditures and avoid windfall profits if the carbon price increases in future years (Chiappinelli et al., 2021; Neuhoff et al., 2019; Vogl et al., 2021). On the downside, there is a risk that CCfDs could lead to overcompensation, depending on the ability of producers to pass on the cost premium for low-carbon technologies. Furthermore, if CCfDs are allocated through tendering – which would be the most efficient approach – they would put regions with lower access to low-cost, renewable electricity at a disadvantage. Additional transitional support might be required for such regions to ensure a just transition towards climate-friendly industry (Vogl et al., 2021).

The recent revision of the EU ETS Directive introduces the possibility for the Innovation Fund to support decarbonisation projects through contracts for difference, CCfDs and fixed premium contracts (EU, 2023c), and a first call for green hydrogen production is planned to be launched soon (EC, 2023v). The effectiveness of these measures will become clearer in the coming years.

In addition, the European Commission has recently proposed several initiatives to (financially, among other ways) support the production of green hydrogen (mainly the Net-Zero Industry Act and EU Green Hydrogen Bank; see Chapter 4 'Energy supply'), which could also contribute to the decarbonisation of the industry sector. The revised 2022 State aid guidelines on energy and climate also include a range of options for Member States to (financially) support the decarbonisation of their industries (EC, 2022i). However, Member States' budgetary abilities have been constrained in recent years, and increasing the available public budget for climate-related State aid faces multiple challenges (see also Section 12.5).

([18]) For electrification technologies, they might need to be complemented by other measures to shield early movers from volatile electricity prices to achieve this goal.

Finally, article 22a of the recently adopted RED III (EU, 2023f) introduced legally binding objectives for Member States to increase the share of renewables in industrial energy and feedstock use. Firstly, Member States are required to 'endeavour' to increase the share of renewable sources in both the final industrial energy use and the use of energy sources for feedstock purposes by at least 1.6 pp per year. Secondly, they must ensure that at least 42 % of total hydrogen use in 2030 for energy and non-energy purposes in the industrial sector comes from renewable fuels of non-biological origin. Whereas the first requirement only imposes an effort obligation on Member States, the second requirement imposes a result obligation. In response to the RED III, Member States are expected to implement additional policies in the coming years to promote the uptake of renewable energy and feedstocks in the industry sector, including by supporting the deployment of new industrial technologies.

5.5 Summary tables

Table 6 Progress summary - industry

Indicator	Reference period	Historical progress	Required up to 2030	Required in 2031–2050
I1: GHG emissions	2005–2022	– 17 Mt CO_2e/yr	– 29 Mt CO_2e/yr	– 21 Mt CO_2e/yr
I2: total material use				
I2a: steel	2017–2021	Stable	No benchmark	No benchmark
I2b: cement	2017–2021	+ 6 Mt/yr	No benchmark	No benchmark
I2c: high-value chemicals	2017–2021	– 0.7 Mt/yr	No benchmark	No benchmark
I3: circular material use rate	2017–2021	+ 0.1 pp/yr	+ 1.3 pp/yr	No benchmark
I4: GHG intensity				
I4a: steel	2017–2021	– 0.8 kg CO_2e/t/yr	No benchmark	No benchmark
I4b: cement	2018–2022	– 18 kg CO_2e/t/yr	No benchmark	No benchmark
I4c: high-value chemicals	2018–2022	– 6 kg CO_2e/t/yr	No benchmark	No benchmark
I5: final energy use	2017–2021	+ 0.8 TWh/yr	– 38 TWh/yr	Stable
I6: energy mix				
I6a: % of fossil fuels	2017–2021	Stable	– 0.4 pp/yr	– 2 pp/yr
I6b: % of renewables	2017–2021	+ 0.1 pp/yr	+ 0.2 pp/yr	+ 0.2 pp/yr
I6c: % of electricity	2017–2021	– 0.1 pp/yr	+ 0.3 pp/yr	+ 0.7 pp/yr
I7: low-carbon projects				
I7a: steel	2023	48	No benchmark	No benchmark
I7b: cement	2023	63	No benchmark	No benchmark
I7c: high-value chemicals	2023	85	No benchmark	No benchmark

Legend

On track	The required change ([a]) is ≤ 1.
Almost on track	The required change ([a]) is between 1 and 1.5.
Somewhat off track	The required change ([a]) is between 1.5 and 2.
Considerably off track	The required change ([a]) is ≥ 2.
Wrong direction	The required change ([a]) is < 0.

([a]) See Section 2.2 for more details on how the required change is calculated.

Table 7 Policy consistency summary - industry

Policy gaps	– Demand management and materials efficiency have until recently remained largely unaddressed by EU policies (e.g. CEAP 1 which mainly targeted recycling). This is better addressed under CEAP 2, but the legislative measures thereunder are not yet adopted. – Dedicated policies to support early deployment / market formation of low-emission technologies have been largely missing in the past. New policies have been put in place (e.g. the introduction of contracts for difference and CCfD's under the Innovation Fund) or are under development (e.g. the Ecodesign for Sustainable Products Regulation).
Ambition gaps	– High levels of free allocation to industry in combination with the lack of a carbon price on materials imports, and the exclusion of the waste sector under the EU ETS have undermined the carbon price signal that could trigger such demand-side measures. The gradual introduction of a CBAM to replace free allocation is expected to address this gap, at least for the sectors covered by it. Waste incineration might be included under the EU ETS as of 2028.

6 Transport

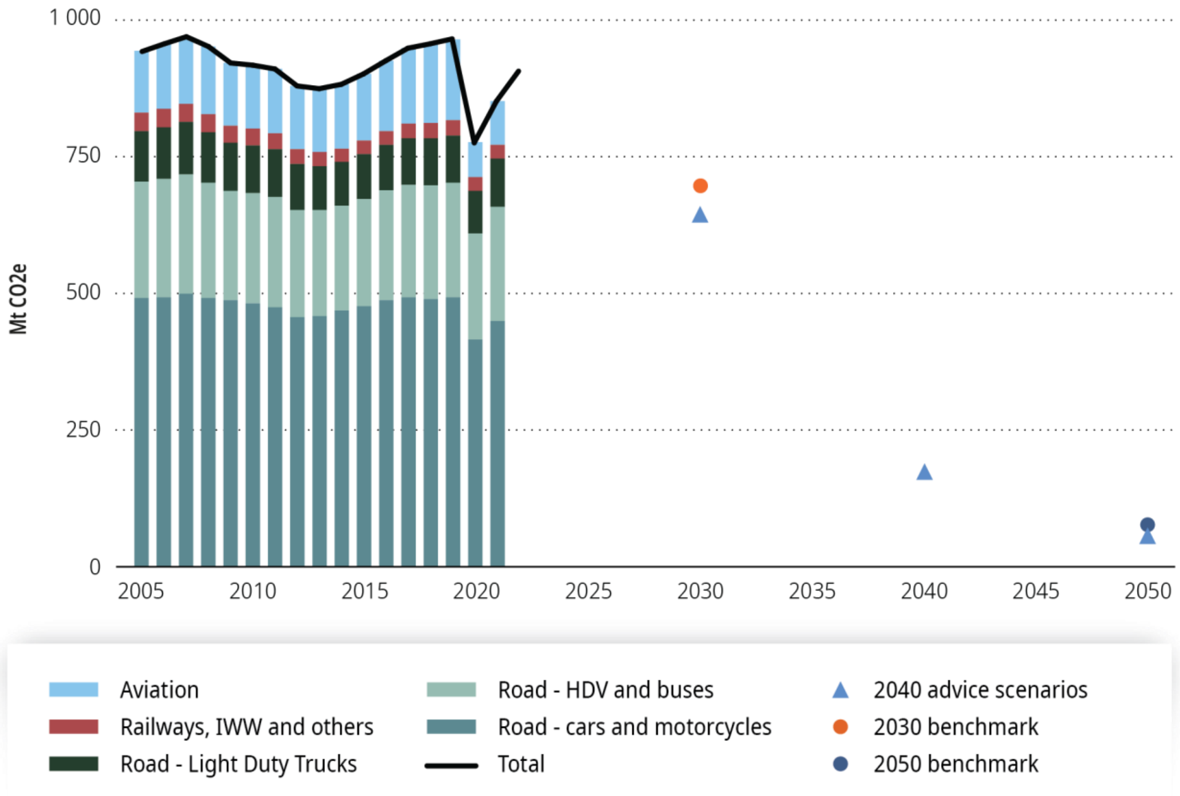
Key messages

The pace of GHG emission reductions in the EU transport sector needs to at least double to align with the EU's climate objectives.

As shown in Figure 32, the EU has not managed to structurally reduce the GHG emissions of its transport sector since 2005. There have been improvements in vehicle efficiency and the GHG intensity of transport fuels, but these have been offset by increased overall transport demand (in particular for aviation) and – in more recent years – the shift towards heavier, less-efficient passenger cars. A substantial decrease occurred in 2020 (– 20 % compared to 2019) in the context of the COVID-19 pandemic, but emissions have largely rebounded since then (– 4 % in 2022 compared to 2019). In recent years, the share of zero-emission vehicles (ZEVs) in new sales has been increasing, in particular in the passenger car segment; which is expected to lower GHG emissions in the coming years.

The average rate of reduction since 2005 (by 2 Mt CO_2e per year) needs to increase more than tenfold to be consistent with the trajectories towards the overall 2030 – 55 % objective (– 26 Mt CO_2e per year in 2023–2030), and even more so after 2030 to be consistent with the 90 % reduction objective for transport GHG emissions by 2050 (– 31 Mt CO_2e per year in 2031–2050). Even steeper reductions (– 52 Mt CO_2e per year) would be required in 2031–2040 to be consistent with the scenarios underpinning the recommended 90–95 % reduction objective for 2040.

Figure 32 Indicator T1 – overall progress in reducing transport GHG emissions



Sources: See Figure 34 for detailed sources and notes.

Moderate growth in overall transport demand and encourage a modal shift.

Needs. The growth in overall transport demand in the EU needs to slow down, and part of the remaining demand should shift towards lower-emission transport modes (e.g. from aviation and road to rail and inland waterways (IWW) to be consistent with the scenarios that underpin the EU's 2030 and 2050 climate objectives. Activating demand-side mitigation levers in parallel with decarbonisation of supply is important to reduce pressure on constrained resources, to accelerate emission reductions and to reduce emissions in subsectors where supply-side decarbonisation technologies are not yet proven at scale (e.g. synthetic fuels). Whereas such demand-side levers primarily rely on (sub)national policies, these can be supported by EU policies, in particular when considering cross-boundary transport flows.

Gaps. Moderation of overall transport demand is not considered as an option in the EU's Sustainable and Smart Mobility Strategy **(policy gap)**. Furthermore, EU policies to support a modal shift (the Combined Transport Directive, the Rail Freight Corridors Regulation, the Trans-European Transport Network (TEN-T) regulation) have so far had little success owing to lack of ambition (e.g. outdated provisions in the Combined Transport directive that prevent digitalised workflows, lack of adequate delivery mechanisms in the Rail Freights Corridors Regulation, lack of an overview of current and future required capacities of intermodal terminals under the TEN-T regulation) **(ambition gap)** and incomplete and heterogeneous implementation at the Member State level **(implementation gap)**. Recent proposals by the European Commission (the 2021 proposal to revise the TEN-T regulation, the recent proposals for a regulation on the use of railway capacities and the revision of the Combined Transport Directive) aim to address these gaps. Given how recent they are, the Advisory Board has not been able to assess the adequacy of these proposals.

Recommendation T1. EU policies should seek to curb growth in overall transport demand, for example by supporting more efficient spatial planning at the (sub)national level where possible (see also Section 7.5).

Recommendation T2. EU policies should also more effectively support a modal shift by tackling non-market barriers that hinder a shift towards lower-emission transport modes, including operational and regulatory barriers, infrastructural bottlenecks, and lack of available and integrated data. To this end, EU legislators should adopt an ambitious revision of the Combined Transport Directive and the regulation on the use of railway infrastructure capacities. In parallel, both overall demand moderation and a modal shift should be further facilitated through a further alignment of pricing policies with climate objectives (see recommendations T5 and T6).

Promote uptake of the most efficient ZEVs.

Needs. The share of ZEVs in new registrations has been increasing in recent years, but the increase needs to accelerate to achieve the EU's objectives, in particular for vans and HDVs. Adequate charging/refuelling infrastructure and the availability of critical raw materials and batteries are the two main prerequisites for accelerated uptake of ZEVs.

Gaps. The EU has put in place several policies to increase the uptake of ZEVs. These include strengthened CO_2 emission performance standards for passenger cars and vans (adopted) and HDVs (proposed, currently under negotiation), the Alternative Fuel Infrastructure Regulation to enhance charging and refuelling infrastructure (adopted) and the revised Clean Vehicles Directive (adopted). In addition, EU State aid guidelines allow Member States to provide financial support for the purchase of ZEVs. Whereas these policies can effectively accelerate the uptake of ZEVs, they currently do not incentivise efficiency (smaller, more efficient vehicles) within the segment of ZEVs **(ambition gap)**, and might even incentivise the uptake of larger, less-efficient ZEVs **(policy inconsistency)**, increasing pressure on the already constrained availability of critical resources.

Recommendation T3. EU policies that incentivise the uptake of ZEVs should prioritise the uptake of energy- and resource-efficient ZEVs.

Prioritise direct electrification where possible, and promote biofuels only from sustainable feedstocks.

Needs. Achieving the required reductions by 2050 will require deep GHG reductions in all transport modes, and an acceleration of the trend in phasing out fossil fuel use. Direct electrification is an energy-efficient option with relatively low sustainability concerns. However, despite recent improvements in battery technology, decarbonising aviation, maritime and (specific segments of) heavy-duty road transport will probably require the use of low-carbon fuels, including synthetic fuels and sustainable biofuels.

Gaps. The RED III, ReFuelEU Aviation and FuelEU Maritime set specific objectives for the uptake of low-carbon fuels in the transport sector, while limiting the potential contribution of biofuels with high negative spillover risks. Nevertheless, concerns remain, as these policies continue to promote some biofuels with potentially high indirect effects, such as fuels made from food and feed crops (up to 7 %), intermediate crops and specific types of animal fats (so-called "category 3 animal fats") **(ambition gap)**. Furthermore, there are well-founded suspicions of fraud in the labelling of biofuels as sustainable **(implementation gap)**. This illustrates that the risk of spillover effects is inherent to biofuels, as impacts can be indirect (e.g. demand for fuel can contribute to land use change far away from a specific supply chain), and their sustainably available supply is constrained.

Recommendation T4. EU policies should prioritise direct electrification in the transport sector where possible. Given their limited availability, the use of sustainable biofuels and hydrogen-based fuels should be promoted for only those transport modes for which direct electrification is not suitable, such as aviation, long-haul shipping and possibly some cases of heavy-duty road transport. These policies should only promote the use of biofuels made from truly sustainable feedstocks, reflecting their overall limited availability.

Further align EU pricing policies in the transport sector with the EU's climate objectives (see also Chapter 10 'Pricing emissions and rewarding removals')**.**

Needs. Consistent EU pricing policies are needed to incentivise emission reduction options across all possible transport choices, including demand moderation, a shift towards lower-emission transport modes, and the uptake of ZEVs and low-carbon transport fuels. Such policies need to be accompanied by measures to address potentially adverse social impacts (see Chapter 11 'Whole-of-society approach').

Gaps. Recent policy developments are expected to improve the alignment of the EU's pricing policies in the transport sector with its climate objectives. The revised EU ETS will gradually phase out free allocation for aviation and extend the system to maritime transport by 2026, while introducing a separate EU ETS 2 for (amongst others) road transport fuels in 2027 or 2028. The revised Eurovignette Directive (adopted) mandates a shift from time-based to distance-based road pricing, which would better internalise externalities. The proposed revision of the ETD would limit current exemptions for commercial transport fuels, and for aviation and maritime transport.

However, gaps remain even when taking these recent developments into account. The price difference between the EU ETS and the EU ETS 2 (which is more likely due to the 'soft' price cap under the latter) would continue to promote fossil fuel use over electrification in the transport sector **(policy inconsistency)**. Furthermore, extra-EU aviation and half of extra-EU maritime transport remains exempt from the EU ETS **(policy gap)**. Finally, progress on the adoption of the ETD proposal has been slow, and current exemptions are still in force **(policy inconsistency)**.

Recommendation T5. In the short term, the proposed revision of the ETD should be adopted to phase out exemptions for commercial, aviation and maritime transport.

Recommendation T6. In the longer term (after 2030), carbon price levels between the EU ETS and the EU ETS 2 should converge to level the playing field between electrified and fuel-based transport (see also Chapter 10 'Pricing emissions and rewarding removals').

6.1 Scope and sectoral assessment framework

Scope

This chapter covers all activities that result in transport GHG emissions as reported under the United Nations Framework Convention on Climate Change (UNFCCC), including:

— emissions from road, rail, domestic navigation and domestic aviation, and other transport (CRF category I.3 – energy use in transport);
— emissions from international aviation and international maritime transport (on the basis of bunker fuels sold in the EU, which would cover all outgoing voyages and 'at berth' fuel consumption; reported as memo items in the GHG inventory).

Transport by active modes (walking, cycling, etc.) is not covered in the data shown in this chapter.

Throughout the chapter, it is further specified whether data shown includes international bunker fuels or not.

Greenhouse gas emission reductions required in the transport sector to reach climate neutrality

The European Green Deal (EC, 2019c) states that the transport sector will have to reduce its emissions by 90 % ([19]) by 2050 (compared to 1990, which implies a reduction of 92 % compared to 2005) as a contribution to the overall climate neutrality objective. The European Commission's LTS A Clean Planet for all (EC, 2018e) presents a similar reduction level, with transport emissions reduced by 89–90 % by 2050 under the 1.5TECH and 1.5LIFE scenarios (compared to 1990). Scenarios underpinning the Advisory Board's recent report on a greenhouse target for 2040 suggest that CO_2 emissions in transport could be reduced by up to 79 % by 2040 and 93 % by 2050 (compared to 1990) ([20]).

By 2030, the European Commission's scenarios that underpin the overall 55 % reduction objective require transport emissions excluding international aviation and maritime to reduce by 29 % compared

([19]) This includes international aviation, but not international maritime. Emissions from international maritime should reduce by 80 % by 2050 compared to 1990 (see footnote 8 of SWD(2020) 331 final).

([20]) Based on reductions in domestic transport emissions from the 90–95 % reduction scenarios assessed by the ESABCC, combined with an illustrative reduction for aviation based on the Sustainable and Smart Mobility Strategy.

to 2005. Emissions from international aviation and maritime transport would peak in 2025, and return to 2005 levels by 2030.

Assessment framework for the transport sector

The selection of outcomes, mitigation levers and enabling conditions is primarily based on the transport chapter (chapter 10 of the contribution of Working Group III) (IPCC, 2022j). Whereas the IPCC covers the challenges and opportunities to decarbonise the transport sector at a global level, its findings also apply to the EU context.

Outcomes. IPCC AR6 highlights a growing awareness that achieving the necessary GHG emission reductions in the transport sector will require a combination of demand management with new technologies. In line with this, two main outcomes are considered for the assessment:

— **curbing demand for emission-intensive transport**, which covers the need both to moderate overall demand (e.g. through digitalisation) and to switch part of it from emission-intensive to lower-emission transport modes,
— **decarbonising the transport fleet** through scaling up ZEV and fuel technologies, and improving the energy and resource efficiency of vehicles (in order to reduce emissions and resource use along the whole supply chain).

Mitigation levers. To achieve these outcomes, five main mitigation levers were identified, based on the different mitigation pathways described in IPCC AR6.

— An overall **moderation of transport demand** would lower GHG emissions, and can be pursued through a range of measures, including changes in infrastructure and spatial planning (referred to as 'urban form' in IPCC AR6), promoting changes in travel habits, shorter supply chains and digitalisation trends.
— A **modal shift** from emission-intensive (e.g. cars, lorries, planes) to lower-emission (e.g. rail, maritime and waterways, active transport) transport modes – including through multimodality – can contribute to GHG emission reductions, if the shift leads to an overall reduction in the activity of the most GHG-intensive transport modes (road and air).
— The uptake of **ZEVs** is a key lever to decarbonise the transport sector, and notably road transport. Electromobility has the potential to rapidly reduce GHG emissions, especially when combined with low-carbon electricity supply (see Chapter 4 'Energy supply'), but might need to be complemented by other types of ZEVs such as hydrogen-powered fuel cell electric vehicles or low-carbon fuels (see the final lever below) in specific circumstances.
— More **energy-efficient vehicles** can reduce GHG emissions both directly (lower tailpipe emissions) and indirectly (lower emissions from electricity production in the case of BEVs), fuel refining in case of internal combustion engine vehicles (ICEVs)). Similarly, more **resource-efficient vehicles** can indirectly reduce emissions from car manufacturing, including battery manufacturing (in the case of BEVs).
— For those subsectors that cannot be (fully) electrified, **a switch towards non-fossil, low-carbon fuels** can be used to achieve deep GHG emission reductions. This is particularly the case for the aviation and maritime sectors, and for some parts of heavy-duty road transport in particular circumstances. For these sectors, advanced bio- and hydrogen-based fuels (e.g. synthetic jet fuels for aviation, methanol and ammonia for maritime transport) are emerging as viable options, with the first pilot projects already in or close to operation today (IPCC, 2022g). The contributions of such fuels to atmospheric GHG concentrations depend strongly on their the types of inputs used (e.g. the type of biomass feedstock, hydrogen and CO_2 used) and their production processes.

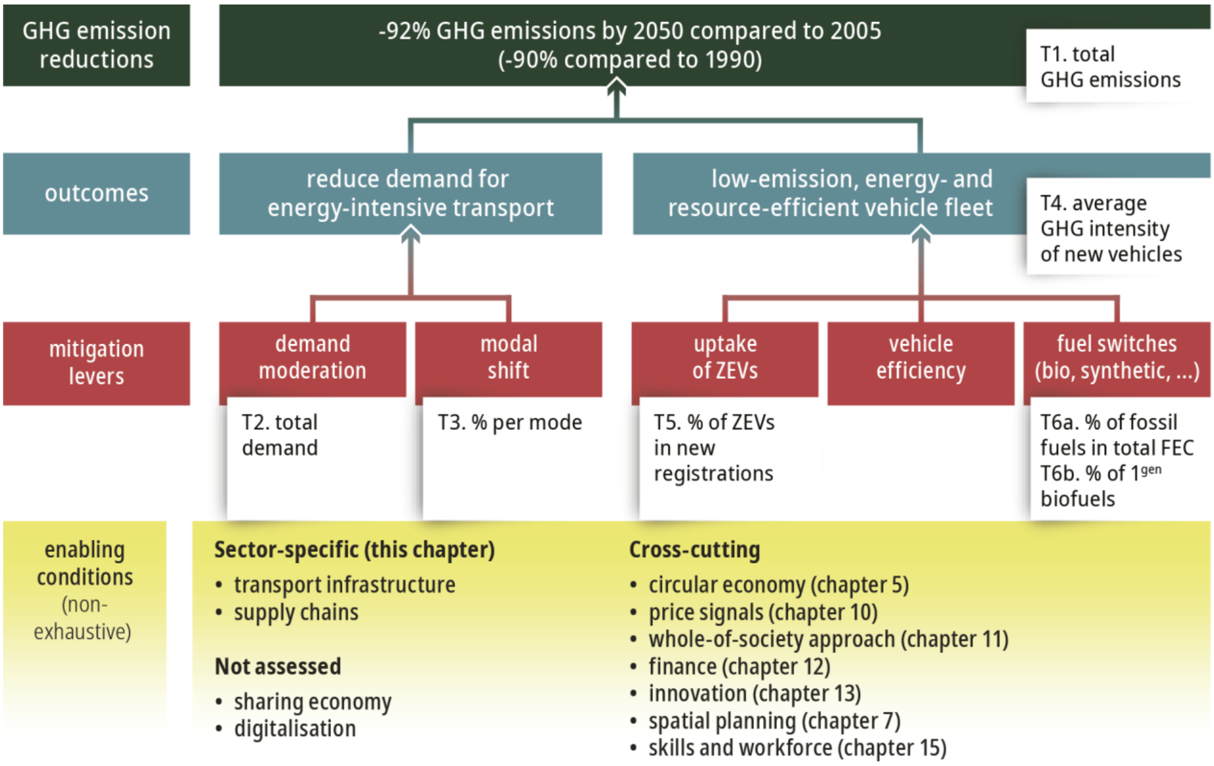
Enabling conditions. In addition, the Advisory Board identified seven enabling conditions (based on IPCC AR6) that can facilitate one or several of the levers described above.

— **Transport infrastructure** such as road, rail and waterway networks, cycling infrastructure and airport capacities is an important driver of overall transport demand and modal choices (IPCC, 2022j). Charging and refuelling infrastructure is a crucial enabler to facilitate the rapid uptake of ZEVs and non-fossil transport fuels in the transport system, in particular to increase user-friendliness and overcome range anxiety (IPCC, 2022j).
— **Price signals** determine the cost of use for different transport modes, vehicle technologies and fuel types, and can therefore enable both overall demand moderation and shifts to lower-emission transport modes, technologies and fuels. They include, for example, carbon prices, road charging, fuel taxes, congestion charges and parking fees. In general, transport GHG emissions are highly inelastic, at least in the short term (IPCC, 2022j). However, there are also indications that price elasticity increases over time and is three to four times larger if the price change is driven by persistent policies rather than market fluctuations. This is because policy-induced changes are expected to cause a more structural, long-term price increase than short-term fuel market price fluctuations, and are therefore more likely to trigger behavioural change and steer investment decisions (Andersson, 2019; Rivers and Schaufele, 2015).
— **Spatial planning** refers to the physical characteristics of human settlements, including their shape, size, density and configuration. It determines the need, time, space and cost of travel, which in turn can drive transport demand and modal choices (IPCC, 2022j) (see also Section 7.5).
— The **sharing economy** refers both to traditional mobility concepts such as carpooling and to more recent developments such as vehicle sharing and mobility as a service. There is still much uncertainty about the net effect of shared mobility on net emissions, although there is growing evidence that structural, large-scale behavioural change through shared mobility can indeed facilitate emission reductions (IPCC, 2022j).
— The **circular economy** could support emission reductions in the transport sector by reducing the amount of materials that need to be transported (through lower material use) and by reducing the distance across which these need to be transported (through more local value chains) ([21]). However, the net impact is still uncertain, as some evidence suggests that reductions in material use from more efficient product design are offset by increased consumer demand. Furthermore, the collection of waste streams for recycling purposes might also increase transport demand (IPCC, 2022j).
— **Digitalisation** can enable transport emission reductions in several ways (IPCC, 2022j). It enables teleworking and teleconferencing, which reduce travel demand. It also enables online shopping, although the net impact of this on transport emissions can be either positive or negative. Finally, it can support smart mobility, which could reduce transport demand and increase efficiency.

Some other cross-cutting enabling conditions, which are discussed in other chapters of this report (whole-of-society approach, finance, innovation and a skilled workforce), are also relevant to the transport sector, as shown in Figure 33. This figure also shows the indicators (shown in the white boxes) that were selected to track progress in the transport sector.

([21]) A similar impact could be achieved by other measures to shorten supply chains.

Figure 33 Assessment framework for the transport sector



Source: Advisory Board (2024).

6.2 Emission reduction progress

The EU has not managed to structurally reduce the emissions of its transport sector since 2005. A breakdown is shown in Figure 34. There were some reductions in 2008–2013, triggered at least partially by the economic crisis of 2008–2010. However, emissions have increased again since 2014, and by 2019 emissions were 2.4 % above 2005 levels. This increase was mainly caused by a strong growth in aviation emissions (+ 31 % by 2019 compared to 2005) combined with very limited reductions in other transport modes (– 1.5 % in 2019 compared to 2005) ([22]). The underlying drivers of the limited decrease in non-aviation emissions are an overall increase in transport activity and the lack of a modal shift to low-emitting transport modes, which have largely offset any improvements from efficiency improvements and fuel switches. The observed increase in car GHG emissions in the years preceding 2020 was mostly due to an increasing share of larger and heavier cars, such as sport utility vehicles (EEA, 2022d).

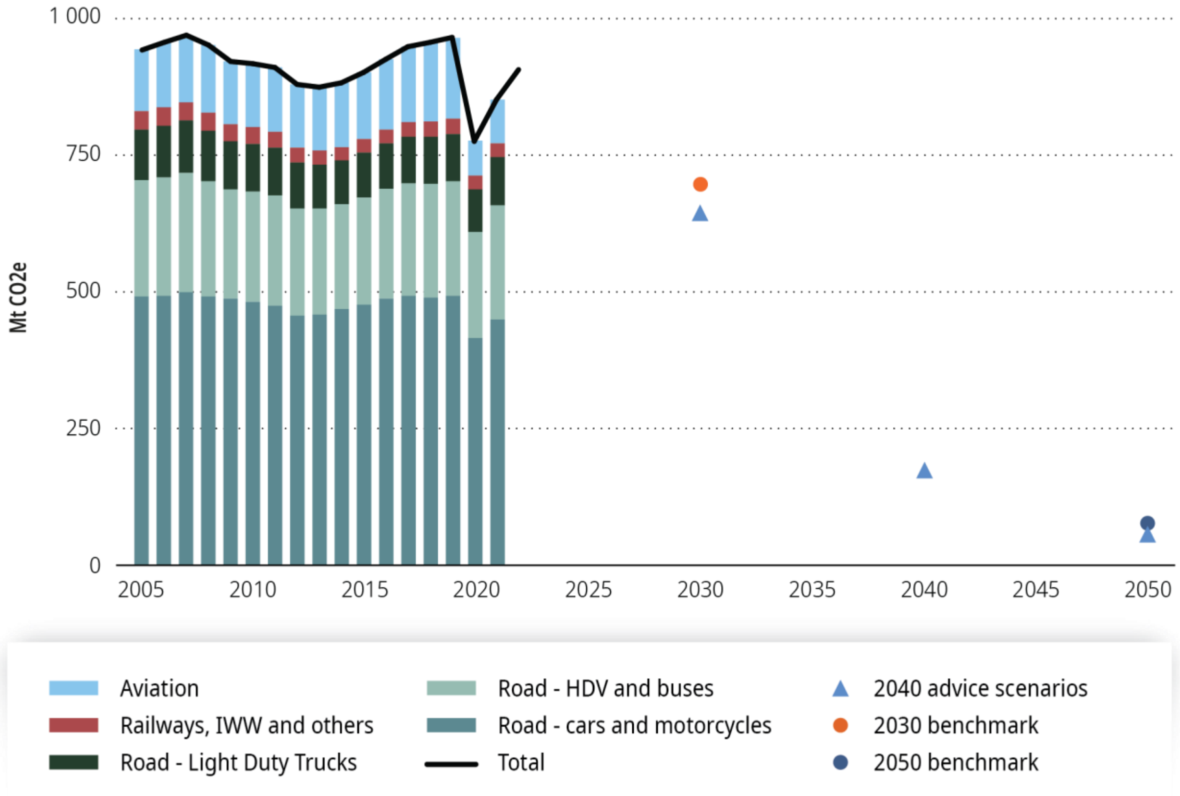
The COVID-19 pandemic caused a significant reduction in transport emissions in 2020, notably in emissions from aviation and cars. Although there was a partial rebound in 2021–2022, they were still 6 % below 2019 levels in 2022 (based on proxy data). Eurostat quarterly GHG emission data shows that this rebound continued in Q1 2023 (Eurostat, 2023q).

The average rate of emission reduction since 2005 (– 2 Mt CO_2e per year) needs to accelerate more than tenfold to be consistent the trajectories towards the overall 2030 – 55 % objective (– 26 Mt CO_2e per

([22]) Emissions including international aviation but excluding international maritime, in line with the 90 % reduction objective put forward by the European Green Deal.

year in 2023–2030), and even further after 2030 to be consistent with the 90 % reduction objective for transport GHG emissions by 2050 (– 31 Mt CO_2e in 2031–2050) as set out in the European Green Deal. In pathways consistent with the 90–95 % objective recommended by the Advisory Board, the reduction rate for 2031–2040 would need to be even higher (– 52 Mt CO_2e per year).

Figure 34 Indicator T1 – overall progress in reducing transport GHG emissions (including international aviation, excluding international maritime)



Notes: Historic emissions up to 2021 from the EU GHG inventory, with 2022 data based on proxy data reported to the EEA. 2030 benchmark based on the Fit for 55 MIX scenario. 2050 benchmark is calculated as a 90% reduction compared to 1990 as put forward by the European Green Deal and Sustainable and Smart Mobility Strategy thereunder. The 2040 advice range represents average domestic transport emission levels in the scenarios which underpin the Advisory Board's 2040 advice, combined with an illustrative path for aviation based on the Sustainable and Smart Mobility Strategy. All data includes international aviation but excludes international maritime transport, in line with the 90% reduction objective by 2050.

Sources: EU GHG inventory (EEA, 2023f), Fit for 55 MIX scenario (EC, 2021v), Sustainable and Smart Mobility Strategy (EC, 2020k), Advisory Board 2040 advice scenarios (ESABCC, 2023b).

6.3 Outcome 1: reduce demand for emission-intensive transport

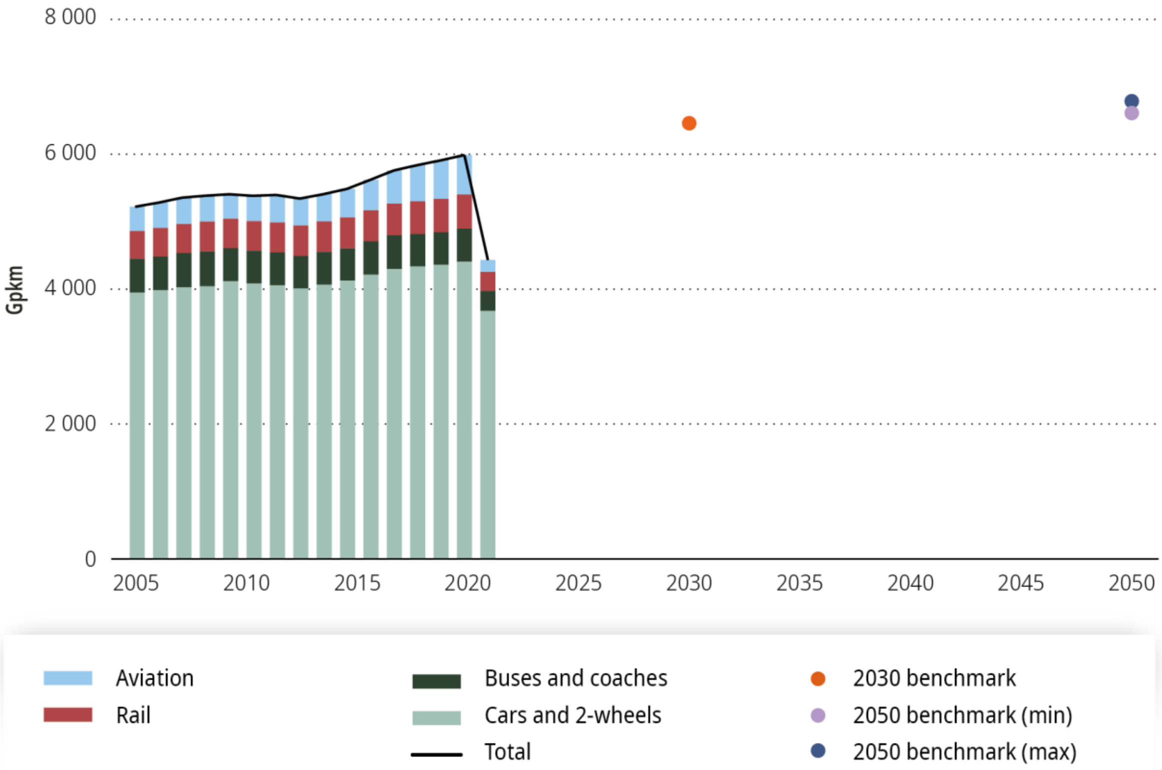
Lever: demand moderation

Both transport and freight demand have been increasing at a rate that is not in line with the European Commission's scenarios that underpin the EU's climate objectives.

Total passenger transport (including domestic and intra-EU aviation, but excluding water-based transport and extra-EU aviation because consistent data is lacking) increased from 2005, with an acceleration after 2013, before a sudden drop in 2020 linked to the COVID-19 crisis (see Figure 35).

About three quarters of the observed increase in 2005–2019 is due to higher demand per capita, with the remaining growth linked to the EU's increasing population. In relative terms, growth has been strongest for aviation (+ 62 % in 2005–2019), followed by rail (+ 23 %) and private road transport (+ 11 %). Total transport by bus and coach declined slightly (– 2 %). Under the European Commission's scenarios underpinning the EU's climate objectives, transport demand would continue to increase, but the average rate of increase would decrease by more than half compared to 2015–2019 until 2030, and then slow further in 2031–2050.

Figure 35 Indicator T2a – passenger transport demand

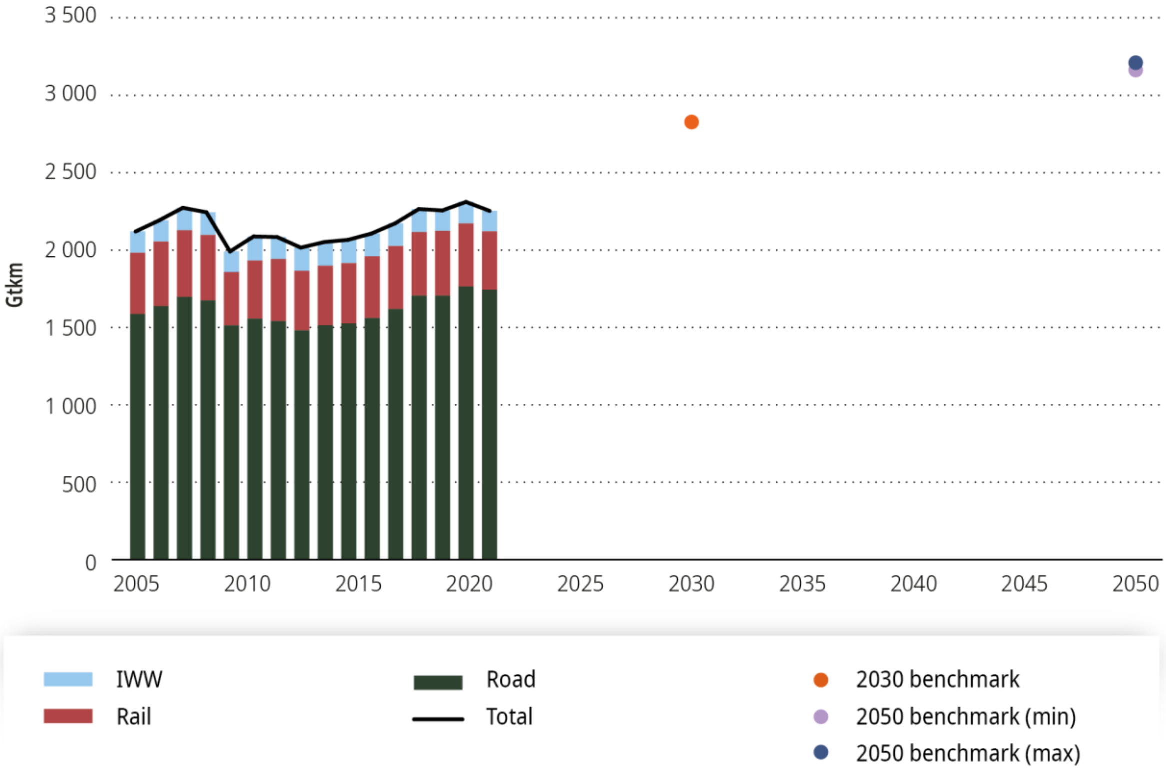


Notes: The 2030 benchmark is based on the Fit for 55 MIX scenario. The 2050 benchmarks are based on the 1.5TECH and 1.5LIFE scenarios of the in-depth analysis accompanying a Clean Planet for All (see figure 45, recalibrated for EU27 based on 2015 data). All data includes domestic and intra-EU aviation, but excludes extra-EU aviation, IWW and intra-EU maritime transport. All data expressed in billion passenger-kilometers (Gpkm).

Sources: Statistical pocketbook on transport 2022 (EC, 2022al), Fit for 55 MIX scenario (EC, 2021v), in-depth analysis accompanying A Clean Planet for All (EC, 2018e)

Figure 36 displays total freight transport demand, excluding aviation and maritime freight. Demand dropped following the economic crisis in 2008–2010 but rose steadily from 2013 until a limited drop in 2020 linked to the COVID-19 crisis. The relative increase was considerably higher for road transport (+ 11 % in 2005–2019) than for rail transport (+ 3 % in 2005–2019), whereas the volume of freight transported by IWW remained stable. Similarly to passenger transport, the European Commission's scenarios underpinning the EU's climate objectives assume a continued growth in freight transport demand but at a slower pace, in particular after 2030.

Figure 36 Indicator T2b – total freight transport demand



Notes: The 2030 benchmark is based on the Fit for 55 MIX scenario. The 2050 benchmarks are based on the 1.5TECH and 1.5LIFE scenarios of the in-depth analysis accompanying a Clean Planet for All (see figure 45, recalibrated for EU27 based on 2015 data). All data includes domestic and intra-EU aviation, but excludes extra-EU aviation, IWW and intra-EU maritime transport. Domestic maritime transport in 2030 was filtered out of the MIX scenario data based on the 2015 ratio between IWW and domestic maritime transport. All data expressed in billion tonne-kilometers (Gtkm).

Sources: Statistical pocketbook on transport 2022 (EC, 2022al), Fit for 55 MIX scenario (EC, 2021v), in-depth analysis accompanying A Clean Planet for All (EC, 2018e)

The EU's overall strategy to reduce transport GHG emissions does not aim to moderate demand.

The EU's overall strategy to reduce GHG emissions in the transport sector has been to focus exclusively on modal shifts and technological, supply-side improvements, without considering the option of curbing growth in demand. The 2011 White Paper on transport (EC, 2011) – which formed the overarching strategy for EU transport policies between 2012 and 2022 – had the objective of allowing continued transport growth while reducing GHG emissions by 60 % by 2050 thanks to a combination of modal shifts, increased efficiency and technological changes. It explicitly excluded the option of curbing mobility to achieve emission reductions. This overall strategy was maintained in the European Commission's Sustainable and Smart Mobility Strategy (EC, 2020k), which is the EU's overarching mobility strategy under the European Green Deal. It states that the greening of the mobility system, through modal shifts and technological changes, must be a new licence for the transport sector to grow, thereby confirming that the strategy will not aim to moderate or curb transport growth. So far, this strategy has proven ineffective in reducing GHG emissions, as incremental efficiency improvements and fuel switches have been outpaced by increased transport demand (see Section 6.2).

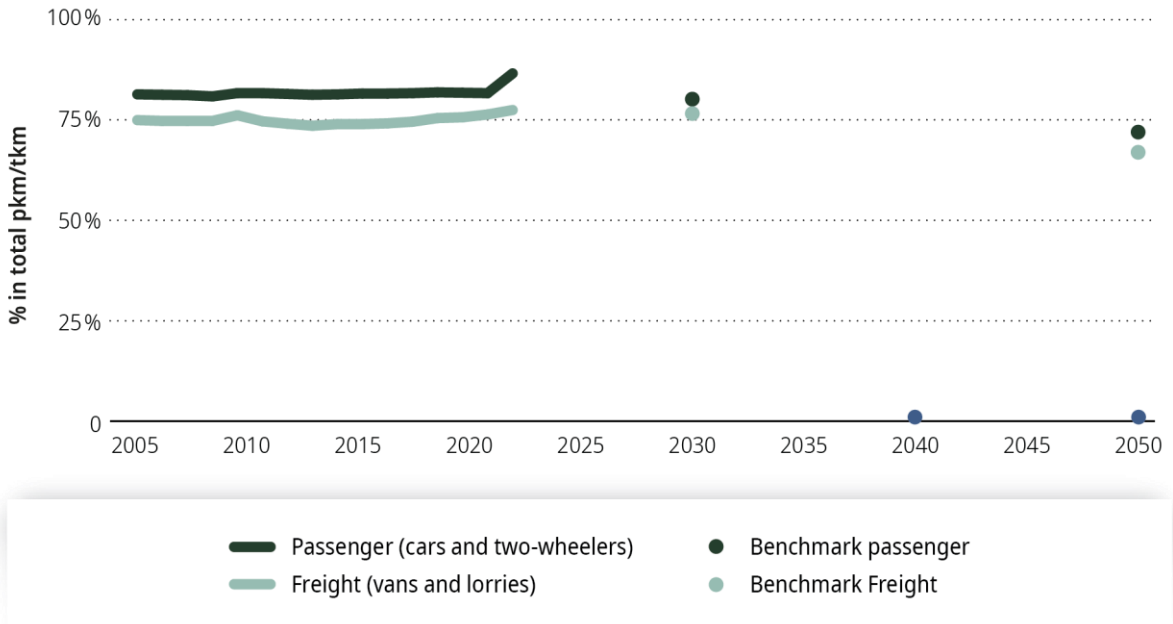
As transport demand has historically been strongly correlated with household income and overall economic activity (IPCC, 2022j), there is a risk that efforts to reduce overall transport demand could lead to reduced economic activity and corresponding income losses. Nevertheless, there are several enabling conditions that policymakers could activate to decouple this correlation (IPCC, 2022j). For instance, spatial planning policies that encourage more compact urban forms and reduce the distances people need to travel to work, education or services can also have positive economic and social co-benefits. A large body of literature (see Puga (2010) and Rosenthal and Strange (2004) for overviews) has found that density and spatial clustering of economic activity is linked to higher productivity, incomes and innovation – referred to as 'agglomeration economies'. The exact causes of agglomeration economies can vary, although research has generally pointed to how densification leads to the development of deeper labour markets, supply chain efficiencies, greater opportunities for knowledge spillover between workers and companies, and closer access to goods and services. While these benefits can come with trade-offs that must also be managed through spatial planning policies, such as congestion, pollution and higher land/housing prices (Duranton and Puga, 2020), there are synergies with other policy areas that can help to mitigate these trade-offs (e.g. reduced congestion from modal shifts, and lower pollution from uptake of ZEVs and renewable energy technologies).

Lever: modal shift

The EU has so far not managed to achieve a shift towards lower-emission transport modes.

Over the past decade, the increase in overall transport demand (both passenger and freight) has not been accompanied by notable shifts towards low-emission transport modes. As seen in Figure 37, road transport remained dominant in demand in inland transport, both for passenger and freight transport. Its share has even slightly increased in recent years. This trend is not in line with the European Commission's scenarios underpinning the EU climate objectives, which would require a decrease in the overall share of road in both passenger and freight transport by 2030 and 2050.

Figure 37 Indicator T3a – share of road transport in total motorised inland transport (excluding aviation and maritime, excluding active transport modes)



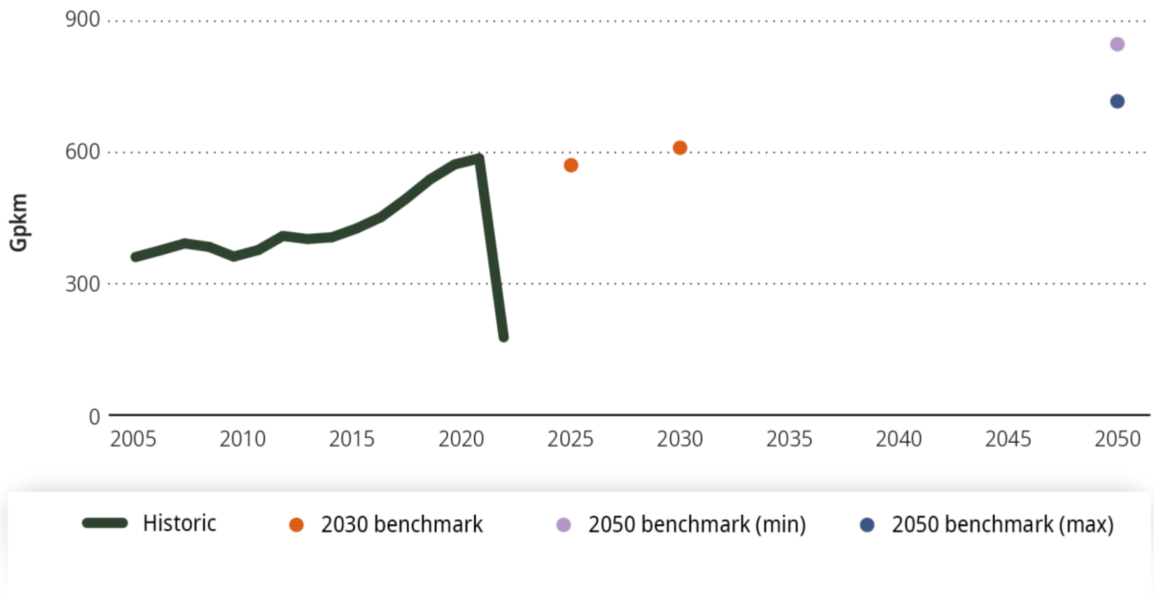
Notes: 2030 benchmark based on the Fit for 55 MIX scenario. 2050 benchmarks based on the 1.5TECH and 1.5LIFE scenarios of the in-depth analysis accompanying a Clean Planet for All (see figures 45 and 46, recalibrated for EU27 based on 2015 data).

All shares expressed as percentage of passenger-kilometers or percentage of tonne-kilometers in total motorised transport by road, rail or IWW. Aviation and international maritime are excluded, to filter out the effect of substantial growth in international (extra-EU) transport. Active transport modes (walking, cycling) are also excluded for lack of data. The 1.5TECH and 1.5LIFE scenarios do not provide a split between private and public road transport, so the share of buses and coaches has been assumed to remain at 9% under these scenarios.

Sources: Statistical pocketbook on transport 2022 (EC, 2022al), Fit for 55 MIX scenario (EC, 2021v), in-depth analysis accompanying A Clean Planet for All (EC, 2018e)

As mentioned in Section 6.2, there has been a particular increase in passenger aviation transport (see Figure 38). Between 2015 and 2019, intra-EU aviation grew by on average 33 Gpkm per year. This rate of increase is not in line with the European Commission's scenarios underpinning the EU's climate objectives, which anticipate growth of only 2 Gpkm per year until 2030 and 5–12 Gpkm per year thereafter.

Figure 38 Indicator T3b – intra-EU passenger transport by air



Notes: The 2030 benchmark is based on the Fit for 55 MIX scenario. The 2050 benchmarks are based on the 1.5TECH and 1.5LIFE scenarios of the in-depth analysis accompanying a Clean Planet for All (see figure 45, recalibrated for EU27 based on 2015 data).

Sources: Statistical pocketbook on transport 2022 (EC, 2022al), Fit for 55 MIX scenario (EC, 2021v), in-depth analysis accompanying A Clean Planet for All (EC, 2018e)

The Sustainable and Smart Mobility Strategy has put forward specific objectives to substantially increase passenger transport by high-speed rail (+ 100 % by 2030 and + 200 % by 2050 compared to 2015), and freight transport by rail (+ 50 % by 2030 and + 100 % by 2050 compared to 2015) and IWW (+ 25 % by 2030 and + 50 % by 2050 compared to 2015). As reflected in Figure 39, achieving these objectives would need a substantial acceleration of the observed annual rate of change in 2015–2019 for high-speed rail (+ 33 %) and rail freight transport (+ 600 %), and a reversal of the declining trend observed for IWW.

Figure 39 Indicator T3c – passenger transport by high-speed rail, and freight transport by rail and IWW

Sources: Statistical pocketbook on transport 2022 (EC, 2022al), Sustainable and Smart Mobility Strategy (EC, 2020k)

EU policies to trigger a modal shift have been ineffective.

In the past, the EU has put several policies in place to shift transport from road to rail and IWW. The 2011 White Paper on transport (EC, 2011) already included an objective to achieve a 50 % shift of medium-distance intercity passenger and freight journeys from road to rail and waterborne transport by 2050. However, as evidenced above, so far these objectives have not been achieved. Several causes have been identified for this lack of progress, including persistent operational and regulatory barriers (e.g. lack of interoperability, insufficient coordination and information sharing, lack of accessible data), infrastructural bottlenecks (hindered by high investment needs and low investment capacities), lack of available and integrated data and digital platforms, and higher costs of lower-emission transport modes (either perceived or effective) (ECA, 2023b; Finger et al., 2021; Pastori et al., 2018; Serafimova et al., 2022).

Several EU policies are already in place that address these issues, but so far they have been ineffective and insufficiently aligned with the EU climate ambitions. The Combined Transport Directive (EU, 1992), which governs intermodal freight transport in the EU, has not yet been revised since its inception in 1992, and both the European Commission and the ECA have assessed it as outdated and ineffective at promoting intermodal transport in the EU (EC, 2021s; ECA, 2023b). Key issues identified are legal requirements for paper documentation (preventing digitalised workflows) and a minimum threshold of 100 km for the non-road leg (which limits the scope of the directive). Furthermore, the implementation of the directive by Member States has been heterogeneous, which creates uncertainty for logistics operators. The Rail Freight Corridors Regulation (EU, 2010b) aims to boost the competitiveness of rail freight by creating transnational rail freight corridors but has been found to be insufficiently effective. Reasons include shortcomings within the regulation itself (e.g. the lack of adequate tools to deliver on its objectives, and the absence of an entity in the governance framework that transcends national interests) as well as how it was implemented at the national level (e.g. heterogeneous implementation due to lack of sufficiently clear rules, stakeholders approaching it as a tick-box exercise rather than implementing it in a way conducive to achieving its objectives) (EC, 2021f; Finger et al., 2021).

Finally, until recently EU pricing policies did not effectively support the modal shift. The Eurovignette Directive (EU, 1999) has not – except in a few specific cases – promoted a shift of freight towards lower-emission transport modes. Among the reasons cited are road charges applied under the directive being too low or insufficiently differentiated to trigger a substantial shift, and the lack of sufficient, reliable and efficient alternative transport modes (Gomez and Vassallo, 2020). The EU ETS has put the highest real carbon price (after accounting for free allocation) on electrified transport – such as the majority of rail transport, in which electricity accounts for 75 % of final energy use (Eurostat, 2023b) – whereas aviation has received most of its allowances for free, and road transport fuels have been excluded altogether. The ETD puts relatively high minimum energy tax rates on road transport fuels, but this is undermined by an exemption that allows lower rates for commercial passenger and freight transport. It also completely exempts aviation and maritime transport from energy taxation (see Chapter 10 'Pricing emissions and rewarding removals' for more details on the EU ETS and the ETD).

Several steps have been taken in recent years to address these issues. The Eurovignette Directive was revised in 2022 to expand its scope and to ensure better internalisation of transport externalities (EU, 2022d). The European Commission also announced a range of both legislative and non-legislative initiatives under the Sustainable and Smart Mobility Strategy and the Fit for 55 package, including an action plan to boost long-distance and cross-border passenger rail (EC, 2021k), a revision/replacement of the Rail Freight Corridors Regulation (EC, 2023av), a revision of the Combined Transport Directive (EC, 2023ap), a revision of the TEN-T regulation (see Section 6.5 below), the creation of a new EU ETS 2 for (amongst others) road transport, and a revision of the ETD (Chapter 10 'Pricing emissions and rewarding removals') ([23]). It is a positive development that the European Commission has acknowledged the need for additional efforts to achieve a modal shift and has taken steps in that direction, but it is too soon to assess whether these will be sufficiently effective, notably because these initiatives have not yet been adopted by the co-legislators (the TEN-T Regulation, a regulation on the use of railway infrastructure capacity that would replace the Rail Freight Corridors Regulation, the revision of the Combined Transport Directive) or will start to operate in the future (the EU ETS 2). Other reasons for concern are the lack of progress in the revision of the ETD (which, under the European Commission's proposal, would aim to tax the most environmentally harmful fuels the most and remove certain tax exemptions for fossil fuels, including transport fuels), and the 'soft' price cap under the EU ETS 2 (see Chapter 10 'Pricing emissions and rewarding removals').

When striving for a modal shift to reduce GHG emissions, it is important to consider the total aggregate impact, as measures to promote a modal shift (e.g. the construction of a new railway line) may lead to overall increases in transport demand (Kemp, 2016). Overall, the GHG reduction potential of a modal shift is largest where population density is large, whereas it is limited in more remote areas (Pastori et al., 2018). Furthermore, according to the ECA, urban mobility accounts for only 23 % of total transport emissions (ECA, 2020c). Consequently, although a modal shift in European cities could make significant contributions towards other environmental and societal objectives such as improved air quality, reduced noise nuisance, more efficient and safe mobility, it would yield only limited GHG emission reductions compared with modal shifts in intercity travel.

([23]) For a full overview, see the action plan annex to the Sustainable and Smart Mobility Strategy (EC, 2020k).

6.4 Outcome 2: low-emission and efficient transport fleet

Levers: uptake of zero-emission and efficient vehicles

The average CO_2 intensity of new vehicles is decreasing thanks to the uptake of ZEVs, but the rate of that uptake needs to accelerate to remain on track towards the 2035 objectives.

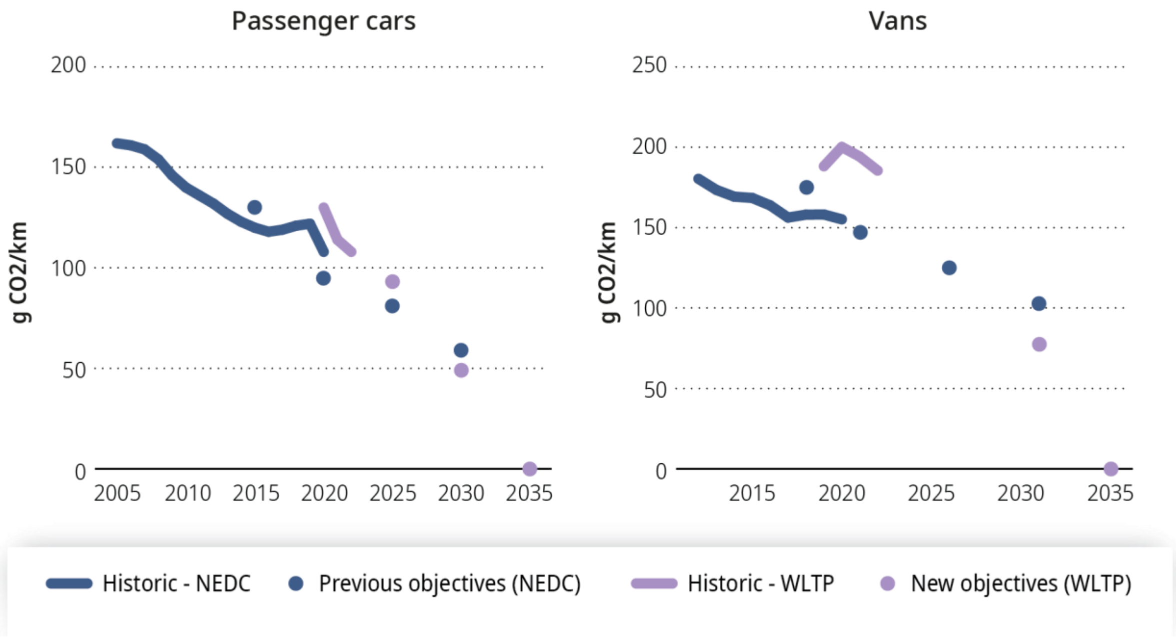
As shown in Figure 40, the average GHG intensity of new passenger vehicles declined in 2005–2015, but rebounded in 2016–2019 owing to a shift from diesel to petrol and the increased market share of sport utility vehicles and other larger and heavier cars (EEA, 2020). As of 2020, the GHG intensity started to decline again thanks to the increasing market share of plug-in hybrid electric vehicles (PHEVs) and BEVs, a trend that continued in 2021 and 2022. Progress in reducing the CO_2 intensity of new vans has been slower than for passenger cars. It declined steadily in 2005–2016, but then stagnated as a result of an increase in the average mass, engine capacity and size of vans. The downward trends resumed as of 2021 thanks to the uptake of zero-emission electric vans (EEA, 2023c).

HDV manufacturers have been required to monitor and report the CO_2 emission intensity of new vehicles since 2019 (EU, 2018d). Reported data so far shows that the average CO_2 intensity for new HDVs sold in 2019 to mid-2020 was 52.75 g CO_2 per tkm (EEA, 2022d). Current legislation requires this intensity to decrease by 15 % by 2025 and 30 % by 2030 (EU, 2019f). In 2023, the European Commission has proposed to increase the objective for 2030 to – 45 %, and to achieve a 65 % reduction by 2035 and a 90 % reduction by 2040 (EC, 2023ar). At the time of writing this report, the European Commission proposal had not yet been adopted by the Council and the European Parliament, and no data beyond 2020 on the average GHG intensity was yet available. Once more up-to-date data is available, it will be possible to assess the progress made and the required acceleration to remain on track towards the objectives set out in EU legislation.

Recent years have witnessed a breakthrough of BEVs on the European **passenger car** market, as illustrated in Figure 41. Their share in new registrations increased from less than 1 % in 2017 to more than 13 % in 2022. In the same period, the share of PHEVs increased from less than 1 % to almost 10 %, meaning that in 2022 more than 23 % of new passenger cars registered in the EU had a plug. Nevertheless, the uptake needs to accelerate even further (from on average + 3 pp in 2018–2022 to on average + 7 pp in 2023–2035) for the EU to achieve the binding objective of 100 % ZEVs by 2035 as set out under the revised CO_2 emission performance standards for cars and vans (EU, 2023k). Preliminary data from the European Automobile Manufacturers Association shows that the share of ZEVs in new car sales continued to increase in 2023 in line with earlier trends (12 % in January–April 2023 compared with 9 % in January–April 2022) (ACEA, 2023).

The uptake of battery electric **vans** seems to be following a similar trajectory, although with a few years' delay compared with passenger cars. The share of ZEVs (predominantly BEVs) among newly registered vans increased from less than 1 % in 2017 to 5 % by 2022, increasing by on average 1 pp per year in 2018–2022. This rate should increase to on average 8 pp per year in 2023–2035 to achieve 100 % ZEVs by 2035.

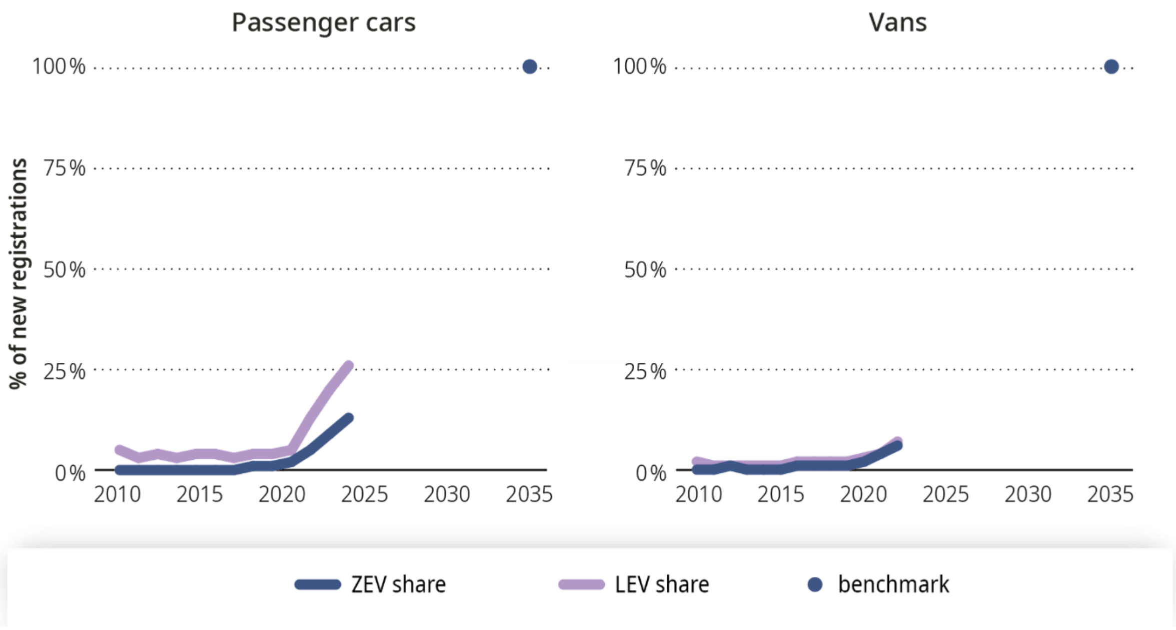
Figure 40 Indicator T4 – average GHG intensity of new passenger cars and vans (g CO_2/km)



Notes: Historic data is based on EEA data on emission intensity according to the New European Driving Cycle (data available up to 2020) and the Worldwide Harmonised Light Vehicle Test Procedure (data available as of 2020). The objectives are based on the CO_2 emission performance standards for passenger cars and vans.

Sources: EEA (2023c, 2023d) , CO_2 emission performance standards for passenger cars and vans (EU, 2019d, 2023k).

Figure 41 Indicator T5a – share of ZEVs in new registrations of passenger cars and vans

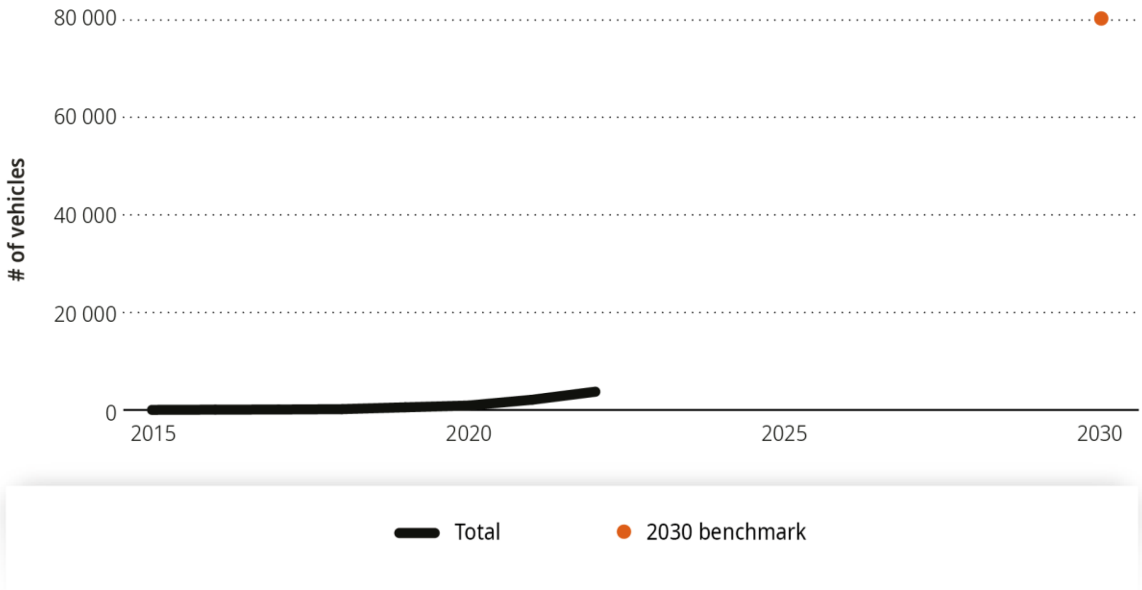


Notes: LEV refers to the share of low-emission vehicles, which primarily constitutes PHEVs, with a smaller contribution of CNG/LNG vehicles

Sources: European Alternative Fuels Observatory (EC, 2023ab), CO_2 emission performance standards for passenger cars and vans (EU, 2023k).

For **HDVs** (shown in Figure 42), the uptake of ZEVs has been slower, reflecting a lower maturity level ([24]) of zero-emission technologies for this segment. According to Eurostat, the share of ZEVs in new vehicle registrations was still very low in 2021 at 0.29 % for tractor trailers and 0.15 % for lorries (Eurostat, 2023b). The average annual rate of uptake would have to increase more than tenfold to have 80 000 zero-emission lorries in the EU fleet by 2030 as envisaged by the Sustainable and Smart Mobility Strategy.

Figure 42 Indicator T5b – total number of zero-emission lorries in the total EU fleet



Sources: European Alternative Fuels Observatory (EC, 2023ab), Sustainable and Smart Mobility Strategy (EC, 2020k).

Overall, ZEV technology is relatively new, and its uptake could be expected to follow a non-linear, S-shaped trajectory (see also Section 2.2). Therefore, although recent historical rates of change are not sufficient compared with the linear trajectories towards the objectives for 2030/2035, developments have been positive, and future years will need to clarify whether the deployment will accelerate as the technology matures. However, so far, the acceleration has not yet started, with the annual increase of ZEV shares in passenger cars relatively stable at 3 pp per year.

EU standards are an effective tool to drive the uptake of ZEVs, but currently fail to incentivise efficiency within the ZEV segment.

Emission performance standards for new vehicles have been the main tool in the EU policy toolbox to drive the uptake of ZEVs and increase vehicle efficiency. The most recent revision of the CO_2 emission performance standards for passenger cars and vans targets a 55 % reduction in CO_2 intensity for cars (50 % for vans) by 2030 (compared to the 2021 objective), and a de facto ban on the sale of non-ZEVs as of 2035 (EU, 2023k). Assuming an average 15-year lifetime for ICEVs, this should result in a completely zero-emission car and van fleet by 2050. The decrease in average CO_2 intensity suggests the policy instrument has been effective. The observed uptake of ZEVs in recent years is particularly promising with a view to achieving rapid emission reductions in the sector.

([24]) In particular, the relatively low energy density of batteries requires a trade-off between the range and the weight (and price) of battery electric HDVs.

However, while current emission performance standards incentivise energy efficiency within the segment of ICEVs and a switch from ICEVs to ZEVs, they do not provide an incentive (in addition to the electricity price) to increase efficiency within the segment of ZEVs (e.g. by prioritising the development and sale of compact, energy- and resource-efficient models). On the contrary, recent analysis (Gómez Vilchez et al., 2023; Thies et al., 2022) has cautioned that the current legislation incentivises car manufacturers to prioritise the development and sale of larger ZEVs over more compact ZEVs in two ways. Firstly, the calculation method to measure compliance with the CO_2 performance standards considers the mass of a vehicle, which means that replacing a large ICEV with a large ZEV will contribute more towards reaching the overall average CO_2 standard than replacing a compact ICEV by a compact ZEV. Secondly, ZEVs are still more costly to produce and have lower profit margins than ICEVs. Car manufacturers will therefore be more inclined to develop ZEVs for their larger car segment, as overall profit margins in that segment are higher (because there is less price elasticity in that market segment). Similarly, current State aid guidelines do not require Member States to differentiate financial support for clean vehicles as a function of their energy efficiency and resource efficiency (e.g. battery pack size), and most Member States are not doing this at the moment (IEA, 2023f). Currently, larger models including sport utility vehicles account for the majority (60 %) of all BEV models on the EU market (IEA, 2023e).

From a narrow perspective, faster electrification of the segment of larger vehicles is beneficial for the climate, as it yields the highest direct emission reductions. However, from a broader perspective the trend towards large electric vehicles is worrisome, as larger vehicles are more resource- and energy-intensive. On average, large BEVs weigh 50 % more, are 20 % less energy efficient and require 70 % more critical raw materials than smaller BEVs (IEA, 2023e). This increases their life cycle environmental footprint both directly (from higher electricity use) and indirectly (from higher resource use). Furthermore, the focus on larger, less efficient BEVs also undermines the overall availability and affordability of BEVs, as they add pressure on the constrained availability of critical raw materials, which is a key driver of their production cost. Reducing the average vehicle size is – together with the development of new battery types – a key pathway to moderate demand for (and therefore enhance the security of supply of) critical raw materials, which is a prerequisite to enable worldwide electrification of the transport fleet (IEA, 2023e).

For HDVs, emission standards were first introduced in 2019 (EU, 2019f), and currently revised under the Fit for 55 package (EC, 2023ar). The European Commission's proposal aims to reduce the average CO_2 intensity of new HDVs by 45 % by 2030 and 90 % by 2040 (compared to 2020 levels) and expands the scope to cover additional vehicle types such as buses and coaches (which would need to become zero-emission by 2030). A first independent assessment (not peer-reviewed) by the International Council on Clean Transport has found that, despite its overall high level of ambition, the regulation would lead to only 64 % GHG emission reductions by 2050 (compared to 1990), which falls short of the 90 % reduction envisaged by the European Green Deal (Mulholland and Rodriguez, 2023).

In addition to CO_2 emission performance standards, the EU also promotes the uptake of clean and energy-efficient road transport vehicles through public procurement, by means of mandatory minimum targets for each Member State set out in the Clean Vehicles Directive (EU, 2019c). Furthermore, in its Sustainable and Smart Mobility Strategy (EC, 2020k), the European Commission announced further proposals to boost the uptake of ZEVs in corporate and urban fleets. To date, to the Advisory Board's knowledge, no further actions in this domain have been taken.

Further action is needed to ensure security of supply and reduce the environmental impact of critical raw materials and batteries.

Battery technology and production costs have improved substantially over the last decade, and the overall expectation is that costs will continue to decrease with technological advances and economies of scale, even when taking into account raw material price increases (Mauler et al., 2021). As a result, the total cost of ownership of passenger car BEVs has decreased and is approaching parity with ICEVs in at least some market segments (IEA, 2022a). These developments have also increased the technological feasibility and economic competitiveness of battery electric HDVs (Bhardwaj and Mostofi, 2022; Nykvist and Olsson, 2021), and several lorry manufacturers are currently offering commercial BEV models or are planning to do so in the coming years (Mollière, 2023).

However, key bottlenecks in their large-scale deployment persist, such as the lack of available charging infrastructure (see Section 6.5) and the availability of critical raw materials and batteries (ECA, 2023d; Hao et al., 2019; IEA, 2021b). The EU is in a particularly vulnerable position, due to its limited domestic capacity to extract and process critical raw materials and produce batteries. Furthermore, global value chains are concentrated in just a few countries, primarily China, which produces 75 % of all lithium ion batteries and is home to 70 % of the production capacity for cathodes and 85 % of the production capacity for anodes (ECA, 2023d; IEA, 2022b). Finally, there is strong competition between different regions in the world to attract private investment in clean technology value chains – including battery production – as illustrated by the US Inflation Reduction Act. The combination of the EU's limited own extraction, processing and production capacities and its high dependence on imports from a limited number of trading partners with strong incentives in other regions of the world to attract investments in battery supply chains, and projected strong increases in demand globally, makes it very vulnerable to supply chain disruptions.

The European Commission is aware of this challenge and has taken several initiatives to tackle the issue. In 2017, it launched a European Battery Alliance, which is a platform for cooperation with key industrial stakeholders, interested Member States, the European Investment Bank (EIB) and the scientific community to build up battery technology and production capacity in the EU (EC, 2017). In 2018, it followed up with a Strategic Action Plan on Batteries, which listed a range of actions to further build up a competitive EU battery value chain (EC, 2018a). In 2023, as part of its Green Deal Industrial Plan in response to the US Inflation Reduction Act, it proposed a Critical Raw Materials Act (EC, 2023ac) and Net-Zero Industry Act (EC, 2023ao), which contain objectives aimed at boosting the EU's domestic supply chains for critical raw materials and manufacturing of strategic net zero technologies (respectively), including for batteries.

A recent report by the ECA (ECA, 2023d) has found that the European Commission's promotion of an EU industrial policy on batteries has been largely effective, despite some shortcomings regarding monitoring, and regarding coordination and targeting of support. Furthermore, it concluded that projected battery production capacity (based on companies' announcements) would be largely sufficient to meet projected EU battery demand for 2025 and 2030. However, it also warned that the actual deployment of this production capacity is subject to several risks, including time lags, and battery manufacturers reversing on their investment plans because of increasing costs in the EU or more attractive financial conditions offered in regions outside the EU. Furthermore, it warned that access to raw materials remains a major strategic challenge for the EU's battery value chain, which faces a looming global shortage of some key raw materials as of 2030. As a result, the EU might not be able to supply sufficient batteries to achieve its objective of 100 % of new cars and vans sold being ZEVs as of 2035. It would therefore have to rely on considerable imports from other regions of the world, which would undermine its security of supply and would outsource investments and jobs in clean technologies.

IPCC AR6 also highlights the need to address adverse impacts of battery production such as GHG emissions, non-climate environmental impacts and labour rights (IPCC, 2022g). There are several possible approaches to pursue this, which can also increase the EU's resilience against supply chain disruptions, such as such as prioritising smaller, more resource-efficient vehicles, increased recycling or repurposing of batteries (Ioakimidis et al., 2019; Iturrondobeitia et al., 2022; Unterreiner et al., 2016) and switching to alternative battery types (Feng et al., 2022).

Lever: fuel switches

Progress in phasing out fossil transport fuels has been too slow, and relied heavily on first-generation biofuels with high indirect land use change (ILUC) risks.

The share of fossil fuels in the transport energy mix (shown in Figure 43) decreased only slightly from 98 % in 2005 to 93 % by 2021. This reduction was almost exclusively achieved by a shift from fossil fuels to biofuels, whereas the share of electricity remained very small (from 1.4 % in 2005 to 1.5 % in 2021).

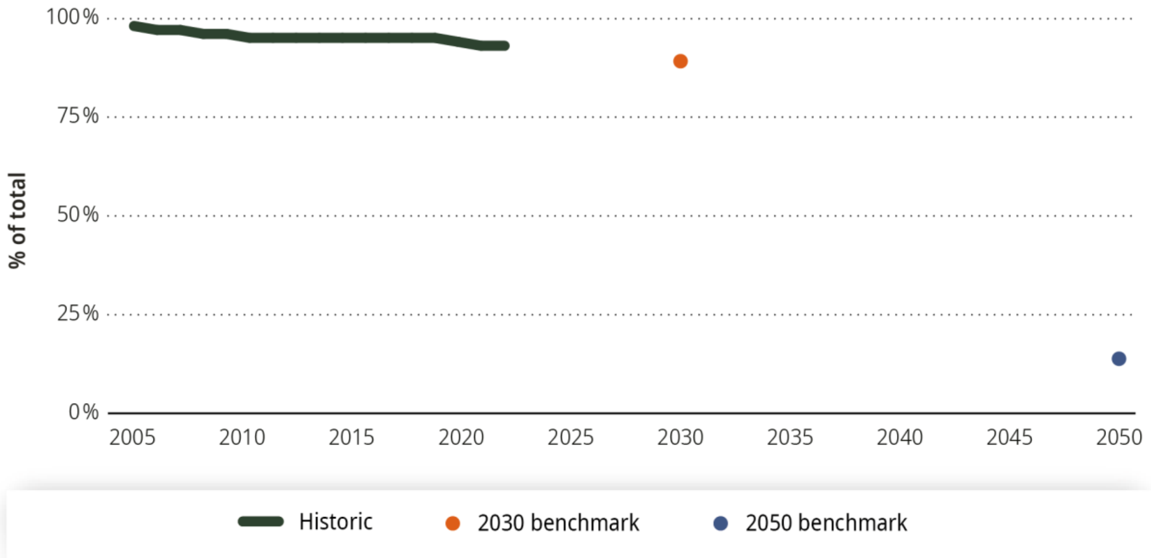
The European Commission's scenarios that underpin the EU climate objectives would require an acceleration of this trend, notably after 2030. This would require a combination of direct electrification and the use of low-carbon fuels (hydrogen and related derivates, and sustainable biofuels). Under the MIX scenario underpinning the Climate Target Plan (EC, 2020s), about 80 % of passenger cars and 70 % of vans would be electric ([25]) by 2050. For HDVs, the feasible share would be lower, with 18 % BEVs and 26 % PHEVs by 2050. Regarding the total energy mix for transport (including aviation and maritime), the share of fossil fuels would decline to 14 % by 2050, to be replaced by electricity (21 % by 2050), hydrogen and related derivates (41 % by 2050) and biofuels (24 % by 2050). However, since the publication of the Climate Target Plan, significant advances have been made regarding electrification technologies, which would make even greater electrification of road freight transport more feasible than it was considered a few years ago, including for HDVs. Nevertheless, low-carbon fuels would still be required to decarbonise international maritime and aviation transport (ESABCC, 2023b).

Biofuels made from food and feed crops (hereafter referred to as first-generation biofuels) accounted for the majority of the biofuels used in the transport sector (EEA, 2022j). Figure 44 displays their absolute volumes, showing that their use increased by almost 60 % in 2011–2019, after which it reduced slightly in parallel with overall lower energy use in the context of the COVID-19 pandemic ([26]). Under the European Commission's scenarios that underpin the EU climate objectives, their use could only increase slightly until 2030, and then phase out completely by 2050.

([25]) The majority (70 % of passenger cars, 63 % of vans) would be fully electric (BEV), with a small minority of PHEVs.

([26]) These figures are based on the SHARES summary results, and only take into account biofuels which meet the minimum GHG savings and sustainability criteria set out in the Renewable Energy Directive.

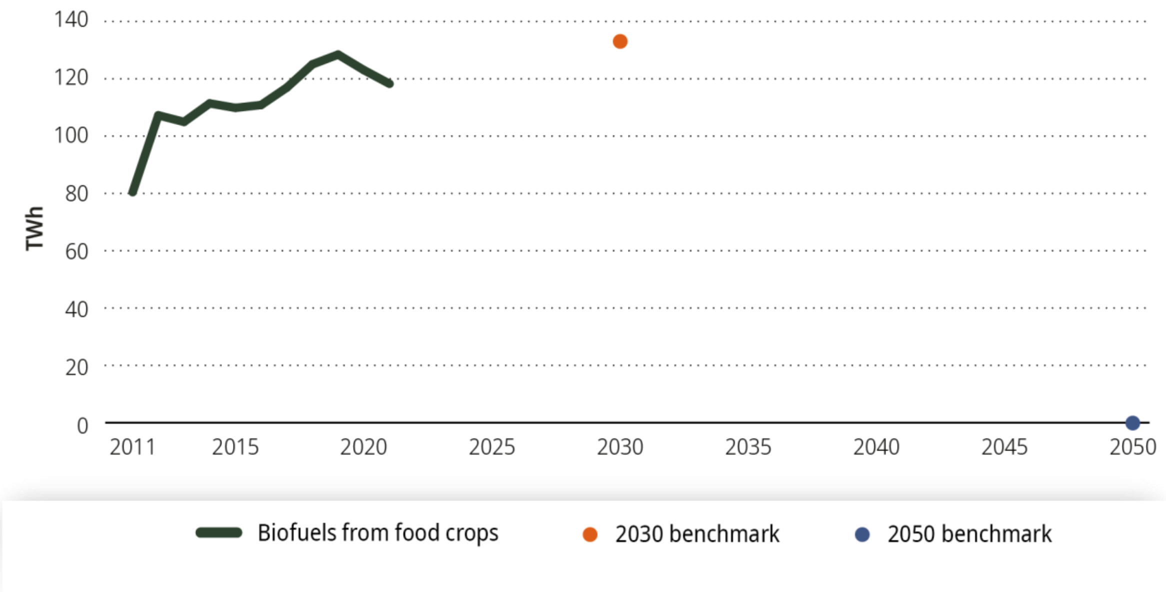
Figure 43 Indicator T6a – share of fossil fuels in transport energy use (including international bunker fuels)



Notes: 2030 and 2050 benchmarks based on the MIX scenario from the Climate Target Plan impact assessment.

Sources: Eurostat energy balances (2023b), Climate Target Plan impact assessment (EC, 2020s).

Figure 44 Indicator T6b – use of first-generation biofuels in the transport sector



Notes: Historic data based on the EU SHARES tool database. The 2030 and 2050 benchmarks are based on the MIX scenario from the Climate Target Plan impact assessment (see figures 77 and 79). Values converted from Mtoe to TWh

Sources: EU SHARES database (Eurostat, 2023r), Climate Target Plan impact assessment (EC, 2020s).

EU policies continue to promote transport biofuels, which have inherent spillover risks.

Since 2003, EU policies have actively incentivised the use of biofuels in the transport sector (EU, 2003). However, awareness has since increased about the high risk of harmful ILUC effects from EU biofuel policies, which could have a net effect of increasing atmospheric GHG concentrations (see e.g. Valin et al., 2015). This led to more stringent rules under the RED II of 2018 (RED II), which increased the total renewable target for transport to 14 % by 2030 but set a cap on the potential contribution of food- and feed-based biofuels at a maximum of 7 % after 2020 ([27]), and required a phase-out by 2030 of the promotion of biofuels made from feedstocks with a high ILUC risk (EU, 2018b).

The Renewable Energy Directive was recently revised (RED III) as part of the Fit for 55 package (EU, 2023). One major change in the agreed outcome is the option for the EU Member States to pursue either a renewable energy target (29 % by 2030) or a GHG intensity reduction target (– 14.5 % by 2030 under the RED III) in the transport sector. The latter option could result in considerably higher overall GHG savings at a considerably lower cost than the renewable energy objective (Christensen, 2021; Baldino and Searle, 2021). Furthermore, the 7 % cap on food- and feed-based biofuels was maintained, as was the required phase-out of fuels made from high-ILUC feedstocks. However, there are concerns that this cap does not sufficiently tackle the problem. The directive continues to promote first-generation biofuels (up to 7 %) and does not stipulate a full phase-out of these fuels (even if they are assumed to be fully phased out by 2050 under the European Commission's scenarios underpinning the 2050 climate neutrality objective). Furthermore, the International Council on Clean Transport has warned that intermediate crops ([28]) are not covered by the 7 % cap, and certain types of them could cause ILUC emissions of the same order of magnitude as regular food and feed crop biofuels. Even more, because they are relatively low-cost to produce, they warn of a potential paradox that the increased renewable energy objective would lead to a high uptake of biofuels from intermediate food and feed crops, thereby reducing overall GHG emissions savings (Baldino and Searle, 2021; Christensen, 2021; Searle, 2021). Furthermore, despite previous warnings by the ECA (ECA, 2016) and reports commissioned by non-governmental organisations (van Grinsven et al., 2020), the issue of fraud in the labelling of biofuels persists (Moskowitz et al., 2023).

In addition to the RED III, the Fit for 55 package also introduced two separate pieces of legislation to decarbonise the fuel mix in the aviation (ReFuelEU Aviation) (EU, 2023q) and maritime sectors (FuelEU Maritime) (EU, 2023p). The first one sets a mandatory requirement for aircraft operators to use a minimum share of 2 % sustainable aviation fuels by 2025, increasing to 6 % by 2030 and 70 % by 2050 (with specific subtargets for synthetic aviation fuels). For maritime fuels, another approach was chosen, which requires their average GHG intensity to decrease by 2 % by 2025, 6 % by 2030 and 80 % by 2050 (compared with a reference value of 91.16 g CO_2e/MJ). Given the lack of progress in these sectors, it is encouraging that separate legislation has been put in place to drive GHG emission reductions in aviation and maritime transport. However, the first assessments have warned they risk reintroducing issues with the sustainability of the biofuels they promote. Whereas ReFuelEU Aviation is more stringent than the RED III on some types of biofuels (e.g. by excluding fuels made from intermediate crops), it does not apply a cap on waste oils and animal fats (which are restricted under the RED III). A report commissioned by a non-governmental organisation has warned that this could increase demand for fuels made from category 3 animal fats, which could drive indirect emission increases by triggering a shift to fossil feedstocks in other sectors such as the chemicals sector (Malins, 2023). The FuelEUMaritime regulation is more stringent than the RED III with regard to fuels made from food and feed crops (which cannot

([27]) Or 1 pp higher than the 2020 value in a specific Member State, whichever value is lower.

([28]) Defined as crops that are not grown as the main crop as per Article 2 (40) of RED II.

count towards the targets under the regulation) but does not put restrictions on biofuels from other feedstocks with high ILUC risks.

The remaining concerns described above highlight the challenge of designing and implementing policies that can effectively promote the use of sustainable biofuels while avoiding potential negative spillover effects. This is because those spillover effects are in large part inherent to biofuels, as impacts can be indirect (e.g. demand for fuel can increase overall demand for agricultural commodities, thereby contributing to land use change far away from a specific supply chain), and their sustainably available supply is constrained.

There are strong arguments for prioritising direct electrification over the use of hydrogen- and bio-based fuels.

There are in total three alternatives to fossil fuels in the transport sector: direct electrification, hydrogen and its derivatives, and sustainable biofuels. A report by Trinomics for the European Parliament (Trinomics, 2023b) found that direct electrification is the most energy efficient and has the lowest sustainability concerns of these three alternatives, even if it also faces potential constraints on raw materials for batteries. Hydrogen-based fuels and biofuels can also deliver substantial GHG emission reductions, but their scalability is constrained by limited availability of the required inputs (sustainable feedstocks for biofuels, zero-emission electricity for hydrogen, and biogenic or atmospheric CO_2 for synthetic fuels), their cost-competitiveness and their technological readiness.

As all transport modes need to be significantly decarbonised to achieve the 90 % reduction objective, there is thus a strong argument for prioritising direct electrification and reserving the use of hydrogen-based fuels and sustainable biofuels for transport modes that are technologically difficult to electrify directly. These include aviation, long-haul shipping and, in some circumstances, heavy-duty road transport (IPCC, 2022j; Trinomics, 2023b).

The study by Trinomics (2023) also compares sustainable biofuels with hydrogen and its derivatives. Whereas sustainable biofuels are more affordable (currently, but probably also in the longer term), they have the disadvantage of facing more stringent availability limitations than hydrogen-based fuels. These constraints are expected to continue in the longer term, as there will be competing demand for biogenic carbon from other sectors. This increases the importance of limiting policy incentives to sustainably sourced biofuels. On the other hand, hydrogen-based fuels are less subject to sustainability constraints, but are more expensive, at a lower technological readiness level and energy-inefficient to produce, which limits their scalability at least in the short to medium term. However, the prospects of future cost reductions through technological improvements, economies of scale and increased availability of zero-emission electricity could improve their scalability in the medium to longer term.

6.5 Enabling condition: transport infrastructure

The EU provides considerable support for transport infrastructure through a range of funds, including the Cohesion Fund, the European Regional Development Fund, the Connecting Europe Facility and the RRF. The Advisory Board has not assessed whether the investments in transport infrastructure under these funds have been consistent with the EU's climate objectives and in particular its ambitions to achieve a shift towards lower-emission transport modes.

The TEN-T regulation is a specific EU policy instrument to develop a consistent, efficient, multimodal, and high-quality transport infrastructure across the EU (EU, 2013b). However, a recent report by the ECA (ECA, 2023b) has criticised the fact that the current regulation does not require an analysis of the adequacy of existing intermodal terminals and the need for future terminals to meet current and potential future traffic flows. It also does not require the collection of information on the digitalisation of terminal infrastructure, which would allow logistics operators to share information efficiently. Furthermore, Member States have made insufficient progress in ensuring the compliance of their infrastructure with the technical requirements set out in the TEN-E Regulation. In 2021, the European Commission published a proposal for a revision of the TEN-T regulation, with the aim of aligning it with the European Green Deal and the ambition to achieve a 90 % GHG emission reduction in transport by 2050 (EC, 2021ah). Specific measures in the proposal include obligations for Member States to allow faster speeds (at least 160 km/h) on all passenger lines on main TEN-T rail stretches, make it possible for lorries to be transported by train, connect large airports to rail, and increase the number of multimodal transport hubs for freight and multimodal stations for passengers. It would also address the shortcomings described above, by requiring better information on terminal location and digitalisation, and including more means for the European Commission to ensure proper implementation at the Member State level (ECA, 2023b). At the time of publication of this report, the European Parliament and the Council had reached a provisional agreement on the proposal.

The lack of available charging infrastructure has been identified as a key bottleneck to achieving rapid and large-scale electrification of the transport fleet (Nykvist and Olsson, 2021; Osieczko et al., 2021; Shoman et al., 2023). To address this, in 2023 the EU adopted the Alternative Fuels Infrastructure Regulation, which sets binding minimum national targets for charging infrastructure (EU, 2023o). Although it is generally recognised as an effective tool to ensure adequate charging infrastructure, an independent assessment (not peer-reviewed) by the International Council on Clean Transport has warned that the targets for HDV charging stations are insufficiently ambitious, as they are based on conservative estimates of the deployment of heavy-duty BEVs (Basma and Rodriguez, 2021).

6.6 Summary tables

Table 8 Progress summary - transport

Indicator	Reference period	Historical progress	Required up to 2030	Required in 2031–2050
T1: GHG emissions	2005–2022	– 2 Mt CO_2e/yr	– 26 Mt CO_2e/yr	– 31 Mt CO_2e/yr
T2: transport demand				
T2a: passenger	2015–2019	+ 92 Gpkm/yr	+ 41 Gpkm/yr	+ 10 to + 17 Gpkm/yr
T2b: freight	2015–2019	+ 51 Gtkm /yr	+ 46 Gtkm/yr	+ 18 to + 19 Gtkm/yr
T3: modal shares				
T3a: % of cars in passenger transport (a)	2015–2019	Stable	– 0.2 pp/yr	–0.2 pp/yr
T3b: % of lorries in freight transport (a)	2015–2019	+ 0.6 pp/yr	– 0.4 pp/yr	–0.2 pp/yr
T3c: aviation passenger transport	2015–2019	+ 33 Gpkm/yr	+ 2 Gpkm/yr	+ 5 to + 12 Gpkm/yr
T3d: high-speed rail passenger transport	2015–2019	+ 5 Gpkm/yr	+ 8 Gpkm/yr	+ 5 Gpkm/yr
T3e: rail freight transport	2015–2019	+ 2 Gpkm/yr	+ 17 Gpkm/yr	+ 10 Gpkm/yr
T3f: inland waterway freight transport	2015–2019	– 2 Gpkm/yr	+ 4 Gpkm/yr	+ 2 Gpkm/yr
T4: road vehicle CO_2 intensities				
T4a: passenger cars (new sales)	2018–2022	– 9 g CO_2/km/yr	– 7 g CO_2/km/yr	– 10 g CO_2/km/yr (b)
T4b: vans (new sales)	2018–2022	– 1 g CO_2/km/yr	– 8 g CO_2/km/yr	– 16 g CO_2/km/yr (b)
T5: uptake of ZEVs				
T5a: passenger cars (% in new sales)	2018–2022	+ 3 pp/yr	+ 7 pp/yr (to reach 100 % by 2035)	
T5b: vans (% in new sales)	2018–2022	+ 1 pp/yr	+ 8 pp/yr (to reach 100 % by 2035)	
T5c: lorries (number of ZEVs in total fleet)	2018–2022	+ 729/yr	+ 9 526/yr	No benchmark
T6: fuel mix				
T6a: % of fossil fuels	2017–2021	– 0.4 pp/yr	– 0.5 pp/yr	– 4 pp/yr
T6b: % of first-generation biofuels	2017–2021	+ 0.4 pp/yr	+ 0.04 pp/yr	– 0.6 pp/yr

Legend

On track	The required change (c) is ≤ 1.
Almost on track	The required change (c) is between 1 and 1.5.
Somewhat off track	The required change (c) is between 1.5 and 2.
Considerably off track	The required change (c) is ≥ 2.
Wrong direction	The required change (c) is < 0.

(a) Inland transport, excluding aviation and maritime transport volumes.
(b) To achieve the legally binding objectives for 2035 (cars and vans) or 2040 (lorries).
(c) See Section 2.2 for more details on how the required change is calculated.

Table 9 Policy consistency summary - transport

Policy inconsistencies	– Current CO_2 emission performance standards incentivise car manufacturers to prioritise larger, less efficient vehicles within the segment of ZEVs. – The price cap mechanism under the EU ETS 2 increases the likelihood of a lower price than under the EU ETS, which undermines electrification in the transport sector. – The ETD continues to provide exemptions for commercial transport fuels, and for aviation and maritime. The proposed revision to tackle this has not yet been adopted. – The RED III, ReFuelEU Aviation and FuelEUMaritime continue to promote some biofuels with potentially high indirect effects, such as fuels made from food and feed crops, intermediate crops and category 3 animal fats.
Policy gaps	– There are no dedicated policies or strategies to curb overall transport demand; moderation of overall transport demand is not considered as an option in the EU's Sustainable and Smart Mobility Strategy. – Extra-EU aviation and half of extra-EU maritime transport remains exempt from the EU ETS.
Ambition gaps	– EU policies to promote a modal shift (the Combined Transport Directive, the Rail Freight Corridors Regulation, the TEN-T regulation) are not yet aligned with the European Green Deal. The European Commission has launched several initiatives to address this gap, including a revision of the TEN-T regulation (provisional agreement reached), a regulation on the use of railway infrastructure capacities (proposed but not yet adopted) and a revision of the Combined Transport Directive (proposed but not yet adopted).
Implementation gaps	– Implementation of the Rail Freight Corridor Regulation and the Combined Transport Directive has been incomplete and heterogeneous across the EU. – There are well-founded suspicions of fraud in the labelling of transport biofuels as sustainable under RED III.

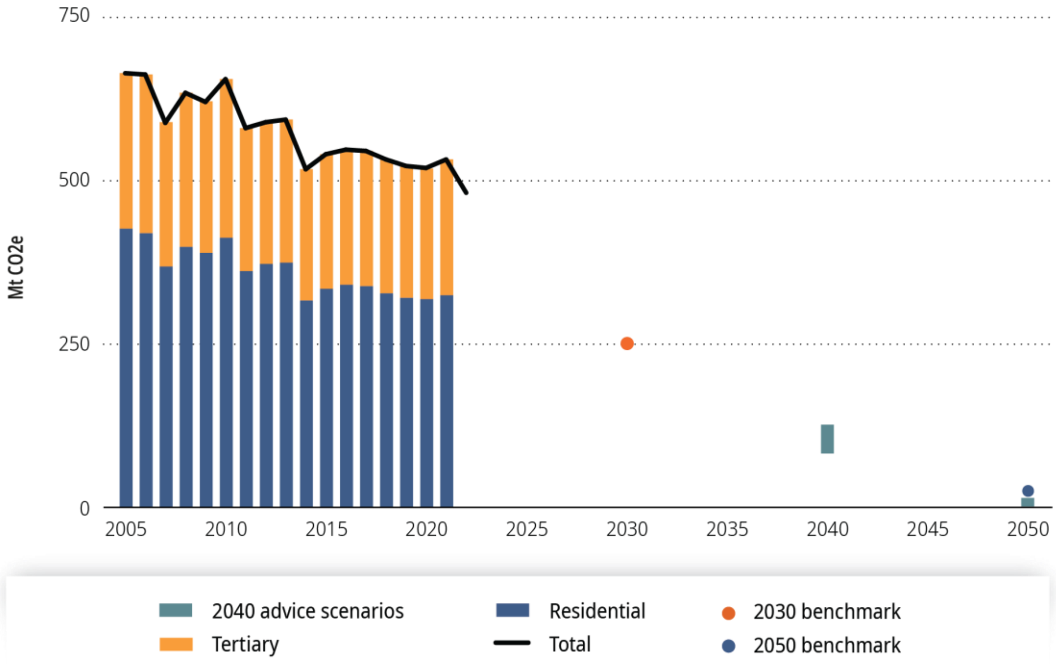
7 Buildings

Key messages

The GHG emission trend in the EU buildings sector is not in line with the EU's climate objectives. Putting it on track towards climate neutrality can be accelerated by a shift to zero-emission buildings and deep energy retrofits of existing buildings, combined with reducing the floorspace and energy demand.

GHG emissions in the buildings sector have decreased by 27.5 % (– 11 Mt CO_2e per year on average) between 2005 and 2022 (Figure 45). However, to be consistent with the European Commission's scenarios that underpin the overall 2030 – 55 % objective, the average rate of GHG emission reductions would need to almost triple in 2023–2030 to 31 Mt CO_2e per year. Achieving that scale of emission reductions in the coming years requires a deep energy retrofit of the EU building stock in combination with a rapid switch from fossil to zero- or low-carbon heating technologies.

Figure 45 Indicator B1 – overall progress in reducing GHG emissions from the EU tertiary and residential buildings



Sources: See Figure 47.

The rate and depth of renovation must increase fast while managing distributional impacts.

Needs. Around three quarters of EU buildings were built before 1990. Most of the buildings (85–95 %) standing in the EU today will also be there in 2050. Around 75 % of buildings in the EU are energy inefficient. Improving the energy performance of the existing buildings can reduce the final energy demand, but the pace and depth of building energy retrofits so far is not sufficient to meet the EU's climate targets by 2030 and 2050. The EU needs to overcome multiple barriers to deep energy retrofits, including stifled price signals, split incentives ([29]), and obstacles linked to the building sector's high heterogeneity in terms of building types, sizes and operational uses. In addition, skills shortages are acute in the construction sector (see Chapter 15 'Labour, skills and capacity building'). Policy design needs to account for the socioeconomic impacts of measures to decarbonise buildings in the context of a just transition (see Chapter 11 'Whole-of-society approach').

Gaps. EU policies so far have not overcome barriers to wide-scale and deep energy retrofits of buildings **(implementation gap)**. The recast of the EPBD aims to address this gap, notably through the gradual introduction of minimum energy performance standards to trigger renovation of the worst-performing buildings, a definition of deep renovation and the introduction of building renovation passports. The introduction of the EU ETS 2 covering energy use in buildings will support energy retrofits but is not in itself a solution to the persisting barriers. Constraints on distribution, organisation, administrative capacity, investment, and data go beyond the insufficient price signals. The quality and ambition of the EU's long-term renovation strategies are not sufficient to guide the required building renovation towards the 2050 climate neutrality objective **(implementation gap)**.

Recommendation B1. The EU ETS 2 should be accompanied by the swift adoption and effective implementation of an ambitious EPBD recast addressing:

— organisational, administrative capacity and investment barriers, for instance through one-stop shops and energy performance contracting,
— regressive socioeconomic impacts, such as through the Social Climate Fund and actions set out in the European Commission's Recommendation (EU) 2023/2407 of 20 October 2023 on energy poverty (see Chapter 11 'Whole-of-society approach')
— skilled workforce availability (see Chapter 15 'Labour, skills, and capacity building').

Recommendation B2. The long-term renovation strategies should be improved and contribute to the national LTSs under the EU climate Governance Regulation (see Chapter 14 'Climate governance').

In most cases, decarbonisation of heating and cooling is most efficiently achieved through direct electrification based on the accelerated deployment of heat pumps. District heating has also an important role to play.

Needs. Fossil fuels and biomass dominate the heating sources for the EU's building stock. Space heating and water heating represent around 80 % of the building energy demand across the EU. Heating, cooling, ventilation, and hot water solutions in the EU building stock need to reflect the changing climatic conditions, advancements in net zero technologies, and direct electrification benefits from efficiency and system perspectives. Heat pumps deliver heat at a higher efficiency than combustion fuel boilers and usually rely on increasingly renewables-dominated electricity grid supply. Very efficient appliances reduce energy demand and hence reduce the need for expanding electricity supply. The EU needs to keep up the momentum created by the energy crisis, which led to a massive uptake of heat pumps.

Gaps. So far, EU policies have been moderately successful in driving non-fossil fuel switching. This is thanks to, among other factors, subsidies to fossil gas allowed under the ETD and EU State aid rules **(policy inconsistency)**, a lack of system integration (see Chapter 4 'Energy supply') and insufficiently robust EU standards leading to incremental energy efficiency improvements and lock-in effects **(policy gap)**.

([29]) A split incentive may occur in the case of rented properties, that is, principal/agent problems in which the tenant benefits from the decarbonisation investment made by the landlord.

Recommendation B3. To maintain the current rate of heat pump uptake and, where relevant, shift to innovative district heating, EU policies should create a conducive framework including carbon pricing, energy taxation (see Chapter 10 'Pricing emissions and rewarding removals), energy system integration guided by the energy efficiency first principle (see outcome 1 subsection below and Chapter 4 'Energy supply') and robust supply chains including available skilled workforces (see Chapter 15 'Labour, skills, and capacity building'). It should support timely and robust local heating and cooling plans, which are required under the EED. The roll-out of heat pumps should be considered in the context of better-integrated social and climate policies (see Chapter 11 'Whole-of-society approach').

Reducing the demand for energy and materials over the life cycle of buildings is an important lever for a fair and just transition. To this end, EU policies can provide information and guidance to national policies, for example in the field of taxation and planning.

Needs. Buildings' energy and materials demands have been increasing overall, as a result of changes in demography, climatic conditions and use of building. The EU's **floor area** has been increasing more than could be justified by the EU's population growth. Reducing the demand for energy and materials, known as sufficiency, relies on widely available measures such as compact cities, shared spaces, voluntary demand reduction, and nature-based solutions such as green roofs that can bring multiple benefits including climate resilience and well-being. In this respect, sufficiency-led **reduction of floor space demand** is one of the most impactful measures to reduce buildings' environmental footprint, including embodied energy and carbon.

Gaps. The revised EED and the EPBD before recast do not explicitly aim to leverage sufficiency, but include provisions that will encourage it, such as the consumer information and empowering programmes. The EU does not prominently guide urban/spatial planning and taxation towards energy and material sufficiency **(ambition gap)**. The EPBD recast aims to tackle buildings' embodied carbon and energy, which could encourage better use of existing buildings rather than new construction.

Recommendation B4. The EU should strongly encourage reduction in demand for energy and materials by promoting sufficiency in the pre-use phase, that is, through urban and territorial spatial planning and building codes, as well as the use phase, that is, through digital solutions, awareness-raising and sharing good practice, for example on land value taxation, and through adequate carbon pricing under the EU ETS 2 (see Chapter 10 'Pricing emissions and rewarding removals'). Innovative policy measures could also incentivise building occupants' behaviour to drive energy and resource savings through, for example, energy saving feed-in tariffs and personal carbon allowances, perhaps based on experience from regulatory sandboxes, since a large proportion of emissions comes from the building operations phase.

Reliable, granular and comparable data on building performance and on the multiple benefits of energy efficiency investment are urgently needed to underpin policy measures.

Needs. When embedded in appropriate policies, reliable building performance data can contribute to (i) attracting private investment, (ii) creating new markets and infrastructure, (iii) innovating to reduce building life cycle emissions, (iv) spurring behavioural changes and (v) better tracking of EU policy progress. The EU increasingly relies on energy performance certificate (EPC) data for tracking the progress and implementation of renovation policies and funding.

Gaps. So far, EU policies have not sufficiently facilitated collection and sharing of reliable, granular, comparable and interoperable information on the energy performance, investments in energy efficiency and multiple benefits of efficient building stock, such as indoor air quality **(policy gap)**. The EPC schemes are of uneven quality and have limitations in terms of reliability, as they are based on data derived from the physical properties of buildings rather than energy demand driven by occupancy behaviour **(ambition gap)**. The recent EPBD recast aims to address this gap.

Recommendation B5. The EPBD recast and follow-up to the EU action plan on digitalisation of energy system should allow better use of the EPCs and minimum energy performance standards and should make it possible to unlock the benefits of data in the context of energy system integration (see Chapter 4 'Energy supply'). The EPBD recast should be implemented swiftly so that national databases on the energy performance of buildings are established and the role of the EU Building Stock Observatory is reinforced. The data collected should be based on actual performance and go beyond the energy parameters, so it includes at least environmental quality, thermal comfort, sufficiency and circularity, as well as building resilience aspects. This should help improve the policy narratives accompanying building decarbonisation measures (see also Chapter 11 'Whole-of-society approach').

7.1 Scope and sectoral assessment framework

Scope

This chapter covers all residential and tertiary buildings. In tracking progress, it covers all direct emissions from fuel combustion in buildings, and energy-related emissions from the agricultural sector. Emissions from district heating and the production of electricity that is used in buildings are covered in the energy supply sector. Emissions from the construction and maintenance of buildings, and F-gases from heating and cooling installations, are reported in the industry sector. For policy consistency, this chapter also considers the role of buildings in the broader energy system.

Greenhouse gas emission reductions required in buildings to reach climate neutrality

Under the 1.5TECH and 1.5LIFE scenarios of the European Commission's in-depth analysis accompanying the 2018 LTS 'A clean planet for all' (EC, 2018e), and under the more recent MIX scenario of the 2020 climate target plan impact assessment (EC, 2020s), buildings sector emissions are reduced by approximately > 95 % by 2050 compared with 2005. The very few remaining emissions in 2050 need to be counterbalanced by emission removals to achieve overall climate neutrality. This is also in line with the latest IPCC AR6 illustrative mitigation pathways, which show deep reductions from buildings in most scenarios by 2050 (IPCC, 2022b).

Assessment framework for the buildings sector

The following building blocks were identified to achieve the required GHG reductions in the buildings sector by 2050.

Outcomes. Based on the latest IPCC assessment report, the following two outcomes were identified as a basis for tracking progress and policy consistency in the buildings sector (IPCC, 2022b):

- **lowering energy and material demand**
- shifting towards **efficient and decarbonised energy supply**.

Mitigation levers. To achieve these outcomes, and building on the IPCC approach, the assessment of the EU policies relevant to buildings follows the sufficiency, efficiency, renewables framework (IPCC, 2022b). **Sufficiency** can be understood as reducing the demand for energy services and materials, often through better use of existing space or the building materials, **efficiency** as continuous short-term marginal technological improvements, and **renewables** as reducing the environmental impacts of supplying energy and materials.

In this context, the following levers for the contribution of buildings to the EU's overall GHG emission reductions have been identified.

— **Deep retrofits and zero-emission new buildings.** Thermal efficiency retrofits of existing envelopes should be followed up by replacing the heating, ventilation and air conditioning and backed up with demand-side measures through digitalisation and the integration of renewable energy, retrofits and new builds in line with zero-emission building standards, in other words buildings with very high energy performance. The remaining energy demand should be covered mainly by local RESs.
— **Heat pumps.** Switch fuel to renewable heating and cooling through heat pumps, and highly efficient district heating, solar thermal, geothermal and sufficiency-led cooling solutions such as indirect evaporative cooling.
— **Energy and material sufficiency.** Reduce demand for space and resources, for example by downsizing dwellings and increasing co-habitation. Make better use of available floorspace rather than construct new buildings.
— **Sustainable construction.** This has a strong link to material sufficiency. Consider and reduce buildings' embodied carbon and emissions, notably through, for example, extending the lifespan of existing buildings while increasing the intensity of building use, reducing the amount of materials required for each unit of newly built floor area (material efficiency), use innovative construction materials and reduce the GHG intensity of material production.

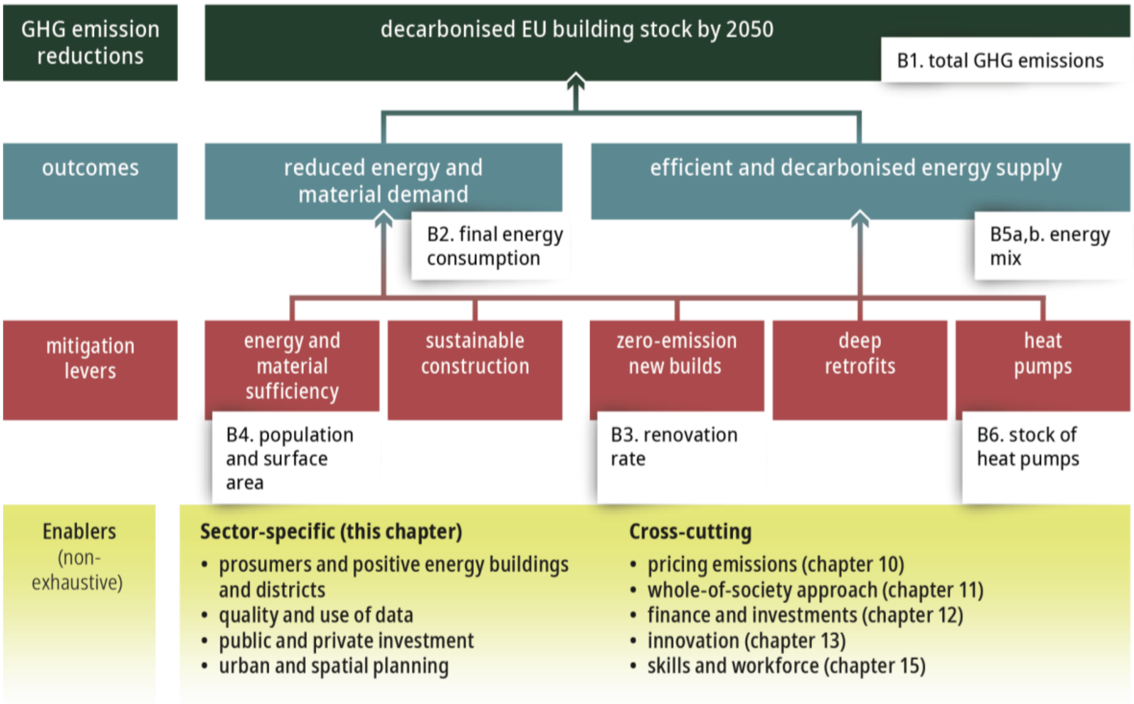
While the EU 2050 vision suggests renewable **hydrogen** and hydrogen blends with fossil gas have a role to play in heating buildings (EC, 2018d), the IPCC warns against it because 'the delivered cost of heat from hydrogen would be much higher than the cost of delivering heat from heat pumps, which could also be used for cooling. Repurposing gas grids for pure hydrogen networks will also require system modifications such as replacement of piping and replacement of gas boilers and cooking appliances, a factor cost to be considered when developing hydrogen roadmaps for buildings. There are also safety and performance concerns with domestic hydrogen appliances … scenarios assessed show a very modest role for hydrogen in buildings by 2050' (IPCC, 2022g).

Enabling conditions. In addition, seven enabling factors have been identified as key to at least one of the mitigation levers described above. They are finance and investments, quality and use of data, prosumers and positive energy buildings and districts, pricing emissions, skills and workforce, whole-of-society approach and innovation. Some of these enabling conditions are assessed in other chapters throughout the report, as shown in Figure 46. The four sector-specific enablers addressed in this chapter are:

— **urban and spatial planning**, for example design of urban and rural settlements enabling reduced demand for floor space, faster deployment of renewables and better adaptive capacities;
— **prosumers and positive energy buildings and districts**, for example adapting electricity grids through infrastructure investment facilitating access to the grid, and enabling buildings to have an active role in electricity system reliability (demand response) through digital and smart solutions integrating energy storage systems, such as on-site batteries and seasonal heat storage;
— **quality and use of data**, for example improving the availability, quality and use of EPCs, digitalising buildings data systems, and integrating data on the multiple benefits of building retrofits into investment decision-making;
— **public and private investment**, for example better use of public funds with a focus on additionality and alleviation of negative socioeconomic impacts; technical assistance and one-stop shops for the crowding-in of private funding; support to sufficiency; and fiscal incentives led by a just transition.

The assessment framework for the buildings sector, including the selected indicators to track progress for this sector (see white boxes), is shown in Figure 46.

Figure 46 Assessment framework for the buildings sector



Source: Advisory Board (2024).

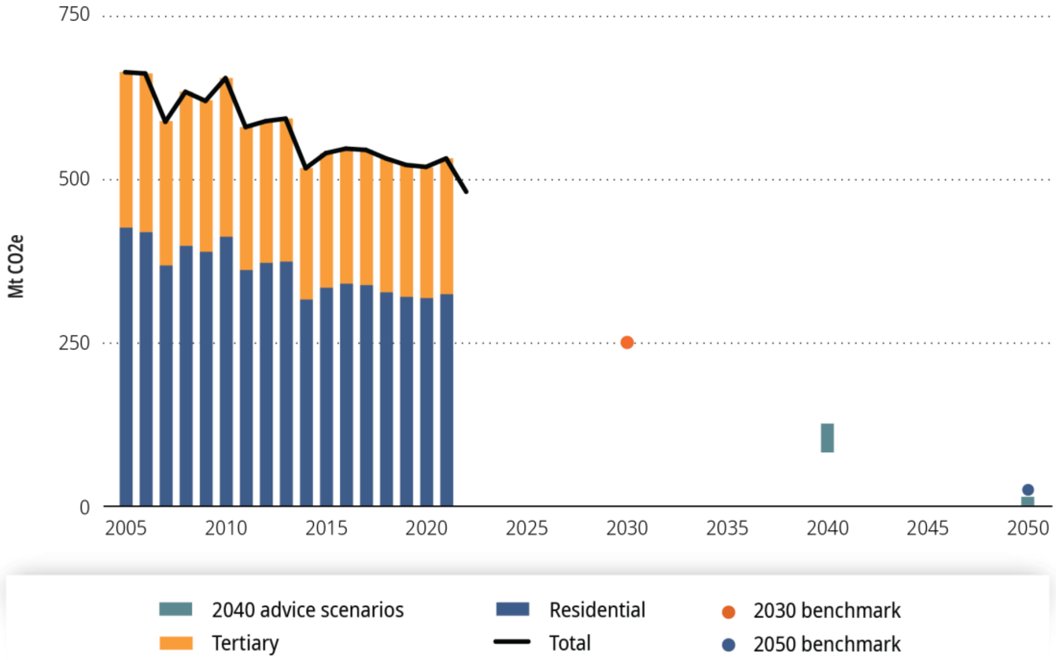
7.2 Emission reduction progress

GHG emissions in the buildings sector ([30]) decreased by 27.5 % (– 11 Mt CO_2e per year on average) between 2005 and 2022. Despite consistent emission reductions since 2005, the sector is not on track compared with the European Commission scenarios that underpin the EU 2030 climate target. The buildings sector's contribution would require the average rate of GHG emission reductions to almost triple in 2023–2030 (to – 31 Mt CO_2e per year) compared with 2005–2022 (see Figure 47).

The emission reduction so far is primarily a result of decarbonising the energy mix and in particular a reduction in the use of oil products (Eurostat, 2023e). Energy is being used more efficiently in buildings (see indicator B4 below), but these efficiency gains are counteracted by shrinking household sizes, more floor area per person (see indicator B3), more electric appliances and increased demand for energy services driven by economic activity. The emission reductions required from the buildings sector by 2030 can be achieved through an accelerated deep energy retrofit of the European building stock in combination with a rapid switch from to efficient, non-fossil heating and cooling technologies.

([30]) This refers to emissions from energy use in the residential sector, the commercial sector (which includes institutions and public services) and agriculture. Although agriculture is not the focus of this chapter, these agricultural emissions are included for comparability with the European Commission analysis, which aggregates energy-related emissions from the three sectors. According to the EU GHG inventory, agriculture has accounted for 6–7 % of these emissions historically.

Figure 47 Indicator B1 – overall progress in reducing GHG emissions from the EU buildings sector



Notes: Historic data refers to GHG emissions from residential and tertiary sectors (including energy use in agriculture) from the EU GHG inventory. 2030 benchmark refers to residential & tertiary CO_2 emissions from the Fit for 55 MIX scenario. 2040 advice range refers to energy-related CO_2 emissions in the residential and tertiary sector in the scenarios that underpin the Advisory Board's 2040 advice, with original data (which does not include agriculture) adjusted upwards for comparability with the other series (assuming the share of agricultural energy in overall emissions from these sectors remains at the 2021 level as per GHG inventory). 2050 benchmark refers to residential and tertiary sector CO_2 emissions reported in the in-depth analysis accompanying A Clean Planet for All, recalibrated for EU27.

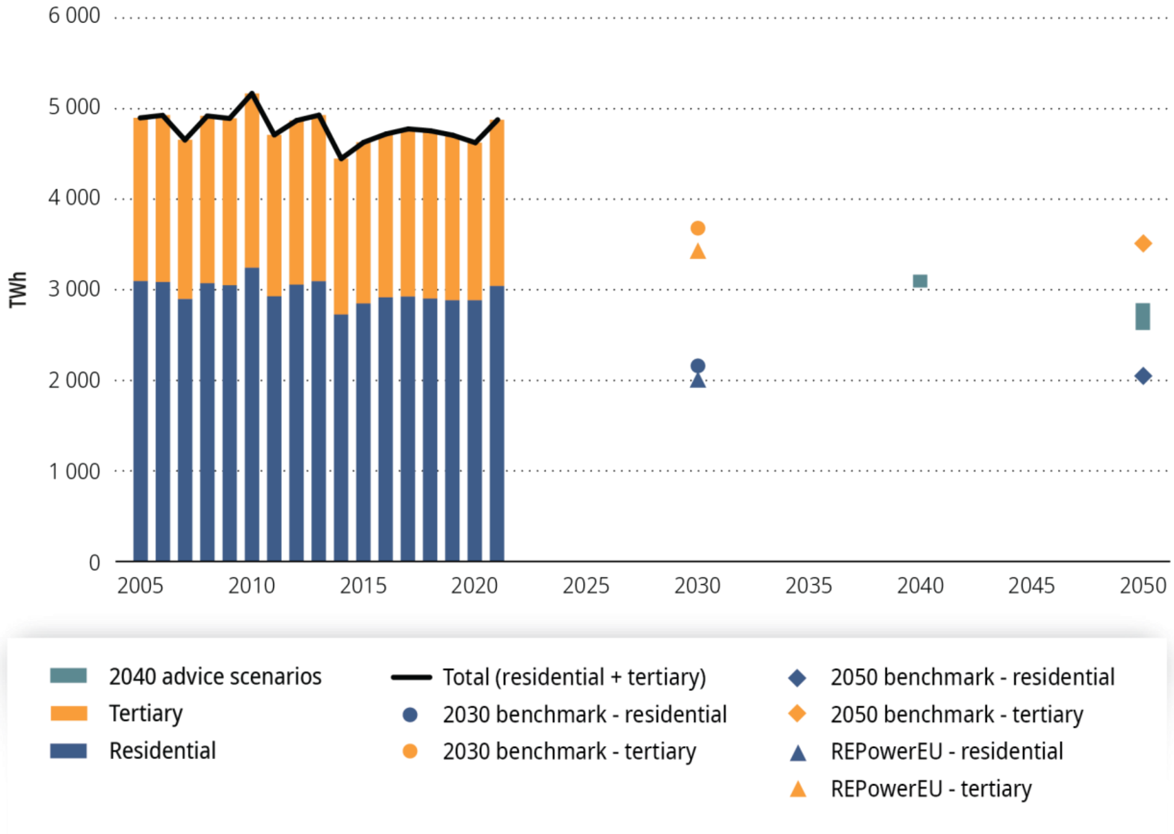
Sources: EU GHG inventory (EEA, 2023f), Fit for 55 MIX scenario (EC, 2021v), Advisory Board 2040 advice scenarios (2023d), In-depth analysis accompanying A Clean Planet for All (EC, 2018e) (Figure 91)

7.3 Outcome 1: reduced energy and material demand

Final energy demand in residential and tertiary buildings does not show a clear declining trend in Figure 48. Significant energy demand reductions are required by 2030 to meet benchmarks consistent with the EU's 2030 climate target underpinned by the REPowerEU plan. The Fit or 55 benchmark would require residential use to fall by 29 % by 2030 compared with the 2021 level, and by 18 % in the tertiary sector. Greater reductions (– 34 % and – 23 % respectively) are envisaged in the REPowerEU scenario. The reduction level consistent with the revised EED lies somewhere between these two levels (EC, 2022a; EU, 2023a) ([31]).

([31]) According to the REPowerEU staff working document (European Commission, 2022a), the Fit for 55 proposals are consistent with reducing final energy consumption (from all sectors) by 9 % in 2030 compared with a reference scenario. The European Commission REPowerEU plan would increase this to 13 %. The revised EED sets a target of 11.7 % compared with the projections of the EU reference scenario, but does not specify the contribution of the residential and service sectors.

Figure 48 Indicator B2 – final energy consumption in the residential and tertiary sectors



Notes: Tertiary sector final energy consumption includes energy from commercial, public, and agricultural buildings. 2030 benchmark and REPowerEU figures refer to energy consumption consistent with the Fit for 55 and REPowerEU scenarios. 2050 benchmark based on the MIX scenario from the Climate Target Plan. All sources include ambient heat harnessed by heat pumps.

Sources: Eurostat energy balances (2023b), REPowerEU staff working document (EC, 2022p) (Table 10), Climate Target Plan (EC, 2020s).

Despite the need to reduce buildings' energy demand, most EU Member States are not on track to meet their energy use targets for 2030 as set in their respective long-term renovation strategies (EC, 2023ba). Regarding the **drivers of energy use by residential and tertiary buildings**, a number of studies suggest that the stability of overall consumption over the past 20 years is in fact due to a variety of countervailing factors, with increased demand related to rising incomes and activity, broadly cancelled out by efficiency improvements driven by energy retrofits, and efficient appliances and new buildings. In the residential sector, Tsemekidi Tzeiranaki et al. (2019) find that energy consumption up to 2016 declined slightly in spite of rising population and incomes, smaller household sizes and increased floor area per capita, aided in part by climatic conditions (fewer heating degree days). They also find that energy efficiency in the residential sector improved, even after adjusting for climatic and economic effects. However, the approximate balance between increased demand and improved efficiency appears to have broken down in more recent years. Reductions in energy consumption have slowed since 2016 (particularly in the residential sector) and most recently appear to have reversed, with energy consumption increasing sharply in 2021. Final energy consumption for heating has fallen steadily since 2005, with the reduction reaching 16 % by 2019 (Odyssee-Mure project, 2023). After controlling for climate effects, this reduction falls to 8 %, suggesting that around half of it is due to a warming climate ([32]). The reduction in energy consumption for heating has far outweighed the increased consumption for cooling in absolute terms (Odyssee-Mure project, 2023). While cooling represents a modest fraction of energy use in buildings today, it is increasing, and studies suggest that it could account for 8–9 % of energy use in residential and non-residential buildings by 2050 (EEA, 2022b).

Regarding material demand, according to the European Commission, the material demand in the EU buildings sector driven by construction activities accounts for about 50 % of all extracted material and is responsible for over 35 % of the EU's total waste generation. GHG emissions from material extraction, manufacturing of construction products, and construction and renovation of buildings are estimated at 5–12 % of total national GHG emissions across the EU. Greater material efficiency could save 80 % of those emissions (EC, 2023c).

Lever: deep retrofits and zero-emission new builds

Improving the energy performance of the existing buildings is a key driver of reduced final energy consumption but its pace is not sufficient to meet the EU climate targets by 2030 and 2050.

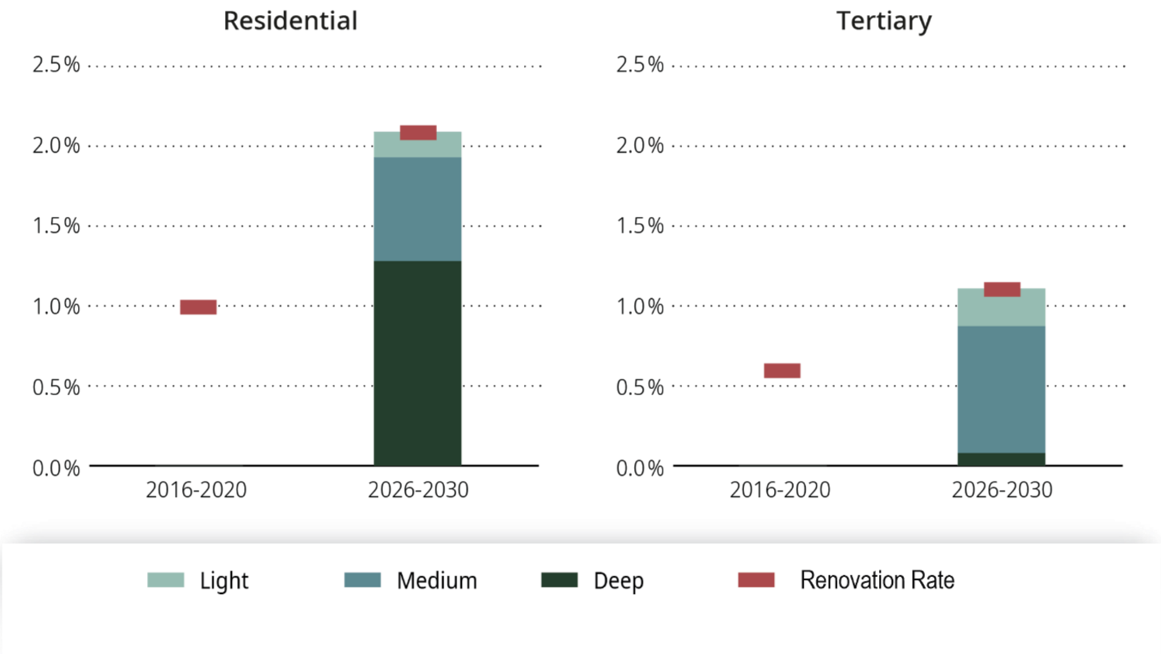
Around three quarters of EU buildings were built before 1990 (EC, 2021i). With the building stock's renewal rate at 1.2 % annually, most of the buildings (85–95 %) standing today in the EU will be there also in 2050. Around 75 % of buildings in the EU are energy inefficient according to current standards (EC, 2021j). Buildings in EPC class A represent a negligible share of the EU building stock (EC, 2021al). Whereas a significant portion of EU buildings are renovated to some extent every year, the depth of the renovation is often very limited. The currently observed retrofits across the EU are dominated by shallow retrofits: incremental changes to energy performance as part of building renovations (EC, 2022f). Only 0.2 % of residential buildings (and 0.3 % of non-residential buildings) are deeply renovated each year. Deep energy retrofits go beyond upgrading of a heating source, and transform the building to zero-emission standard while also improving the occupants' well-being, the dwelling's resilience and the integration of the energy system. To achieve the – 55 % objective, the average renovation rate should be doubled (EC, 2020s) as presented in Figure 49 (indicator B3) below.

The energy retrofits may be part of wider non-energy renovations to address comfort, safety or maintenance issues. Around 15 % of Europeans live in dwellings with leaking roofs or damp walls, floors or foundations, and between 5 % and 39 % live in buildings with rot in the window frames or floors (EEA, 2022a). The available building data is insufficient to indicate the respective energy and non-energy aspects of building renovations, including the depth of energy retrofits and the renovation rate itself (see Section 7.5).

The renovation wave strategy, the EPBD in force and the expected changes under the EPBD recast are intended to encourage deeper energy renovations. The changes included in the revised EPBD (EC, 2021ac) – for instance the introduction of minimum energy performance standards for existing buildings, and tools supporting staged deep renovation, such as a renovation passport towards the zero-emission standard (see Box 4) – go in the right direction in terms of the decarbonisation of buildings. It is too early, however, to comment on the ambition of the EPBD recast or on the delivery of new measures and their overall effectiveness. Its timely implementation will be of the essence, supported by the EU ETS 2. The price signals of the EU ETS and the EU ETS 2, will increase considerably should the progress with the deep retrofits be too slow (see Chapter 10 'Pricing emissions and rewarding removals').

([32]) Controlling for climate effects involves assuming that the number of heating and cooling degree days stands at the long-term average, and adjusting heating and cooling demand accordingly.

Figure 49 Indicator B3 – residential annual renovation rate and depth



Notes: 2016-2020 benchmark data is based on historic data, with 2026-2030 renovation rates and depth for residential and tertiary sectors based on Type 1 renovations (i.e. 'improvement of thermal integrity of buildings through renovation of the building shell') from the MIX scenario of the Climate Target Plan impact assessment. A comparable breakdown of renovation depth is not available for the 2016-2020 benchmark, with only the total renovation rate available.

Sources: Climate Target Plan impact assessment (EC, 2020s) (Figure 53 and Figure 54)

Box 4 From nearly zero-energy to zero-emission buildings

The EPBD recast replaces the **nearly zero-energy** building standard with **zero-emission buildings**, which becomes the new standard for new buildings, the level to be attained by a deep renovation as of 2030 and the vision for the building stock in 2050. It defines a zero-emission building as 'a building with a very high energy performance in line with the energy efficiency first principle, and where the very low amount of energy still required is fully covered by energy from renewable sources at the building or district or community level where technically feasible (notably those generated on-site, from a renewable energy community or from renewable energy or waste heat from a district heating and cooling system)' (EC, 2021ac).

Nearly zero-energy building remains the standard for new buildings until the application of the zero-emission building standard, and becomes the level to be attained by a deep renovation until 2030 (EU, 2010a). It does not require that RES cover the entirety of building energy needs. The specific performance requirement expressed by a numeric indicator of primary energy use in kWh/(m2/y) are defined by the EU Member States.

Ambitious standards underpinned by robust calculation methodologies for zero-emission new builds are urgently needed.

From 2021 all new buildings should be nearly zero-energy under the EPBD in force. The nearly zero-energy buildings requirement has been a strong efficiency standard at the EU level, but there is no uniform approach to its implementation across the EU Member States (D'Agostino et al., 2021a; Tagliapietra et al., 2019) ([33]). The standard is a cost-optimum-driven benchmark level of energy performance (kWh/m^2/y) per building type depending on the climatic zone as established by the European Commission (EC, 2016a). A recent assessment of national implementation shows that levels applied in practice are generally lower than those set out by the European Commission, because, among other reasons, different Member States apply different methods to calculate energy flow (D'Agostino et al., 2021a). Moreover, performance requirements of new buildings do not reflect the best available techniques, new materials, behavioural aspects of energy consumption and an integrated approach to building construction (D'Agostino et al., 2021a; Economidou et al., 2020; IPCC, 2022b). The European Commission's proposal for a revised EPBD (EC, 2021ac) requires all new buildings to be zero-emission as of 2030 (see Box 4). The actual **ambition of the revised standards** for new buildings will depend on thresholds of total annual primary energy use and the corresponding calculation methodologies yet to be set out. Energy demand variations due to occupants' behaviour can be significant, so energy performance measurement is more accurate if based on actual consumption, that is, real-world behaviour and building performance rather than a theoretical value, especially when the operation phase is the critical contributor to the total carbon emissions (Zhang and Asutosh, 2023). Advanced digital building management systems offer such dynamic measurements and help bridge the gap between design goals and actual building energy performance (IPCC, 2022b).

The EU needs better long-term planning of its building stock decarbonisation.

The need for better building data and control through digital tools stems also from the findings on the **long-term renovation strategies** for building stock decarbonisation by 2050 required under the EPBD. Such long-term roadmaps, if properly developed, can address the need for careful planning of building renovations (see for example Re Cecconi et al., 2022; Salvia et al., 2021). However, according to the European Commission, the long-term renovation strategies are not robust enough, so 'there is a lack of a clear pathway to deliver on climate neutrality [and] lack of a coherent framework to allow Member States to develop and plan their building decarbonisation' (EC, 2021j). The level of ambition of the strategies is not always in line with the 2050 decarbonisation goals (EC, 2023ba). To improve the long-term strategic planning for building stock decarbonisation under the EPBD, the EU can rely on more harmonised reporting, better planning, and better building data and control through digital tools (Pasichnyi et al., 2019; Salvia et al., 2021) as part of the national building renovation plans ([34]) under the EPBD recast. Such improved long-term planning and reporting could boost sufficiency measures, for example through bioclimatic design of buildings and efficient consumption of space (IPCC, 2022b), and integration of multiple benefits of building retrofits including better indoor air quality, disaster prevention and protection against climate-related hazards. It has to be underpinned by capacity building for municipal administrations, funding identification and coordination within multilevel governance as part of EU climate governance delivery mechanisms (Salvia et al., 2021 see also Chapters 14 'Climate governance' and 15 'Labour, skills and capacity building').

Lever: energy and material sufficiency

Reduction of demand for energy services and floor space has multiple benefits beyond emission reduction, but its potential is largely untapped across the EU. The EU should encourage sufficiency both in the pre-use phase (e.g. through urban and spatial planning) and in buildings use (e.g.

([33]) For example, the average non-renewable primary energy demand for a new single-family houses varies from as low as 15 kWh/m2/y) to 95 kWh/m2/y in different Member States, with an EU-level average of 52 kWh/m2/y (EC, 2023ba).

([34]) Article 3 of the EPBD recast changes the term 'long-term renovations strategies' to 'national building renovation plans'.

through digital solutions, sufficiency-led progressive housing taxation, and adequate energy tax rates under the ETD and carbon price under the EU ETS 2.

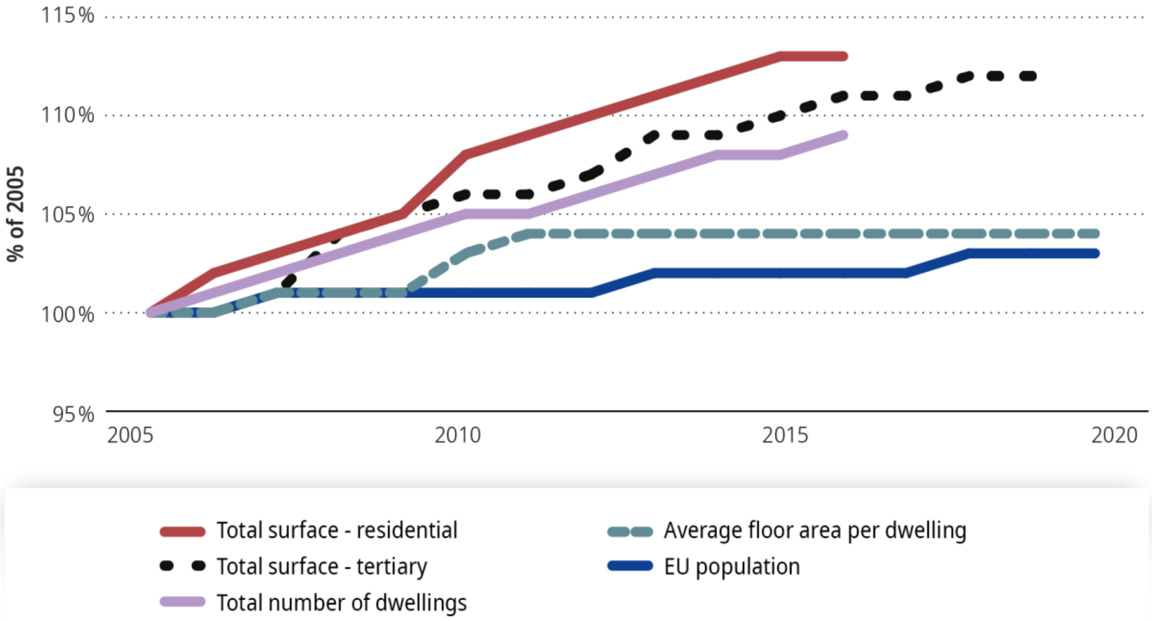
There is a growing scientific consensus regarding the untapped benefits of **reduction of demand for energy services and building materials**, in other words energy and material sufficiency (IPCC, 2022b). Sufficiency-led policies that aim to make better use of existing buildings (Gaspard et al., 2023) can address urban challenges such as energy security, air pollution, ageing populations, social alienation and demographic pressures on (Hook et al., 2023; JRC, 2021c, 2019a; Zannakis et al., 2019). In terms of energy savings, policies focusing on energy sufficiency complement energy efficiency policies (Bertoldi, 2022).

By encouraging cohabitation and higher density per unit of surface area, for example through spatial planning, building codes and taxation, sufficiency measures help to reduce the demand for new accommodation and thus reduce the sector's pressure on resources (see for example Berrill et al., 2021; IRP, 2020; Ivanova and Büchs, 2022). At the city level, compact cities and nature-based solutions, such as for cooling services, can be part of structural sufficiency (Bibri 2020; EEA 2022g) (see also 'Enabling condition: urban and spatial planning' in Section 7.5 below). Building occupants' behaviour driving energy and resource savings can be encouraged by digital tools, such as smart meters, and could be incentivised by innovative policy measures, for instance energy saving feed-in tariffs and personal carbon allowances (Bertoldi, 2022).

Looking at buildings use in the EU, there is no sign of energy and material sufficiency. The trend in building use in recent decades, notably fewer people occupying bigger dwellings, has placed upward pressure on energy consumption and emissions, as Figure 50 demonstrates. Although the total population increase has been modest (+ 3 % since 2005), there have been greater increases in the average floor space per dwelling (which currently stands at 90 m^2) and a reduction in average household size (from 2.4 people in 2010 to 2.3 people today). Between 2020 and 2021 almost all Member States increased their floor area (+ 3 % on average; EC, 2023). The annual number of dwellings for which building permits were granted in the EU increased by a factor of more than 1.3 between 2010 and 2022 (forthcoming).

EU policies do not explicitly focus on energy and material sufficiency in buildings; see for example the renovation wave strategy (EC, 2020b). Moreover, energy price interventions available to EU Member States under the European Commission's State aid guidelines (EC, 2022i), including fossil fuel subsidies (see Section 12.5), and the ETD (see Section 10.5) have been muting financial incentives for sufficiency measures (see for example ESABCC, 2023a). Accordingly, the first round of NECPs have only marginally included building-related sufficiency measures (Zell-Ziegler et al., 2021). Regarding the most recent EU policies, the revised EED and the EPBD recast include provisions that encourage sufficiency, such as consumer information and empowering programmes (EU, 2023e). The upcoming implementation of the EU ETS2 and the ETD revision could also provide sufficiency incentives.

Figure 50 Indicator B4 – population and surface area of homes and businesses



Notes: Data on total number of dwellings and total residential area is only available until 2016, and fragmented.

Sources: European Building Stock Observatory (EC DG Energy, 2023) (total surface – residential, total number of dwellings), Odyssee database (Odyssee-Mure project, 2023) (average floor area per dwelling, total surface – tertiary excluding agriculture), Eurostat (2023) (population, average household size).

Drive sufficiency through housing taxation.

In addition to EU-led measures, national and subnational authorities play a role in driving sufficiency through housing taxation. A recent analysis of the EU Member States' fiscal systems indicates a low level of recurrent property taxation combined with significant tax deductibility for mortgage interest payments, which is often not capped. A significant fraction of the tax income from real estate is from transaction taxes (OECD, 2022). Current taxes favour homeownership for high-income households and indeed increasing home sizes with rising income. They lead to large wealth gains for property owners, and distort households' decisions (JRC, 2019). They adversely affect the efficiency of land and floor space uses and the supply of affordable housing (OECD, 2022). Housing taxation may also be too rigid to encourage residential mobility, for example through transaction taxes and the failure to update property values for recurring taxes, which both constitute tax incentives to stay in large residences even when a family becomes smaller as children or spouses move out (DIW, 2021). Housing taxation also has sizeable distributional impacts (OECD, 2022) and may affect the vulnerability of lower-income households ([35]) (see Chapter 11 'Whole-of-society approach'). Reduced transfer taxes, transfer tax waivers, regular revaluation of taxable values and bonus payments for older couples who sell their houses have been proposed as measures to increase the availability of housing for younger families (Lorek and Spangenberg, 2019; Thomas et al., 2019. The OECD also suggests using housing taxation to provide incentives for energy efficiency upgrades. Both the opportunities and the risks of housing taxation reforms have been recognised in the European Semester process, in which the European Commission

([35]) Lower-income households often live in poorly insulated dwellings and spend a large share of their income on energy and housing. This means they are disproportionately exposed to carbon taxes and stringent building standards (see for example Muellbauer, 2023).

found that 'shifting part of the tax burden from labour to other types of taxes, including environmental and immovable property taxation, while duly taking account of the distributional impact of such a shift, would support the green transition and boost sustainable growth and job creation' (EC, 2023n). Land value taxation ([36]) is also linked to enhanced equity and efficiency of property taxation and may consist of green variants such as split-rate taxes ([37]) that encourage greater urban density and hence boost sufficiency (Muellbauer, 2023; OECD, 2022; Schwerhof et al., 2022). The links between housing taxation, EU climate mitigation efforts and equity need further examination, with a view to guiding Member States' fiscal choices.

Lever: sustainable construction

EU policies do not yet sufficiently leverage resource efficiency and circularity, including extending buildings' lifespans and increasing the intensity of building use, to address embodied carbon and emissions from buildings.

Extending buildings' lifespans and improving building use are among the best ways to lower embodied emissions from buildings (EEA, 2022i; Hertwich, Edgar et al., 2019; IPCC, 2022c, Saenz de Guinoa et al, 2022) and turn parts of the building stock into a temporary carbon sink. In addition, opportunities for material efficiency in the building and construction sector exist at various other levels, with design being one of the key points for intervention. Design is shaped by building codes, which in turn reflect the applicable building policies.

Better building design could address EU buildings' rapidly increasing cooling needs. Use of thermochromic energy-efficient building coating (see for example Butt et al., 2021 and green roofs and facades are among sustainable solutions to this challenge, as they reduce both the heat gains of buildings and the heat island effect (Akbari et al., 2016; EEA, 2021a; IPCC, 2022b). Furthermore, significant life cycle GHG emission reductions are linked to compact, low-rise buildings (IPCC 2022b; Pomponi et al.) and (re)use of recycled and new materials with lower energy and emission intensity than normal ones, for instance replacing concrete with wood and lowering the share of Portland cement thanks to the use of alternative binding materials (IRP, 2020). In the choice of materials, green public procurement, recycled content mandates and virgin material taxation have a role to play (IRP, 2020), and could be facilitated by EU policies (see also Section 5.3).

The EPBD recast is building on an assumption that 'minimizing the whole life-cycle greenhouse gas emissions of buildings requires resource efficiency and circularity', with a new requirement to consider the life cycle global warming potential of new buildings (EC, 2021ac). The life cycle requirement is reinforced by the proposals for the new construction products regulation (EC, 2022x) and for the ecodesign regulation establishing a framework for sustainable products (EC, 2022u). The proposed acts are underpinned by the EU's CEAP 2 (EC, 2020g) and include a mix of policy instruments, mainly regulation and information including standards, labelling and data harmonisation.

The inclusion of embodied GHG emission considerations in the EU building policy framework is a very promising development in terms of 2050 climate neutrality objectives. If the new legal framework proves to be sufficiently robust, leading to timely implementation of standards that have no implementation loopholes and cover key GHG-emitting activities, it can drive the material sufficiency aspect of building

([36]) Land value taxation is a type of property taxation that falls on the unimproved value of land, as opposed to standard property taxation, which takes the total value of property, including structures built upon it, as the tax base (see for example Barbosa and Skipka, 2019).

([37]) According to the OECD (2022), 'split-rate taxes are a hybrid of pure land value taxes and regular recurrent taxes on immovable property, where both the land and improvements on the land are taxed, but land is typically taxed at a higher rate'.

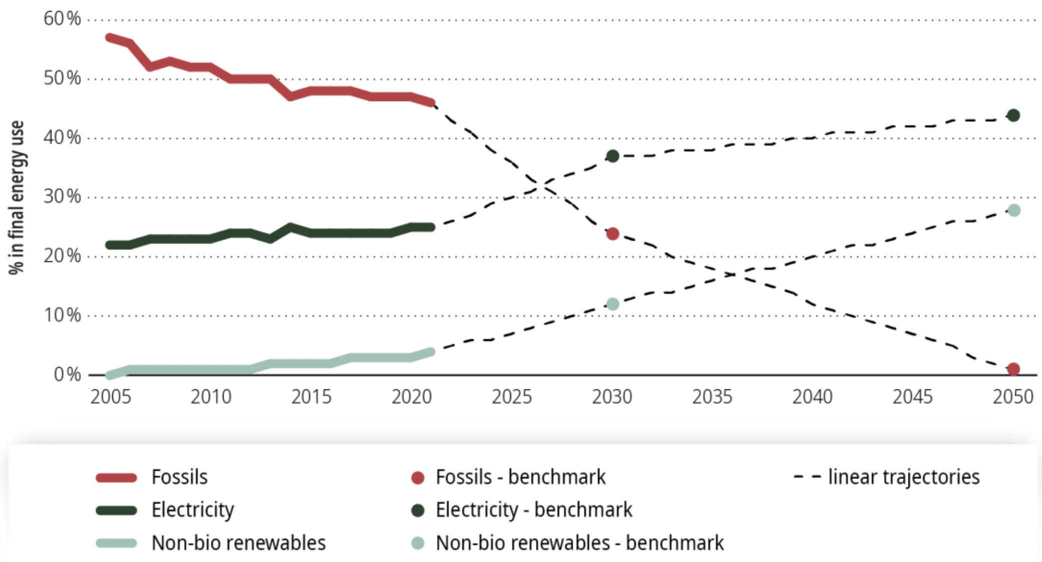
decarbonisation. For this to happen, significant learning and know-how need to be developed along the buildings value chain (see e.g. Michalak and Michałowski, 2022); see also Chapter 15 'Labour, skills and capacity building'.

7.4 Outcome 2: efficient and decarbonised energy supply of buildings

Space heating and water heating represent around 80 % of the energy consumption of residential buildings in the EU (Eurostat, 2023h). Space heating relies mostly on direct use of fossil fuels (EC, 2021j) and is the largest fossil gas consumer in the EU (EC, 2021j). While the share of coal and oil products in residential buildings' consumption has been falling since 2005, no such trend has been observed for fossil gas.

The share of fossil fuels in the energy mix has been declining steadily since 2005, as shown in Figure 51. However, at the current pace (– 0.6 pp per year in 2017–2021), fossil fuels would still account for 42 % of the mix in 2030. The pace of reduction needs to quadruple (to – 2.4 pp per year in 2022–2030) to be consistent with the European Commission scenarios underpinning the 2030 target. Accelerating the phase-out mainly requires a large-scale replacement of fossil fuel boilers by heat pumps, as reflected in the increasing shares of electricity (from + 0.1 pp per year in 2017–2022 to + 1.3 pp per year in 2022–2030) and non-bio renewables, which include ambient heat harnessed by heat pumps (from + 0.3 pp per year in 2017–2021 to + 1 pp per year in 2022–2030). The share of bioenergy has increased from 13 % in 2005 to 17 % in 2012, but has been relatively stable since. Similarly, the share of district heating was relatively stable around 8–9 % in 2005–2021. The shares of both bioenergy and district heating would remain stable until 2050 under the European Commission's decarbonisation scenarios.

Figure 51 Indicator B5a – energy mix in the residential sector



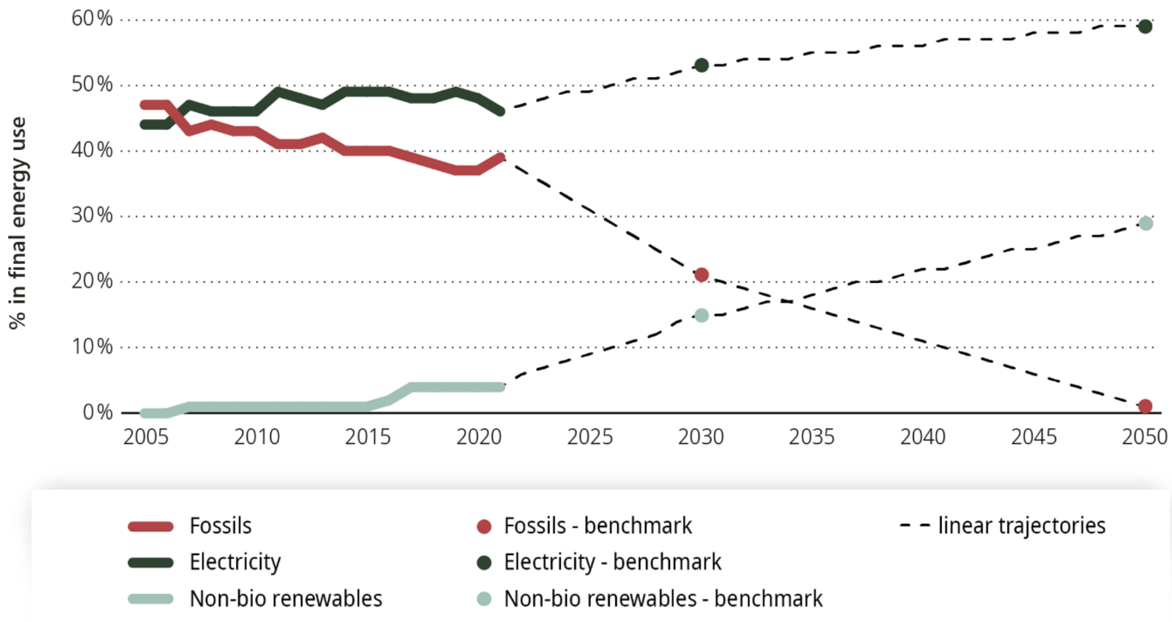
Notes: Benchmark data is based on the MIX scenario from the Climate Target Plan impact assessment. The linear trajectories are shown to increase the readability of the figure, but do not imply that the Advisory Board recommends a linear trajectory towards the benchmarks.

Sources: Eurostat energy balances (2023b), Climate Target Plan impact assessment (EC, 2020s) (Figure 55).

A similar observation can be made about the tertiary sector (see Figure 52, indicator B5b). The share of fossil fuels has declined by 18 % since 2005, although the rate of decline has slowed down in recent years (on average – 0.1 pp per year in 2017–2021). The phase-out needs to accelerate (to, on average, – 2 pp per year in 2022–2030 and – 1 pp per year in 2031–2050) to be consistent with the European Commission scenarios underpinning the EU climate objectives. Under these scenarios, they would mainly be replaced by electricity and non-bio renewables (e.g. ambient heat), whereas the share of bioenergy and district heating would remain relatively stable until 2050.

The RED III (Article 15a) introduced a new indicative national 2030 benchmark of at least 49 % of renewable energy in the buildings sector (EU, 2023f). To achieve the 2030 climate targets, RES roll-out and fossil fuel phase-out need to accelerate.

Figure 52 Indicator B5b – energy mix in the tertiary sector



Notes: Benchmark data is based on the MIX scenario from the Climate Target Plan impact assessment. The linear trajectories are shown to increase the readability of the figure, but do not imply that the Advisory Board recommends a linear trajectory towards the benchmarks.

Sources: Eurostat (2023b), Climate Target Plan impact assessment (EC, 2020s) (Figure 55).

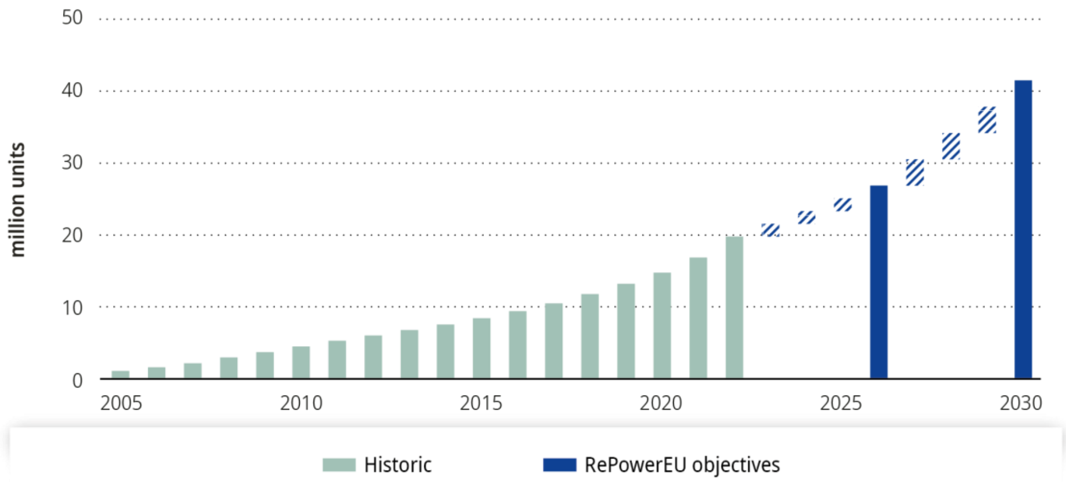
Lever: heat pumps

So far, EU policies have been moderately successful in driving non-fossil fuel switching. Scaling-up of heat pumps and other sustainable heating and cooling sources should accelerate.

Fossil fuels and biomass dominate heating sources in the EU's building stock (EC, 2021j), which is a problem from climate and wider environmental perspectives (see also Chapter 4 'Energy supply' and Chapter 9 'Land use, land use change and forestry'). Net zero transition requires the EU to foster direct electrification of buildings (see Chapter 4 'Energy supply'). This process can be driven by heating source replacement, such as a heat pump taking place of a gas boiler. Heat pumps can be used individually or in conjunction with heat networks and can provide both heating and cooling. This latter function is especially important in the light of experienced and expected rises in temperatures. Heat pumps operate best in highly efficient buildings; hence, their installation should usually be accompanied by insulation and other measures characterising deep building retrofits. Heat pumps can be combined with on-site renewable electricity generation such as solar PV panels and can be backed up by storage solutions (IRENA, 2022b). Their fast and wide-scale roll-out across the EU is a necessity to achieve climate neutrality by 2050. As highlighted by the IPCC, this means 'banning the sale of new fossil fuel-fired boilers, as well as making heat pumps and very efficient appliances standard technologies' (IPCC, 2022b).

The EU heat pump market has grown significantly since 2015, with an acceleration since 2020 (see Figure 53). If the stock of heat pumps continues to grow at its current rate, the EU is on track to achieve the REPowerEU objective of installing 10 million new units by 2026 (EC, 2022m). However, further acceleration will be needed to meet the objective of 41.5 million units installed by 2030.

Figure 53 Indicator B6 - stock of heat pumps (million units) compared with REPowerEU objective



Notes: Dashed bars extrapolating the annual average growth required to meet REPowerEU objectives.

Sources: European Heat Pump Association (EHPA, 2023), REPowerEU Staff Working Document (EC, 2022p).

So far, however, EU policies have been only moderately successful in driving non-fossil fuel switching. This is because, among other reasons, the ETD and EU State aid rules allow subsidies to fossil gas (see Sections 10.5 and 12.3). EU standards and requirements for boilers, driven mainly by the EPBD and the ecodesign directive, have contributed to a decline in heating energy consumption, thanks to, for instance, efficient fossil gas boilers. Moreover, a recent review of scientific contributions regarding EU energy efficiency policies for buildings by Economidou et al. (2020) points out discrepancies in ambition among Member States' efficiency levels for heating and cooling.

A step change in decarbonisation of heating and cooling has been triggered by the European Green Deal and Fit for 55 package, further reinforced by the REPowerEU strategy. The relevant policy landscape is changing drastically following the revisions of heating and cooling product-specific regulations under the ecodesign and energy labelling framework, the EPBD, the RED II, the EED and the ETD, and new measures such as the emergency measure on issuing permits for renewables under Article 122 of the Treaty on the Functioning of the European Union, reforms under the electricity market design proposals (EC, 2023ar), and the proposals for a Net-Zero Industry Act (EC, 2023ao) and for a Critical Raw Materials Act (EC, 2023ac). Heat pumps are listed among net zero technologies under the Net-Zero Industry Act proposal, and an EU heat pump strategy is under preparation. The European Commission warns that 'without a dedicated EU action plan, 22 million old individual heating appliances and several thousand large old fossil-based heating units are at risk of being replaced by fossil boilers' (EC, 2023aj).

Local heating and cooling planning, newly required under the EED for all municipalities with over 45 000 inhabitants, could become a key tool in shifting to sustainable heating and cooling, provided it is properly implemented and expanded to smaller municipalities, with a sense of urgency reflecting the approaching increases in costs of heating with fossil fuel boilers (see Chapter 10 'Pricing emissions and rewarding removals' and Section 14.3 on the importance of multilevel dialogues).

7.5 Enabling conditions

Enabling condition: urban and spatial planning

The EU should systematically promote the integration of climate change considerations into urban and spatial planning, for instance through land use efficiency, the compact city approach and the better use of existing buildings, leading to reduced energy demand and CO_2 emissions, higher RES deployment, climate resilience and societal well-being.

Urban and spatial planning can bring considerable benefits in terms of increased building and land use efficiency leading to, among other things, reduced demand for floor space, faster deployment of renewables and greater capacities of urban and rural settlements to adapt (Devine-Wright, 2015; Kitzing et al., 2021; Nowak et al., 2022; Wiehe et al., 2020). In cities, spatial planning for compact urban form can enable reduced energy demand and changes in service provision, including walkable neighbourhoods and mixed land use, encouraging socio-behavioural change towards active transport (IPCC, 2022k). Urban and spatial planning can also enable electrification and the integration of energy systems (see Chapter 4 'Energy supply') into urban infrastructure. Finally, the IPCC also points out the potential synergies between several sustainable development goals and sustainable land use and urban planning, such as greener spaces, reduced air pollution, improved access to services and opportunities, and demand-side mitigation including shifts to balanced, sustainable, healthy diets (IPCC, 2022l).

Despite the benefits above, many cities in EU Member States are expanding in a dispersed, low-density manner. Such urban sprawl poses difficulties for sustainable land use and the construction of more compact communities, and result in additional transportation needs (Urban Agenda for the EU, 2021).

Rooted deeply in national and subnational decision-making, spatial planning is generally outside the EU's direct field of competence. Nevertheless, it contributes to and has interconnections with several EU policies and initiatives related to climate change, such as the European Green Deal, biodiversity strategy, forest strategy, soil strategy and Nature Restoration Law, strategy on adaptation to climate change, green infrastructure strategy, EU zero pollution action plan, new European Bauhaus initiative, new European mobility framework and the EED. Urban and spatial planning approaches may influence – either enhance or reduce – the potential of the above policies and initiatives to contribute to climate neutrality. Important current initiatives are the mission on climate-neutral and smart cities (EC, 2021; Huovila et al., 2022) with the recent signing of the first climate city contracts, and the European urban initiative (EUI, 2023) which supports urban areas of all sizes with innovative actions, capacity and knowledge building, policy development and communication on sustainable urban development, including greening cities, constructing and renovating in a spirit of circularity and carbon neutrality, adapting and transforming buildings for affordable housing solutions, and regenerating urban spaces.

The orientation for strategic spatial planning is provided by the *Territorial Agenda 2030 – A future for all places*, which was adopted in 2020 as a strategic framework document to support policy responses for societal transformation towards a carbon-/climate-neutral economy. It underlines the importance of balanced territorial development to deal with climate change, to reduce regional vulnerabilities to climate change and to develop capacities for mitigating and adapting to the impacts of climate change (Ministers responsible for Spatial Planning and Territorial Development and/or Territorial Cohesion, 2021). The territorial agenda 2030 promotes actions for stopping net land take by 2050, sustainable land use, open spaces and public green areas, preventing urban sprawl, restoring degraded land and coastal areas, combating deforestation and implementing green infrastructure. It is important to note that the EU territorial agenda 2030 promotes place-based policies for urban regeneration and sustainable urban planning, and considers the application of different geographic approaches, for example using functional urban areas, cross-border areas or urban–rural linkages. A widely recognised trend in the approaches is the creation of functional planning regions that address such flows as commuting patterns, economic relations, river basins, energy networks and others (Nadin and Fernández-Maldonado, 2023). To this end, it is important to assess the potential impact of all placed-based policies and geographic approaches to sectors that contribute to emissions of GHGs, such as transport, energy, agriculture and buildings. Whereas the principle of a place-based approach can support effective climate change mitigation and adaptation plans, functional urban areas may result in additional car-based mobility and land uptake, and should for this reason be treated with caution.

The EU cohesion policy also has a strong sustainable urban development dimension, which is strongly related to climate. For 2021–2027, the urban dimension of cohesion policy has been strengthened, with its policy objectives focusing on a smarter, greener, more connected and more social Europe and a Europe closer to citizens. A minimum of 8 % of the European Regional Development Fund resources in each Member State must be invested in priorities and projects selected by cities themselves and based on their own sustainable urban development strategies. In particular, the focus on a greener Europe refers to a resilient Europe transitioning from a low-carbon towards a net zero-carbon economy, promoting a clean and fair energy transition, green and blue investment, the circular economy, climate change mitigation and adaptation, risk prevention and management, and sustainable urban mobility.

The EU can further support sustainable spatial planning through sharing good practice, building the capacity of local and public authorities, and disseminating guidelines linked to, for example, the European Regional Development Fund and other cohesion policy programmes (ESPON, 2021), and the European Semester process could encourage Member States to improve their spatial planning. There are several EU funding streams addressing sustainable urban planning, such as Urbact IV (which is co-funded by EU cohesion policy funds and aims to enhance the institutional capacity of public authorities (URBACT, 2023) or the European Urban Initiative (EUI, 2023).

Enabling condition: prosumers and positive energy buildings and districts

Net zero transition requires energy system integration allowing buildings to actively participate in the energy system.

The IPCC highlighted the role of market and business models that encourage energy prosumers ([38]), fostering local energy generation and consumption and allowing buildings to actively participate in the energy system. With regard to energy system integration (see Chapter 4 'Energy supply'), new services (e.g. aggregated load management for demand response, peer-to-peer exchanges, energy services companies) will need to complement and to some extent replace the traditional supply of energy services. In this respect energy communities play an increasingly important role (IPCC, 2022b). New services and energy prosumers are encouraged by the falling costs of building-integrated renewables,

([38]) 'Prosumption exists in numerous types and forms: for example, it can be only one household, a group of tenants in a multi-family building or an energy cooperative with participants from the local community. They can produce renewable electricity, heat or both, and some combine this with supporting the grid infrastructure or providing energy storage. Prosumers can apply different ownership structures and business models, which may be run by volunteers or, in the case of larger projects, by paid staff' (EEA, 2022e).

heat pumps and storage technologies, to enable their wide-scale roll-out (D'Agostino et al., 2021; IPCC, 2022c, Ines et al, 2020).

Building-integrated renewable energy infrastructure makes it possible to generate electricity and heat and export them to local networks when they exceed on-site demands. The positive energy balance can be defined at the building or neighbourhood level and could be promoted in parallel with measures aiming to reduce the GHG emissions from building-related uses (EASAC, 2021a). Positive energy districts and compact neighbourhoods could be built on the basis of a 'wider vision of urban sustainability that foresees innovative solutions for street lighting, urban mobility, waste, and public safety' (D'Agostino et al., 2021a; Zakeri et al., 2022). Such integrated planning will further encourage prosumers, energy communities and other citizen-led contribution to climate neutrality.

Positive energy buildings require the roll-out and use of digital building automation and control systems (IPCC, 2022b) as well as smart grids for energy sharing. Notably, distribution networks (low and medium voltage) and business models need to be adjusted to enable the active participation of positive energy buildings. In addition, stationary electric battery storage can unlock unprecedented levels of demand management (see 'Lever: system integration' in Section 4.3).

EU policies, such as the REPowerEU plan and the renovation strategy, recognise the role of prosumers, energy communities and positive energy buildings in the net zero transition. The EU laws enabling individual and collective prosumers and positive energy buildings include the RED III, the EPBD and its recast, the EED and the EU's internal energy market framework. The total number of prosumers in the EU Member States and the EU is not known, because of monitoring gaps (EEA, 2022e). The fragmented available data suggests that number of prosumers is increasing rapidly in some EU Member States. Regarding prosumer-driven demand response, in 2022 only nine EU Member States had given aggregated residential end users access to the wholesale, balancing and ancillary electricity markets (ACER and CEER, 2022). Reasons include, among others, the inadequate national implementation of the EU laws and persisting market participation barriers (Campos et al., 2020; EASAC, 2021a; EC, 2023ag; Magrini et al., 2020; Moura and Brito, 2019; Reis et al., 2013). Given the slow pace of residential demand-side response (ACER and CEER, 2022), the RED III, the European Commission proposals for a Net-Zero Industry Act and reform of the electricity market's design, and the EU action plan on digitalisation of the energy system could accelerate infrastructure development, enabling prosumers, positive energy buildings and system integration. The newly established Energy Communities Repository (EC, 2023x) and the Rural Energy Communities Advisory Hub (EC, 2023bc) are very welcome in this context.

Enabling condition: quality and use of data

Reliable, granular and comparable data on building performance and the multiple benefits of energy efficiency investment are urgently needed to underpin policy measures.

Data availability and comparability are important for decarbonising the building stock, because data is relevant to several aspects of effective policies, including (i) evidence-based policy development and progress assessment, (ii) leveraged private investment in energy retrofits, (iii) energy system integration, new business models and infrastructure, and (iii) behavioural changes thanks to available information (EEFIG, 2023; IPCC, 2022b; Runge-Metzger and Van Ierland, 2019). Why data matters in EU building decarbonisation can be demonstrated by the EPCs, which can inform building owners and induce them to undertake energy renovation. According to Building Performance Institute Europe, 'there is an increasing reliance on EPC data for tracking the progress and the implementation of renovation policies and funding. Yet the uneven quality and reliability of national EPC schemes, coupled with the lack of public trust in the generic list of recommendations may hinder the goal of the EPC to encourage additional investments in energy efficiency' (BPIE, 2023).

The European Commission's assessment of the first long-term renovation strategies and the NECP progress reports concluded that the required data concerning decarbonisation of buildings provided by Member States varies in nature, which makes it difficult to compare the effect of the different national measures and assess their cumulative and quantitative impact. An additional complexity was detected in terms of some key indicators' definitions (EC, 2023, 2022, see also Section 4.3 under 'Lever: energy efficiency'). There is a consensus among practitioners, academia and policymakers that EU does not have sufficient and comparable information on the energy performance and other linked parameters of its building stock (EASAC, 2021; EC and EEFIG, 2023; JRC, 2021a).

EPC limitations in terms of reliability of data based on the physical properties of buildings has also been highlighted by the IPCC in the context of energy demand driven by occupancy behaviour (IPCC, 2022b). To further improve data relevant to occupancy and demand patterns, there is a need for a 'social science-based research to investigate how buildings with the same EPC differ statistically in terms of their measured consumption' (Ali et al., 2020). The task of filling this data gap can be helped by smart electricity meters that quantify the load patterns of electric appliances, for example by using disaggregation techniques (EASAC, 2021a).

Similarly, better data is needed to underpin the consideration of non-energy benefits, such as comfort, health and reduced energy poverty, in designing energy efficiency programmes so that they are adjusted to the customers' needs and therefore to stimulate demand for building renovation efforts (EC and EEFIG, 2022). According to the Energy Efficiency Financial Institutions Group convened by the European Commission (2022), identifying multiple benefits, collecting data on them and evaluating them strengthen the connection between energy efficiency investing and impact investing, as well as decision-making by financial institutions. Thus it can make investing in buildings' energy efficiency more attractive to private investors (see 'Enabling condition: private investment' below).

The EU policy measures driving the collection and use of this essential data include the EPBD, the Infrastructure for Spatial Information in Europe directive (EU, 2007), non-legislative initiatives such as the EU Building Stock Observatory and Odyssee-Mure database (ADEME et al., 2023), the renovation wave strategy (EC, 2020h) and the EU action plan on digitalisation of the energy system (EC, 2022k). Regarding spatial planning and urban land use efficiency, it is the EU Copernicus programme that provides an insight complementary to the building-level data (EEA, 2023e; Schiavina et al., 2022)

The EPBD recast strengthens the role of the EU Building Stock Observatory as the EU database for data related to building renovation, EPC and smart readiness indicators. Importantly, a step change in this respect could be driven by the EU action plan on digitalisation of the energy system (EC, 2022k), which recognises the need for seamless data exchanges 'supporting smart energy buildings as a source of renewable energy production and flexibility in the energy system, and making the data from buildings available to define business cases for renovation' (EC, 2022k). It includes putting in place a common European energy data space for improving access to, exchange of and reuse of data. These developments are still at early stage of delivery but have significant potential to contribute to decarbonising the building stock across the EU.

Enabling condition: private investment

EU policies need to better leverage private investment in the energy efficiency of buildings and avoid lock-in risks linked to shallow retrofits.

Decarbonising EU's building stock by 2050 requires the scaling-up of private investment to meet estimated additional investment needs of EUR 90 billion per year (EC, 2020h). Estimates by the JRC indicate that across the EU around EUR 15 billion per year are allocated to energy efficiency in buildings (JRC, 2019a). The energy efficiency investment gap is well documented in academic publications (see e.g.

Bertoldi et al., 2021) and reflected in several EU policy documents (see e.g. EC, 2020f). It points to the great heterogeneity of the buildings sector, which is subject to, among other challenges, split incentives, inadequate information about costs and benefits of energy retrofit investment, loss aversion, complex decision-making processes, long pay-back periods and high transaction costs that hamper private investment (Economidou et al., 2020; IPCC, 2022c, Perez Navarro et al, 2023). For those reasons, technical support is often the key enabler to attract private investment in the energy efficiency of buildings, as it helps to overcome the various organisational and other non-financial obstacles such as the split incentive dilemma and the need for investment aggregation.

Analysis of the recovery and resilience plans submitted by the EU Member States to the European Commission in 2022 shows that 'most of the spending on energy efficient renovations goes to schemes that have the objective to achieve, on average, a medium-depth level renovation, which amounts to at least 30 % primary energy saving' (EC, 2022f). In 2022 a flagship technical support to Member States was launched under the RRF regulation (EU, 2021a), with a focus on (i) renovation along thematic areas of the Renovation Wave, including energy poverty alleviation, public buildings and the wider renovation ecosystem; (ii) the implementation of planning tools, especially long-term renovation strategies and recovery plans; and (iii) the implementation of cohesion policy funding for building renovation.

The rather shallow depth of energy retrofits in the Member States' plans under the RRF appears to echo the technical screening criteria (TSC) for sustainable economic activities set out in the delegated act supplementing the Taxonomy Regulation (EU, 2020). The TSC for renovation of existing buildings require building renovation to comply with the applicable requirements for major renovations under the EPBD or to lead to a reduction of primary energy demand of at least 30 %. Such shallow energy retrofits may not be aligned with the EU's climate neutrality objective and may create dangerous lock-ins (see for example Schütze and Stede, 2021) unless they are part of a staged intervention, for instance under a building renovation passport leading to a deep retrofit while recognising the complexity of such investment (BPIE, 2017; Sesana et al., 2020; Villarejo et al., 2021). Voluntary building renovation passports will be introduced in the EPBD recast.

Regarding the new construction, acquisition and ownership of buildings, the criteria are somewhat more robust, as, for buildings constructed in 2022 and after, they go beyond the current EPBD requirements (EC, 2021b).

Several EU funding schemes aim to bridge the investment gap by supporting the retrofitting of buildings. Such support ranges from research and market uptake to large-scale retrofits as part of the EU cohesion policy. In the 2014–2020 programming period, the cost-effectiveness of the EU cohesion policy spending on energy efficiency in buildings (about EUR 14 billion over the period) was rather low because of inadequate targeting of investments through grants with low additionality, that is, crowding out private investment that would probably have happened anyway. Moreover, the monitoring system in place did not make it possible to measure energy savings triggered by the investment (ECA, 2020a). Both weaknesses – lack of additionality, and inadequate data about impact – perpetuate the challenge of attracting private finance to invest in the energy efficiency of buildings.

To make better use of public funds, some EU funding programmes (e.g. L'Instrument Financier pour l'Environnement (LIFE), Horizon, InvestEU) develop, test and scale up financing schemes and business models such as on-bill financing, one-stop shops and energy performance contracting, in line with the IPCC findings (IPCC, 2022c, Sequeira, & Gouveia, 2022, Pardalis et al, 2022). They also provide financial guarantees and project development assistance to energy efficiency investment at building portfolio levels ([39]). These are promising efforts to leverage private investment through public funds, but they should go hand in hand with fiscal policy within the EU Member States, supported by the upcoming revision of the ETD (EC, 2021y) and the State aid guidelines to discourage further use of fossil gas as a heating source for buildings (see also Sections 10.5 and 12.3).

([39]) For instance, the European Local Energy Assistance programme created under Horizon 2020 and implemented by the EIB leverages private investment in the energy efficiency of buildings (EIB, 2023a). The EIB is also crowding in private finance to sustainable infrastructure for buildings by providing financial guarantees under the InvestEU programme. The overall InvestEU Fund budget guarantee of EUR 26.2 billion is expected to trigger EUR 372 billion of public and private investment in all sectors between 2021 and 2027 (EU, 2023h).

7.6 Summary tables

Table 10 Progress summary - buildings

Indicator	Reference period	Historical progress	Required up to 2030	Required in 2031–2050
B1: GHG emissions	2005–2022	– 11 Mt CO_2e/yr	– 29 Mt CO_2e/yr	– 11 Mt CO_2e/yr
B2: final energy use				
B2a: residential	2017–2021	+ 29 TWh/yr	– 98 to – 113 TWh/yr	– 35 to – 42 TWh/yr
B2b: tertiary	2017–2021	+ 23 TWh/yr	– 36 to – 47 TWh/yr	– 15 to – 21 TWh/yr
B3: Type 1 renovation rate				
B3a: residential buildings	2016-2020	+ 1 %/yr	+ 2.1 %/yr	*No benchmark*
B3b: tertiary buildings	2016-2020	+ 0.6 %/yr	+ 1.1 %/yr	*No benchmark*
B4: built surface				
B4a: residential surface area	2012–2016	+ 128 km^2/yr	*No benchmark*	*No benchmark*
B4b: tertiary surface area	2015–2019	+ 23 km^2/yr	*No benchmark*	*No benchmark*
B5: fuel mix				
T5a: % of fossils in residential final energy consumption	2017–2021	– 0.6 pp/yr	– 2.4 pp/yr	– 1.1 pp/yr
T5b: % of fossils in tertiary final energy consumption	2017–2021	– 0.1 pp/yr	– 1.9 pp/yr	– 1.0 pp/yr
B6: heat pumps (total stock)	2018–2022	+ 2 million/yr	+ 2.7 million/yr	*No benchmark*

Legend

On track	The required change ([a]) is ≤ 1.
Almost on track	The required change ([a]) is between 1 and 1.5.
Somewhat off track	The required change ([a]) is between 1.5 and 2.
Considerably off track	The required change ([a]) is ≥ 2.
Wrong direction	The required change ([a]) is < 0.

([a]) See Section 2.2 for more details on how the required change is calculated.

Table 11 Policy consistency summary - buildings

Policy inconsistencies	– Subsidies to fossil gas persist as they are allowed under the Energy Taxation Directive and EU state aid rules
Policy gaps	– In terms of heating and cooling decarbonisation, lack of system integration and insufficiently robust EU standards have led to incremental energy efficiency improvements and lock-in effects. – The EPBD recast aiming to tackle buildings' embodied carbon and energy, which could encourage better use of the existing buildings rather than new construction, has not yet been adopted. – EU policies have not sufficiently facilitated collection and sharing of reliable, granular, comparable and interoperable information on the energy performance, energy efficiency investment and multiple benefits of efficient building stock, such as indoor air quality.
Ambition gaps	– The revised EED and the EPBD before recast do not explicitly aim to leverage sufficiency. – The EU does not prominently guide urban and spatial planning and taxation towards energy and material sufficiency. – The EPC schemes are of uneven quality and have limitations in terms of reliability, as they are based on data derived from the physical properties of buildings rather than energy demand driven by occupancy behaviour.
Implementation gaps	– EU policies so far have not overcome barriers to wide-scale and deep energy retrofits of buildings. – The quality and ambition of the EU's long-term renovation strategies are insufficient to guide the required building renovation towards the 2050 climate neutrality objective.

8 Agriculture

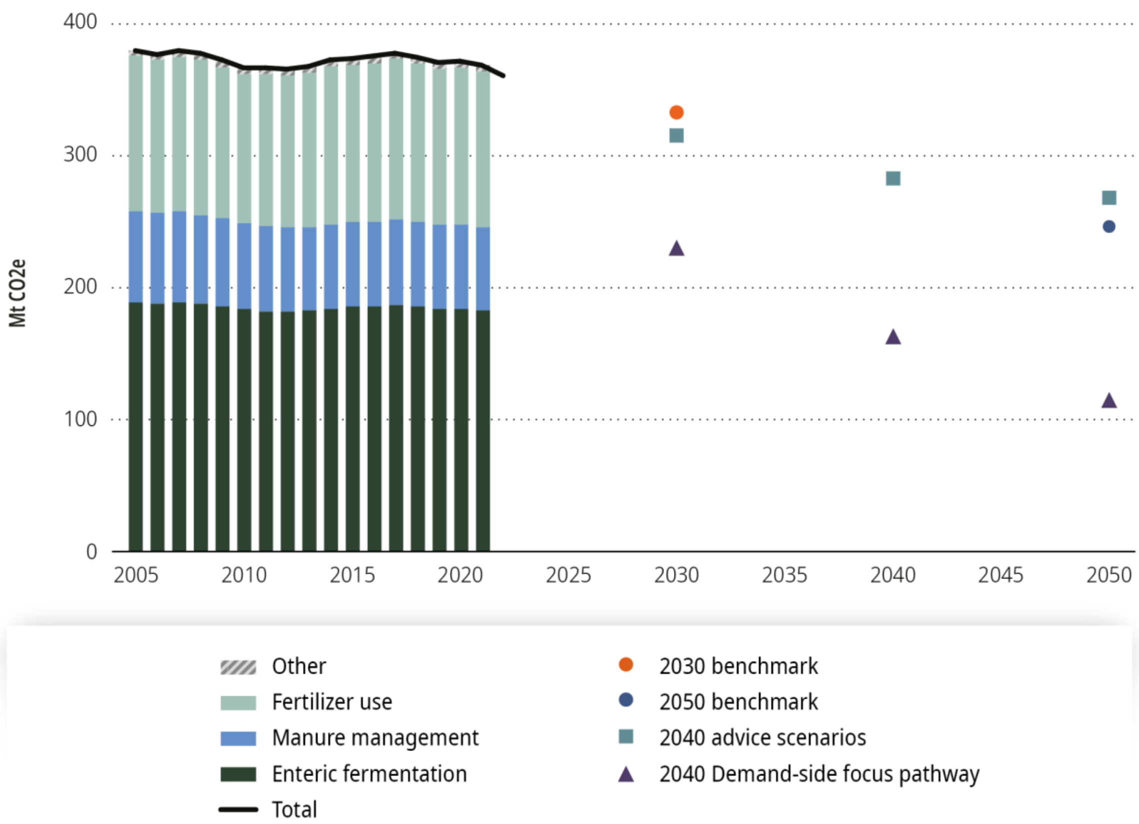
This chapter covers non-CO_2 greenhouse emissions associated with the production of crops and livestock, and the relationship of these emissions with the food system. Some aspects of agriculture are dealt with in Chapters 9 and 10. Chapter 9 'Land use, land use change and forestry' covers emissions, removals and storage of GHGs on land, including in forests and agricultural soils. Chapter 10 'Pricing emissions and rewarding removals' contains a dedicated section discussing how emissions and removals from agriculture and land use can be incorporated into an emission-pricing regime.

Key messages

Emissions from agriculture have remained largely unchanged since 2005, and reductions are needed to align with the EU's climate objectives.

Today, non-CO_2 emissions from agriculture account for 11 % of the EU's total net GHG emissions ([40]). They have remained largely unchanged since 2005. Although the sector is regarded as having lower mitigation potential than other parts of the economy, emission reductions can be achieved and are identified in pathways consistent with EU and global climate goals. EU-level pathways examined by the European Commission and by the Advisory Board suggest that a reduction of around 30 % below 2005 levels by 2050 could be achieved largely through supply-side measures identified in the literature, and around 60 % in the most ambitious pathways featuring additional demand-side action.

Figure 54 Indicator A1 – overall progress in reduction of agricultural non-CO_2 emissions



Source and Notes: See Figure 56 for detailed sources and notes.

([40]) This excludes emissions from energy use in agriculture, which are covered in other chapters. CO_2 emissions from agriculture (apart from its energy use) are minor (2–3 % of the sector's GHG emissions).

Ambitious climate targets, and the policies and incentives for achieving them, should be at the heart of the EU's CAP.

Needs. GHG emissions from agriculture need to be reduced to a level consistent with the EU's climate neutrality objective. The EU and Member States therefore need to adopt and implement policies and incentives consistent with this level of ambition.

Gaps. Within the CAP, the aim of contributing to climate change mitigation is largely qualitative and forms part of a broader set of agri-environmental objectives (also covering adaptation, soil and biodiversity preservation, and animal welfare) **(ambition gap)**. The CAP's climate and environment aims are pursued by Member States in their CAP Strategic Plans (CSPs), where the emphasis given to climate change mitigation is largely discretionary and difficult to quantify *ex ante* **(ambition gap)**. Although the 2023–2027 CAP includes some mandatory good practices (conditionality), the CAP still provides direct support to emission-intensive agricultural practices such as livestock production rather than focusing financial support on the transition to less emission-intensive activities **(policy inconsistency)**. Emissions from agriculture are also not covered by a GHG emission-pricing regime **(policy gap)**.

Recommendation A1. The CAP should be reformed to include standalone emission reduction objectives in addition to obligations to pursue other environmental and sustainability objectives.

— The CAP should move towards mandatory good practices with greater clarity about their mitigation outcomes. Land management rules (both statutory management requirements and conditionality under the CAP) and criteria for eco-schemes should be strengthened and defined more concretely to ensure that they are more closely related to positive environmental outcomes and that their mitigation impact can be estimated quantitatively.

— The EU should shift CAP support away from emission-intensive agricultural practices, including livestock production, and towards lower-emitting products, environmental services and economic diversification (see Chapter 11 'Whole-of-society approach'). In parallel, the EU should strengthen measures to encourage healthier, more plant-based diets, and develop a framework for just transition to an agricultural sector consistent with the climate neutrality objective.

Recommendation A2. A system for estimating and pricing agricultural emissions targeting the source should be introduced, complemented by policies that seek to ensure that more sustainable, healthier food choices are available to consumers at all income levels. This could be activity-based (rewarding specific activities) or results-based (such as a cap-and-trade system based on verified emission estimates). Their socioeconomic impact of emissions pricing – in particular on small farms and farms in vulnerable regions – should be assessed *ex ante,* and potentially adverse economic, social and environmental impacts should be addressed to ensure a just and fair transition. See also next recommendation, on sustainable food systems, and Chapter 10 'Pricing emissions and rewarding removals'.

EU policies on agriculture and biofuels should also better reflect the need to maintain and expand the area of forests and wetlands for carbon sequestration purposes (see Chapter 9 'Land use, land use change and forestry').

The Farm to Fork Strategy should be translated into concrete policies for delivering a sustainable food system, reducing food waste and encouraging healthy, plant-based diets.

Needs. From a strictly climate mitigation perspective, reductions in the production and consumption of GHG-intensive agricultural products (especially livestock products) need to go hand in hand, otherwise emission reduction efforts risk being offset by increased imports (displacing emissions to other countries) or exports (maintaining EU emissions in spite of consumption changes).

From a broader perspective, there is a need to shift towards healthier diets, reducing the over-consumption of animal products and increasing the consumption of plant products, since these are associated with lower emissions. Ensuring sustainable production and consumption of food – as well as reduced food waste – also requires further action in the middle part of the agri-food value chain (food processing, distribution and retail companies), given its influence on food product availability, accessibility and affordability, marketing strategies and information provision.

Gaps. The overarching framework for climate action in the food system is the Farm to Fork Strategy, published in 2020. At the time of writing, however, the European Commission has not made a proposal on some of its key initiatives (such as the legislative framework for a sustainable food system, and rules on labelling and sustainable public procurement of food). In other cases, proposed legislation has not yet been adopted by policymakers (such as targets on food waste reduction) **(policy gap)**. The Farm to Fork Strategy has been criticised for lacking quantified objectives (and delivery mechanisms for achieving the objectives that it has) and for its reliance on monitoring and labelling requirements and information provision measures. This represents an **ambition gap** (and a **policy gap**, since, at the time of writing, the European Commission has not yet released its proposal on some of the topics announced in the strategy). Other **ambition gaps** identified in food system governance include the expected low impact of the EU Code of Conduct on Responsible Food Business and Marketing Practices, the food waste reduction targets of the Waste Framework Directive revision proposal (which falls short of the 50 % reduction target of the Farm to Fork Strategy) and the revised Industrial Emissions Directive, which postpones stronger controls on emissions from intensive livestock production to 2030 at the earliest.

Recommendation A3. Policies should encourage and incentivise the sale and marketing of, and access to, healthier, more plant-based foods, the reduction of food waste and a sustainable food culture.

— In the middle of the food chain, EU-level food policy should go beyond voluntary codes of conduct and explore binding regulations and incentives to improve the sector's climate performance (for example on food waste) and empower consumers to make more sustainable choices (for example through regulation of labelling and marketing).
— Additional policies should be considered to encourage and improve access to more sustainable, healthier diets, paying particular attention to the influence of the social environment on food choices. Action on sustainable public procurement of food is an example of this. Other opportunities should be identified.

Needs. Reducing agricultural emissions implies shifting away from bioenergy for uses that can be decarbonised by other means (see Chapter 6 'Transport').

Gaps. Continued promotion of first-generation biofuels in EU energy policy also represents a **policy inconsistency** in applications where electrification offers a lower-emitting route to decarbonisation.

Recommendation A4. Future revision of EU energy policies should limit support for biofuels to areas that cannot reasonably be decarbonised by other means.

8.1 Scope and sectoral assessment framework

Scope

This chapter covers all non-energy related emissions from agriculture as reported under the UNFCCC (CRF category 3), primarily CH_4 and N_2O emissions from livestock and N_2O emissions from fertiliser use ([41]).

— Energy-related emissions in the agricultural sector are included in the buildings (space heating), transport (rolling equipment) and industry (food processing) sectors respectively.
— CO_2 emissions and emission removals from agricultural soils and forestry are included in the LULUCF sector.

Greenhouse gas emission reductions required in the agricultural sector to reach climate neutrality

Today, non-CO_2 emissions from agriculture account for 11 % of net EU GHG emissions. There is an overall scientific consensus that the cost-effective mitigation potential in agricultural non-CO_2 emissions is limited compared to the reduction potential of energy-related CO_2 in other sectors, if production and consumption patterns remain unchanged (Fellmann et al., 2021), but also that emission reductions from this sector are an important element of achieving both global and EU climate goals (JRC, 2023c; IPCC, 2022a; Leahy et al., 2020).

Although the European Green Deal does not specify the extent of climate mitigation expected from the agricultural sector, the sector's non-CO_2 emissions are reduced by 30–45 % below 2005 levels by 2050 in scenarios underpinning the European Commission's analysis (EC, 2018e, 2020s). Scenarios assessed in the Advisory Board's recent report on a GHG target for 2040 suggest that a 23–57 % reduction could be achieved by 2040, depending on the extent of demand-side action, including a shift to sustainable, healthy diets ([42]).

The European Commission's scenarios see agricultural emissions remaining essentially flat up to 2030 (– 3 % compared to 2022), JRC analysis has identified supply-side options equivalent to a 20 % reduction ([43]) (Pérez Dominguez et al., 2020) and the Advisory Board's 2040 analysis suggests a reduction of at least 10 % below the 2022 level could be achieved by 2030.

Climate change impacts might undermine the capacity of the agricultural sector to deliver on all these different objectives, and therefore the sector will also have to enhance its resilience against these impacts.

Assessment framework for the agriculture sector

Outcomes. Achieving the mitigation contribution described above requires some combination of the following two outcomes.

— **Reduced production and demand for GHG-intensive agricultural products.** Reducing production of the most GHG-intensive products will lower EU GHG emissions, while lower

([41]) In CRF category 3 (which excludes energy-related emissions in agriculture), CO_2 emissions typically account for 2–3 % of total GHG emissions.

([42]) This refers to emission reductions compared to 2015 at 'R10' geographical wider Europe ('R10') geographical resolution (all of Europe). The range encompasses the pathways underpinning the Advisory Board's 90-95% recommendation (23%-26%) as well as the reductions achievable in Demand-side focus pathway which has a greater focus on healthy & sustainable diets (-57%)

([43]) Figures 17 and 21 of Pérez Dominguez et al. (2020) identify approximately 75 Mt CO_2e of mitigation at the EU-27 level though measures such as feed additives, anaerobic digestion, winter cover crops and fallowing histosols.

consumption will reduce the market for them (as well as bringing health benefits in general). The two must go hand in hand to ensure that climate policy objectives are not counteracted by international trade. The issue of emission leakage (the movement of activity and emissions to locations with laxer climate regulation) is discussed in Chapter 10 'Pricing emissions and rewarding removals'.

— **Lower GHG-intensity of agricultural production in the EU.** This would deliver additional emission reductions.

Levers. To achieve these outcomes, five main levers were identified based on the agriculture, forestry and other land use chapter of IPCC AR6 (contribution of Working Group III) (IPCC, 2022a) ([44]).

— **Low-emission livestock production.** CH_4 emissions can be reduced by measures to reduce emissions from enteric fermentation (the digestion process of ruminant livestock such as cattle) and by improved manure management.

— **Low-emission crop production.** This would reduce N_2O emissions from fertiliser use (and CH_4 emissions from rice cultivation).

— **Reduced livestock production** and **sustainable and healthy diets.** These would reduce EU GHG emissions both directly (reduced livestock emissions) and indirectly (reduced demand and production of feed crops), provided that reduced meat and dairy demand and reduced livestock production happen simultaneously in the EU.

— **Reduced food waste.** This would also reduce EU emissions provided that reduced demand leads to reduced domestic production.

— **Minimise demand for biofuel crops.** According to the IPCC, it is not possible to precisely determine the scale of bioenergy (and BECCS) deployment at which negative impacts outweigh benefits, given the multiple interactions with food, land and energy systems. Minimising demand for biofuel crops is therefore included since this determines overall demand for (and therefore production of) agricultural crop production.

Enablers. In addition, eight enablers were identified that would facilitate the five levers described above.

— **Price signals and incentives** can support all the abovementioned levers, both on the demand side and on the supply side.

— **Information provision and education** can help consumers to reduce food waste and make informed food choices, which can contribute to more sustainable and healthy diets. However, they are insufficient on their own and need to be combined with other, more stringent types of policies.

— Cultural and social values might hinder the adoption of more sustainable diets and or more GHG-efficient agricultural practices. Therefore, it is necessary to promote **supportive social and cultural values** to enable the transition, for example by highlighting the various co-benefits (such as the health benefits of more sustainable diets), by working with the social context in which food is produced and consumed.

— Adequate access to **finance** combined with GHG-pricing incentives can enable an acceleration of the uptake of sustainable agricultural practices. While some mitigation measures in the agricultural sector relate to changes in management practices and can be implemented without large

([44]) Relevant topic headings in the IPCC chapter's agriculture and food sections (7.4.3–7.4.5) include the phrases 'soil carbon management', 'enteric fermentation', 'crop nutrient management', 'manure management', 'bioenergy and BECCS', 'sustainable healthy diets' and 'reduce food loss and waste'.

investments ([45]), others require considerable upfront investments. Rates of adopting these measures could be slow without available finance, even if price signals are implemented.

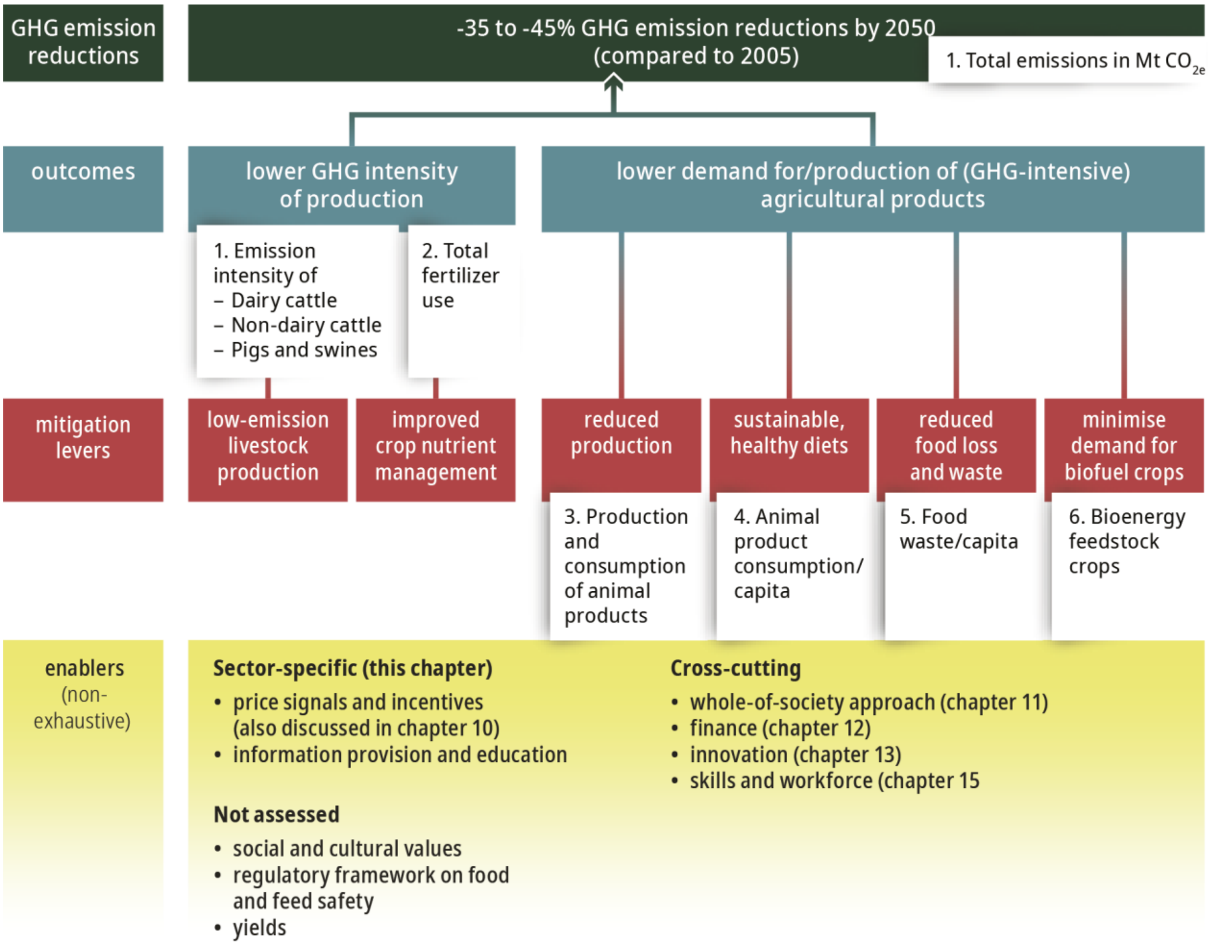
— European farmers, farm advisory agents and other professionals providing services to farmers (e.g. vets, or feed and fertiliser suppliers) need to be equipped with the required **skills and know-how** to implement different mitigation practices in an effective and efficient way, and need to be supported by industries.
— Some options for reducing GHG emissions require additional RD & D and **innovation**, especially in order to become affordable and deployable at scale. The IPCC gives several examples including ongoing innovations in crop breeding (e.g. through gene-editing technologies), feed additives and genomic selection to reduce enteric CH_4 in livestock, and further developments in precision agriculture (the use of sensors and satellites to improve crop yields, animal production and manage inputs more effectively) and remote sensing (IPCC, 2022a).
— The **regulatory framework on food and feed safety** needs to be aligned with the ambitions to reduce food losses and food waste and to enable novel, low-GHG-emission food and feed types (e.g. insect-based protein) to enter the market, without compromising public health or animal welfare.
— Overall, improved **yields** using the same amount of resources or less at the farm level can reduce overall GHG emissions, but only if they do not lead to higher aggregate production.

The assessment framework for the agriculture sector – including the selected indicators to track progress for this sector (see white boxes) – is shown in Figure 55.

Aside from the mitigation measures summarised in Figure 55, there are a number of climate action and broader environmental measures whose impact on overall GHG emissions is less certain. Organic farming has the potential to reduce emissions directly per unit land due to higher soil carbon sequestration (counted under LULUCF) and lower N_2O emissions from fertiliser use. However, it also leads to lower productivity, which could lead to additional land used for agricultural production if demand remains unchanged (EEA, 2022h; EC, Joint Research Centre et al., 2021; Skinner et al., 2014; Tuomisto et al., 2012). Similarly, evidence about shorter value chains is mixed, and could lead to both decreases and increases in emissions depending on specific circumstances (EEA, 2022h).

([45]) For example, the European Commission Target Plan (Figure 71) estimated that 12 Mt CO_2e of agricultural non-CO_2 emissions could be abated at a cost of up to EUR 5/t, while a further 35 Mt CO_2e could be abated at a cost of up to EUR 100/t (EC, 2020s). More detailed abatement cost curves for European agriculture are estimated by the JRC (JRC, 2020b).

Figure 55 Assessment framework for the agricultural sector



Source: Advisory Board (2024)

8.2 Emission reduction progress

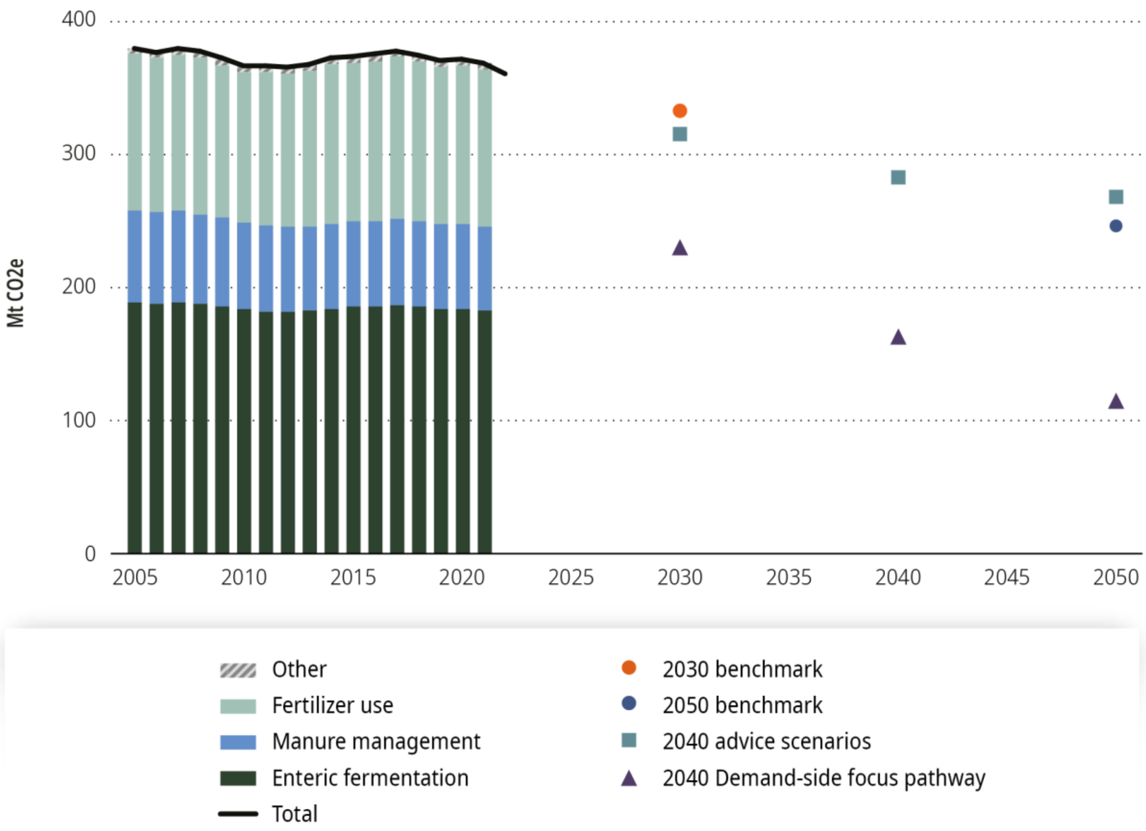
In the 1990s, agricultural non-CO_2 emissions in current EU Member States were considerably higher than today's levels (average 420 Mt CO_2e per year). However, the EU has not achieved consistent annual reductions in agricultural emissions since 2005 (see Figure 56).

Emissions decreased slightly in 2007–2012 but rebounded again until 2017 before starting a new but modest downward trend. By 2022, emissions were 5 % below 2005 levels. In 2005–2022, emissions reduced by on average 1 Mt CO_2e per year. This rate would need to accelerate to on average 3.5 Mt CO_2e per year to put the sector on track towards reaching modest reductions by 2030 that are in line with the European Commission's reduction scenarios. After that, the average pace of emission reductions would need to accelerate further (to 4 Mt CO_2e per year) to reach the 35 % emission reductions (compared with 2005) presented in the European Commission's scenarios underpinning the EU climate objectives.

Scenarios underpinning the 90–95 % recommendation of the Advisory Board reduce emissions more quickly, by 17 % in 2030 and 26 % in 2040 compared with 2005 levels. Greater emission reductions than this (63 % below 2005 levels by 2050) are achieved in the demand-side focus pathway assessed by the Advisory Board, which has a particular focus on healthy and sustainable diets in line with the recommendations of the EAT-Lancet European Commission (Willett et al., 2019).

Direct livestock emissions (excluding emissions related to feed production) account for two thirds of agricultural non-CO_2 emissions, which consist mainly of enteric CH_4 emissions (50 % of total) and CH_4 and N_2O emissions from animal manure (17 % of total) (EEA, 2023f). The other third of total agricultural emissions are N_2O emissions related to fertiliser use on crop- and grasslands, a substantial proportion of which is also related to feeding livestock ([46]). These shares remained relatively stable throughout 2005–2021.

Figure 56 Indicator A1 – overall progress in reduction of agricultural non-CO_2 emissions



Notes: Historic emissions to 2021 from the EU GHG inventory, with 2022 data based on proxy data reported to the EEA. 2030 benchmark based on the MIX scenario underpinning the Fit for 55 package, with 2050 benchmark based on the MIX scenario from the Climate Target Plan impact assessment. 2040 advice refers to average agricultural non-CO_2 emissions in the scenarios which underpin the Advisory Board's 2040 advice. Data for demand-side focus pathway is downscaled from wider Europe (R10 region) resolution to EU27 for comparability. The Advisory Board's 2040 advice describes the demand-side focus pathway in greater detail.

Sources: EU GHG inventory (EEA, 2023f), Fit for 55 MIX scenario (EC, 2021v), Climate Target Plan impact assessment (EC, 2020s) (Figure 19), Advisory Board's 2040 advice (ESABCC, 2023b).

([46]) For example, Guyomard et al. (2021) state that more than 60 % of the EU's agricultural area is used for feeding animals.

8.3 EU food and agriculture policies, and movement towards a whole-system perspective

EU policies affect agricultural emissions mainly through the CAP and the more recent farm to fork Strategy. This section examines each of these and considers the extent to which EU policies constitute a consistent approach to reducing GHG emissions within a broader context of environmental, social and sustainability goals.

Common agricultural policy

The CAP primarily supports food production, incomes and environmental outcomes.

The CAP is the EU's overall agricultural policy. It was established in 1962 and revised most recently in 2021 (covering 2023–2027) (EC, 2023e). Its founding objectives include increasing agricultural productivity, and ensuring fair incomes for the agricultural community and affordable food for consumers (EU, 2016). These objectives are still central to the CAP today, but the scope has gradually broadened to include environmental concerns, and the design of financial support has changed accordingly. It currently represents 35 % of the total EU budget, making it the largest budget item (EEA, 2022h).

The CAP for 2023–2027 requires Member States to set targets, including on climate action, under a new pledge-and-review system.

The CAP regulation for 2023–2027 (EU, 2021d) establishes a pledge-and-review process (often referred to as a performance- and results-based approach) whereby each Member State produces a CSP, sets targets and reports progress (with regular reviews by the European Commission). The regulation also establishes a series of objectives and indicators that Member States are to use, including on climate change mitigation and adaptation. The climate indicators include targeting and monitoring the share of land covered by measures to reduce emissions, store carbon or adapt to climate change, and investments in renewable energy capacity (measured in megawatts). Member States use these indicators to set their own targets and milestones, and must aim to make a 'greater overall contribution' to the achievement of environment and climate objectives than in 2014–2020 (Article 105 of EU (2021d)).

Implementation of the CSPs is subject to an annual review meeting and biennial performance review by the European Commission. If the review reveals a significant shortfall with respect to its milestones or targets, the European Commission may ask it to submit an action plan detailing remedial actions.

The majority of the CAP budget is not dedicated to climate change mitigation per se.

For 2023–2027, the majority of the CAP budget (75 % of pillar I and 65 % of pillar II) will continue to be spent on agricultural activities that do not per se contribute to climate mitigation, although there is some mainstreaming of climate action into the CAP via environmental **conditionality** requirements. These are largely based on the greening criteria of the 2013–2020 CAP but are now mandatory for all beneficiaries of CAP support. They include climate-relevant criteria such as requirements to maintain or protect grassland, wetland, peatland and soil cover.

Reviews such as those by the EEA (2022h) and Pe'er et al. (2022) argue that the CAP, overall, continues to consolidate rather than phase out conventional GHG-intensive farming practices. Even with a switch to area-based payments as the dominant approach (rather than direct payments, which subsidise production volume), the tendency in the EU is to use intensive farming methods to maximise income. The CAP therefore continues to indirectly provide considerable subsidies to food production practices that can result in high GHG emissions. In addition, the revised CAP will continue to subsidise the livestock sector, including through coupled support ([47]), which is a direct subsidy for GHG-intensive food products and undermines the goal of having food products reflect their true costs.

Dedicated green spending accounts for a growing proportion of the budget.

Although it does not account for the majority of spending, the green share of the CAP has increased over time. During 2014–2020, over a quarter of the CAP budget was assigned to climate change mitigation and adaptation, and consequently representing half of the EU's total climate spending (ECA, 2021). For 2023–2027, 40 % of the CAP budget is 'expected' to contribute to the achievement of climate-related objectives (recital 94 of EU (2021d)). The climate share of the budget will be tracked by the European Commission, with progress towards the indicative 40 % climate-mainstreaming target encouraged through annual review meetings and biennial performance reviews between the European Commission and Member States (EC, 2022g; EU, 2021d).

The CAP's 'green architecture' consists of mandatory environmental criteria and voluntary incentives.

Measures under the CAP that promote climate action and environmental protection are referred to as its green architecture. According to Guyomard et al. (2023), this consists of three main elements.

— Conditionality requirements are mandatory for all CAP beneficiaries.
— Eco-schemes and agri-environment climate measures are additional support that farmers can receive in exchange for implementing additional sustainability practices. Eco-schemes must represent at least 25 % of pillar I budget allocations (direct income support) over 2023–2027, and agri-environment climate measures must represent at least 35 % of pillar II (rural development funding).

There are considerable concerns regarding the likelihood that the green architecture will deliver additional climate action.

Although the CAP's green architecture provides significant opportunities for Member States to address both climate and biodiversity challenges, its delivery mechanism is primarily based on voluntary efforts. Independent assessments indicate that these are unlikely to be effective for the reasons given below.

The conditionality requirements consist mainly of broadly defined principles, which allow a high degree of flexibility for Member States, including broad exemptions (Guyomard et al., 2023; Matthews, 2021; Pe'er et al., 2022). Furthermore, ensuring compliance with these requirements, in terms of both monitoring and enforcement, remains a weak point (Pe'er et al., 2019). Guyomard et al. (2023) argue that the ambition of these measures cannot be truly appreciated without knowing about the implementation choices made by Member States. For example, Ecorys et al. (2023) point out that it is difficult to estimate the carbon sequestration effect of the requirement to maintain permanent grassland, since the definition of this term varies between Member States.

Similarly, the possible eco-schemes are defined in general terms in EU legislation, leaving their elaboration up to Member States. As a result, they risk funding (or continuing to fund) measures with very limited added value from an environmental perspective, which would de facto make them additional income support mechanisms under the guise of being environmental schemes (Matthews, 2021; Pe'er et al., 2022). Scientists have therefore made specific recommendations about developing eco-schemes, including avoiding support for practices that can be harmful to one of the environmental objectives of

([47]) 'Coupled support' refers to support payments to farmers that are linked to the level of production.

the CAP, and focusing the bulk of the budget on measures with high added (environmental) value on multiple dimensions (climate, biodiversity, etc.) (Pe'er et al., 2022).

The governance of the CAP allows Member States a great deal of flexibility. This arrangement provides opportunities for Member States to take climate action, but little incentive to be ambitious. An approach incorporating national flexibility can be advantageous, given the heterogeneous character of the agricultural sector and national geographies, but only if that flexibility does not come at the expense of ambition. The new CAP regulation requires Member States to set targets to achieve its specific objectives (which include climate action) but does not specify the ambition level of these targets (other than the requirement that they be more ambitious than in the past). Therefore, Member States arguably have an incentive to keep their ambition levels low in order to avoid having to justify themselves and develop potential remedial action during their performance reviews with the European Commission (Matthews, 2021).

Furthermore, although the European Commission can make recommendations on the CSPs, Member States are not obliged to adhere to them as long as they are in compliance with the broadly defined legal requirements of the CAP. Finally, national CAP budgets are pre-allocated under the MFF, regardless of the ambition levels of their CSPs, which leaves the European Commission with neither carrot nor stick to enhance their environmental ambition levels (Matthews, 2021).

It is also likely that many national administrations will lack the capacity and know-how to develop and implement ambitious CSPs, despite the technical assistance offered by the European Commission (Matthews, 2021; Pe'er et al., 2022).

This lack of incentive is confounded by a lack of quantified objectives that need to be met (as also evidenced by the lack of benchmarks that could be found for this report), and the few quantified objectives put forward by the Farm to Fork Strategy have yet to be endorsed either legally or politically. This means that the European Commission cannot refer to such targets as an argument for more ambition.

As a result, the impact of the new CAP on climate change mitigation is difficult to assess quantitatively, as the European Commission acknowledges in its summary assessment of the final CSPs submitted in 2022 (covering 2023–2027) (EC, 2023bf). In general, this assessment and the detailed mapping analysis underpinning it (Ecorys et al., 2023) are able to identify efforts that should contribute to mitigation, but are not able to estimate outcomes in terms of reduced emissions. For example, they identify efforts to support agroforestry and improve nutrient management, which should increase carbon sequestration or reduce N_2O emissions. Livestock emissions are identified as a priority area in 20 CSPs, but only 12 include a target, leading to an EU average of only 9 % of livestock units being covered by commitments to reduce GHG emissions or ammonia. The ability of the European Commission to reach these kinds of conclusions is in part due to the national recommendations formulated as part of the Farm to Fork Strategy including a request to set 'national reference values' for Green Deal targets such as reducing pesticide use and nutrient loss (Annex I of EC (2020r)). The summary assessment also acknowledges that further work is needed to support quantification of the CSPs' impacts and suggests that this is ongoing as Member States prepare to implement amended CSPs ([48]).

([48]) The European Commission's summary assessment (published 23 November 2023) covers the CSPs submitted and approved up to the end of 2022. However, Member States are required to assess (and potentially amend) their CSPs in light of the ESR and the LULUCF regulation. The summary assessment indicates that 18 amendments had been submitted, and 9 had been adopted by the European Commission, as of 4 October 2023.

Farm to Fork Strategy

The Farm to Fork Strategy is the European Green Deal's overarching strategy for pursuing a sustainable food system (EC, 2020f). Its main aims are to 'reduce the environmental and climate footprint of the EU food system and strengthen its resilience, ensure food security in the face of climate change and biodiversity loss, and lead a global transition towards competitive sustainability from farm to fork and tapping into new opportunities' (EC (2020f), p. 4).

The lack of an overarching strategy for the EU agri-food system had been identified by the scientific community as a major gap in the EU policy mix (EC, Group of Chief Scientific Advisors, 2020; SAPEA, 2020). The scientific community has generally welcomed the Farm to Fork Strategy as an important step in the right direction, while pointing out several shortcomings (EEA, 2022h; König and Araújo-Soares, 2021; Moschitz et al., 2021; Schebesta and Candel, 2020).

The strategy includes six environmental targets, of which the most relevant to lowering GHG emissions from the EU agricultural sector are reducing fertiliser use by 20 % and increasing the share of organic farming to 25 %, both by 2030 (EC, 2020f). As noted earlier in this chapter, while organic farming has the potential to reduce emissions directly per unit of land, it can increase overall land use (and therefore emissions) on account of lower productivity.

The Farm to Fork Strategy also announced 27 initiatives – both legislative and non-legislative – to deliver on its objectives, with mixed results so far in terms of ambition and delivery.

These aims, targets and initiatives reflect previous criticisms concerning the lack of clear and quantified environmental objectives under the CAP (Matthews, 2021). The Farm to Fork Strategy does not have a single delivery mechanism to achieve its objectives. Instead, the European Commission's approach has been to enhance food- and sustainability-related aspects of other initiatives. Some new legislation has been adopted (on the Farm Sustainability Data Network). Some legislation has been proposed by the European Commission but not yet adopted by the Parliament and Council (food waste reduction, corporate governance framework). The European Commission has also taken some non-legislative action (CAP recommendations, a voluntary code of conduct on responsible food business and marketing). However, the European Commission has not yet delivered several proposals announced in the Farm to Fork Strategy, including on sustainable food systems, public procurement, food labelling and regulation of feed additives. The list below details progress on the initiatives most relevant to climate change mitigation.

- The legislative framework for sustainable food systems was due to appear before the end of 2023 but has not been published at time of writing. Its stated aim is to promote policy coherence at the EU and national levels, mainstream sustainability in all food-related policies and strengthen the resilience of food systems. However, although the inception impact assessment recognises many of the challenges and bottlenecks – including the lack of financial incentives, of internalisation of externalities, and of a clear and common objective – there are signals that the upcoming proposal will be limited to a voluntary labelling scheme, and some limited mandatory measures for public procurement practices (EC, 2021t; Euractiv, 2023).
- In agriculture, outputs linked to the strategy include recommendations (featuring a dedicated climate section) to each Member State for consideration when drafting its CAP CSP (EC, 2020r), and the establishment of the Farm Sustainability Data Network to improve the collection of farm-level environmental and social data (Council and Parliament of the EU, 2023a). However, the proposal to revise legislation on feed additives (which could facilitate efforts to reduce livestock CH_4 emissions) has not been tabled at time of writing (European Parliament, 2023c).

— In the middle of the food chain (processing, wholesale, retail, hospitality and food services), a voluntary code of conduct on responsible food business and marketing practices has been produced and signed by a number of companies and associations, accompanied by individual pledges (discussed further in the next subsection) (EC, 2021o). Large companies (including in the food sector) would also be affected by requirements to incorporate climate and sustainability into their corporate strategies under the Directive on corporate sustainability due diligence (political negotiations are ongoing at time of writing (European Parliament, 2023b)).
— Regarding sustainable food consumption, the Farm to Fork Strategy mentions minimum mandatory criteria for sustainable food procurement, and sustainability labelling for food products. The European Commission consulted on both of these issues during 2021 and 2022 (EC, 2021an) but has not made a proposal at the time of writing.
— Regarding reduction of food waste, the European Commission proposed a revision of the Waste Framework Directive that would include a 10 % food waste reduction target in processing and manufacturing, and a 30 % per capita target among retailers, restaurants, food services and households (EC, 2023aq). At time of writing, this is being negotiated at the political level, with the possibility that some targets will be weakened, postponed or narrowed in scope (European Parliament, 2023d).

Towards a whole-system approach

According to the IPCC, a food system approach enables the identification of cross-sectoral mitigation opportunities, including both technological and behavioural options (IPCC, 2022e). Taking a whole-system approach to EU agriculture and food policies would involve exploring options for mitigation by producers, consumers and intermediate links in the food supply chain, and ensuring that a coherent approach is taken to balancing the different environmental, economic and social demands placed on the agricultural sector.

On farming, in addition to the CAP and the Farm to Fork Strategy, emissions from the largest pig and poultry farms are governed under the Industrial Emissions Directive. In November 2023, the European Parliament and Council agreed a revision of this directive that will expand the number of farms covered (Council and Parliament of the EU, 2023b). In its original proposal, the European Commission estimated that a revised directive would reduce CH_4 emissions by 7.4 Mt CO_2e per year ([49]) (equivalent to around 3.2 % of annual agricultural CH_4 emissions) (EC, 2022ae). However, the politically agreed revision is considerably less ambitious than this, since it covers fewer pig and poultry farms and excludes cattle entirely, although it mandates the European Commission to produce an assessment of how best to address CH_4 emissions from cattle by 2026. The functioning of the directive's implementation will be reviewed every 5 years starting in 2028. However, the new rules on animal farming will only start to be applied from 2030.

The middle part of the agri-food value chain (food processing, distribution and retail companies) plays a vital role in the transition given its influence on food product availability, accessibility and affordability, marketing strategies and information provision. Aside from energy-related emissions (which are addressed in other chapters), actors in the middle of the supply chain can reduce emissions directly through improvements in the packaging, conservation and GHG intensity of food, and indirectly through their influence on consumers and producers. An effective policy mix should include targeting those in the middle of the agri-food value chain, through a combination of voluntary measures and

([49]) Conversion from 265 000 t of CH_4 per year using the 100-year global warming potential given in the IPCC Fifth Assessment Report (IPCC, 2013).

more stringent types of policy (carbon pricing and regulations, including on advertising practices, standards and financial incentives) to achieve the necessary scale of change.

While the Farm to Fork Strategy addresses the middle part of the agri-food value chain, it does so primarily through soft policies such as voluntary agreements. However, there is limited scientific evidence to lead one to expect such an approach to have a significant impact on its own. An EEA report on Europe's food system gives the example of the EU Code of Conduct on Responsible Food Business and Marketing Practices (EEA, 2022h). Firstly, the code of conduct has become more general and less concrete than originally envisaged, as illustrated by the deletion of references to avoiding advertising cheap meat. Secondly, it relies completely on self-regulation and voluntary pledges, and signatories have a high degree of choice about to which of the aspirational objectives they want to commit. Despite the high level of subscription to the code (130 signatories in mid 2022, representing a considerable share of the EU market), its overall impact is expected to be low. This is also confirmed by the European Commission's own 2022 mapping report, which concludes that, although the commitments made under the initiative are generally aligned with the Farm to Fork Strategy (and in some cases anticipate EU regulation on deforestation-free supply chains), there is room for improvement concerning their level of ambition and specificity (EC, 2022ag).

Shifting to sustainable food consumption and production is an essential part of climate policy in food and agriculture.

Aside from the multiple benefits of sustainable and healthy diets, several studies have pointed out that a strategy focusing exclusively on supply-side reductions risks being undermined by trade-related leakage effects (e.g. (Henderson and Verma, 2021; Zech and Schneider, 2019)). The importance of sustainable food consumption, including its health and environmental benefits, is recognised in the EU farm to fork Strategy, and in IPCC AR6, which finds that a transition to more plant-based consumption (including more pulses, fruits and vegetables) and reduced consumption of animal-based foods (in particular from ruminant animals) has considerable potential to reduce GHG emissions both directly (reduced enteric and manure-related emissions) and indirectly (reduced land and inputs needed for feed production). In addition, it could enhance public health and bring a range of other environmental co-benefits (biodiversity, reduced air, soil and water pollution). Potential trade-offs relate mainly to the risk of adverse economic and social impacts on the livestock sector, which would need to be well managed to ensure a just transition (IPCC, 2022a). Up to now, EU policies to encourage sustainable diets have focused primarily on information provision and voluntary codes of conduct, but these measures are not sufficient by themselves. Further action of this kind, on food labelling and public procurement, is promised in the Farm to Fork Strategy, although these at time of writing these proposals have not yet been tabled (see subsection 'Farm to Fork Strategy' above).

More ambitious policies to encourage healthy, sustainable diets, such as the introduction of emission pricing, would also have to be managed carefully, taking into account the social environment and economic implications for low-income consumers (see 'Lever: sustainable, healthy diets' below and Chapter 11 'Whole-of-society approach').

However, studies have warned that the farm to fork Strategy's goals of reducing fertiliser use and expanding organic farming risk displacing production and related environmental pressures outside the EU, if not accompanied by reduced demand for the most GHG-intensive products, which can be achieved through more sustainable and healthy diets and reduction of food waste (Bremmer et al., 2021; EC, Joint Research Centre et al., 2021; Matthews, 2021). **Climate change impacts are already affecting crop and livestock productivity in the EU**, and are projected to reduce crop productivity in parts of southern Europe and to improve conditions for growing crops in northern Europe in some years. Furthermore, increased intensity and frequency of extreme weather events are expected to negatively affect agriculture in the EU overall (EEA, 2019). Reduced productivity risks undermining mitigation ambitions, as it could require increased inputs (including land use) to continue to meet demand, as well as risking maladaptation.

Achieving the ambitions of the European Green Deal will also require a **just transition in the agricultural sector**. Millions of farmers across the EU will need to change their farming practices, and this will require investments and lead to increased costs/reduced income in the short term. On the other hand, it is also recognised that in a broader sense the European Green Deal can improve farmers' incomes and resilience by reducing environmental damage and providing new income streams (e.g. bio-economy feedstocks, payment for carbon sequestration) and reduce costs (resource efficiency and circular economy) (Matthews, 2021; NESC, 2023). As discussed above, the mix of policies that would deliver a Green Deal-based transition in agriculture is not yet agreed. Nevertheless, a report commissioned by the Institute for European Environmental Policy attempts to identify who might benefit in a hypothetical transition, and who might be negatively affected (IEEP, 2021). The report indicates that potential beneficiaries include farmers and businesses able to exploit markets such as products with higher value added (nuts, fruit and vegetables), higher-welfare livestock products, organic products, ecosystem service and carbon sequestration markets, and recreation, amenity and hospitality activities. Those who may be negatively affected include some livestock producers and workers in meat-processing industries, suppliers of agrochemical inputs and producers with high reliance on these inputs, as well as famers unable to take advantage of growing markets or new support schemes.

Given the limited investment capacity and low profitability of many (mainly smaller-scale) farms in the EU, active policies will be needed to ensure the transition to a greener agricultural sector will be fair. In terms of building a policy approach for just transition (in the CAP beyond 2027), the Institute for European Environmental Policy report recommends combining better use of CAP basic payments to support environmental sustainability, development of new income streams and markets for sustainable activities, thorough preparatory work including building capacity and skills in the agricultural sector, and enhanced engagement to identify and address multiple dimensions of fairness (e.g. towards multiple stakeholders along the food supply chain, and those initially disadvantaged in the transition).

This need is not sufficiently reflected in the CAP. Although its latest revision has increased the overall environmental ambitions, its overall budget has remained unchanged in nominal terms, meaning that the additional requirements are not met by additional means (Matthews, 2021). Furthermore, CAP subsidies have been biased towards larger farms by the 'per hectare' basis of direct income support, and the system does not have any dedicated instruments to address potentially uneven social repercussions resulting from a sustainability transition (EEA, 2022h).

The Farm to Fork Strategy is a step forward in this regard, putting the aim of a just transition at the centre of its strategic goals. However, as with other objectives of the strategy, the main shortcoming is the lack of an effective delivery mechanism to achieve this objective (EEA, 2022h).

8.4 Outcome 1: lower greenhouse gas intensity of production

The GHG intensity of EU agriculture has remained largely unchanged over the past 10 years, as measured by GHG emissions per tonne of production in the livestock sector, and by use of nitrogen fertiliser per hectare in crop cultivation (as a proxy for intensity of N_2O emissions).

As discussed above, the reformed CAP for 2023–2027 is expected to consolidate rather than challenge existing high-GHG-intensity production practices, since these continue to be subsidised while the encouragement of more sustainable practices through the green architecture is largely voluntary or at Member State discretion.

Lever: low-emission livestock production

The emission intensity of livestock has remained largely unchanged over the past 10 years. Livestock production can become less emission-intensive through improved manure management and measures to reduce emissions from enteric fermentation.

In the livestock sector, the data shown in Figure 57 indicates an increase in GHG emission intensity for beef of 3 % by 2020, compared with 2010, which has partially offset the 4 % reduction in production levels (leading to an overall emission reduction of 2 %). By 2020, the direct emission intensity was about 15 kg CO_2e/kg product.

The direct emission intensity of dairy products and pig meat fell by 11 % and 6 % respectively over the same period. However, the improvements in GHG emission intensity were offset by increased production, which resulted in a quasi-stabilisation of total GHG emissions.

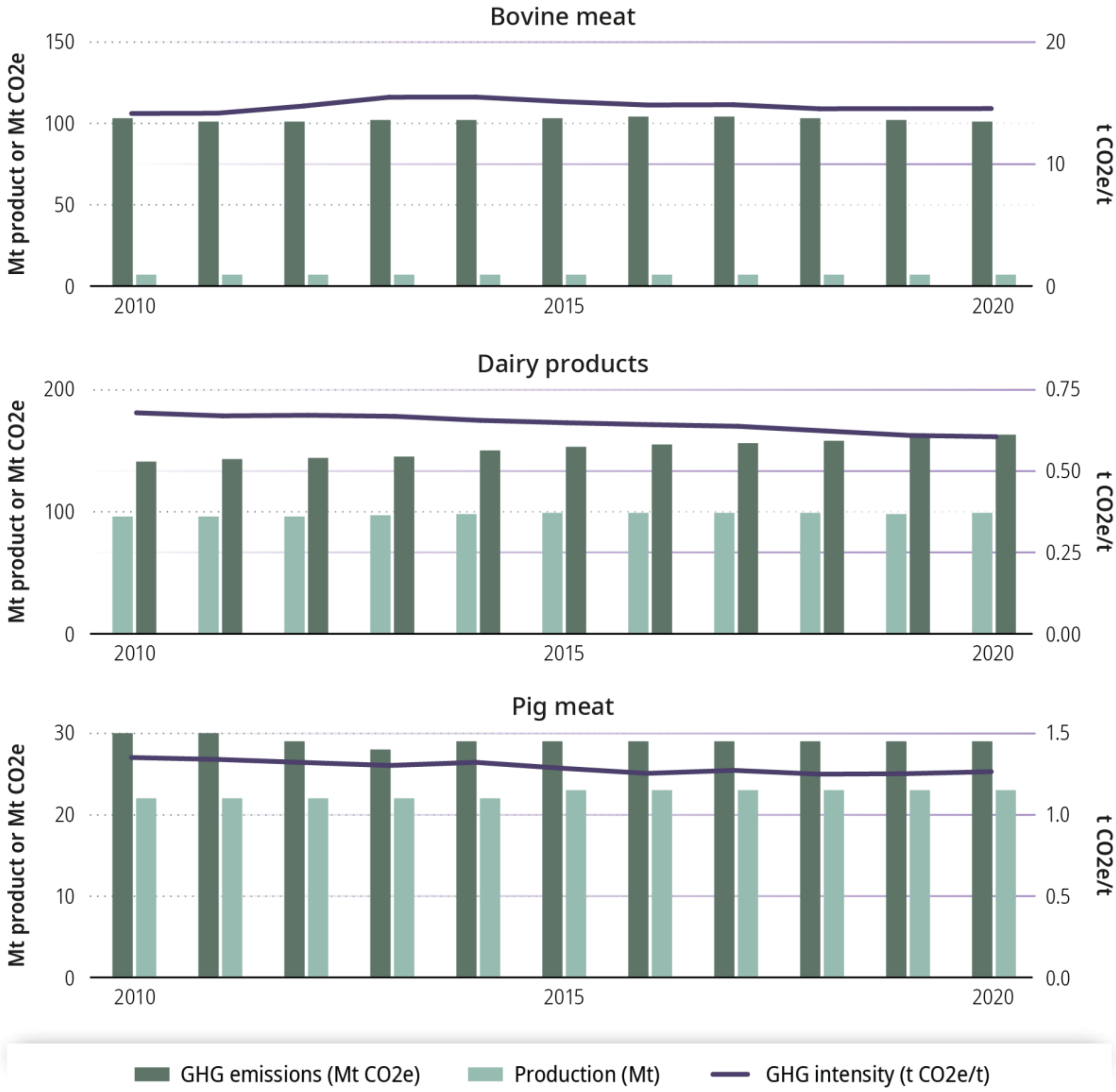
It should be noted, though, that these indicators only cover direct emission intensity and do not take into account indirect emissions from feed production. Feed production can cause considerable GHG emissions due to land use, fertiliser use and transport. JRC data (JRC, 2023) shows that about 50 % of all cereal supply (own production + imports) in the EU is used for feed purposes, indicating that the indirect GHG emissions of feed production constitute a large part of the livestock total GHG impact. For oilseed crops and related products, the share of total supply use for feed is even higher, at 66 %. With 50 % of total oilseed product supply coming from imports, the use of this feed type could be linked to significant indirect emissions – including those due to deforestation – outside the EU.

CH_4 emissions per unit of output can be reduced by focusing on two areas, namely enteric fermentation and manure management, as discussed by Reisinger et al. (2021) and the IPCC (2022a).

Enteric fermentation is a natural part of the digestion process of several species of livestock such as cattle, sheep and goats (ruminant species). The resultant CH_4 emissions account for half of total agricultural GHG emissions in the EU ([50]). A range of options exist to reduce these emissions, including changes to the feeding mix and the addition of feed additives. Other measures that can reduce emissions from both enteric fermentation and manure are optimising herd composition (fewer non-productive animals), improved animal health, livestock breeding and genetics to improve overall efficiency, and precision livestock-farming technologies. It is difficult to give a precise estimate of these measures' mitigation potential, given their inherent differences and varying technological maturity. Nevertheless, Reisinger et al. (2021) estimate potential reductions of 20–50 %, while the IPCC (2022a) reports that the reductions in the literature range from 16 % to 70 % for chemically synthesised CH_4 inhibitors, and also notes the large potential of additives derived from plants and algae. Potential co-benefits include enhanced resilience against climate change impact and higher productivity, whereas potential trade-offs include poor permanence of mitigation, ecological impacts associated with changes in feed mix, and potential toxicity and reduced animal welfare.

([50]) Emissions expressed in terms of CO_2 equivalent using 100-year global warming potential as per EEA (2023f).

Figure 57 Indicator A2 – livestock products: total production and GHG emissions (left axis), and GHG emission intensity (right axis)



Notes: GHG emission intensity calculated as emissions/production.

Sources: EU CRF tables (EEA, 2023h), FAO Food Balances (FAO, 2023)

CH_4 emissions from manure management are the third most important source of EU agricultural emissions (accounting for around 17 %) (EEA, 2023k). Changes in manure management can contribute to reductions in both CH_4 and N_2O emissions. The main reduction options – in addition to those mentioned in the previous paragraph – are switches in manure management systems (e.g. anaerobic digestion and slurry acidification), the application of nitrification and urease inhibitors to stored manure or urine patches, improved manure removal and storage systems, changes in grazing and housing practices, and changes in the feeding mix. Potential co-benefits are renewable energy production (biogas), improvements to the fertiliser potential of manure, additional income streams for farmers, and improved air and water quality from reduced ammonia emissions. Potential trade-offs include increased N_2O emissions from manure application to poorly drained or wet soils, trade-offs between N_2O and ammonia emissions, potential eco-toxicity associated with some measures, and increased incentives to maintain livestock herd numbers.

At the EU-28 level (including the United Kingdom), JRC modelling estimates that 21 Mt CO_2e of mitigation can be achieved at a carbon price of EUR 100/t CO_2e through a combination of anaerobic digestion, low nitrogen feeding, feed additives and vaccination against methanogenic bacteria (Figure 17 of Pérez Dominguez et al. (2020)) ([51]).

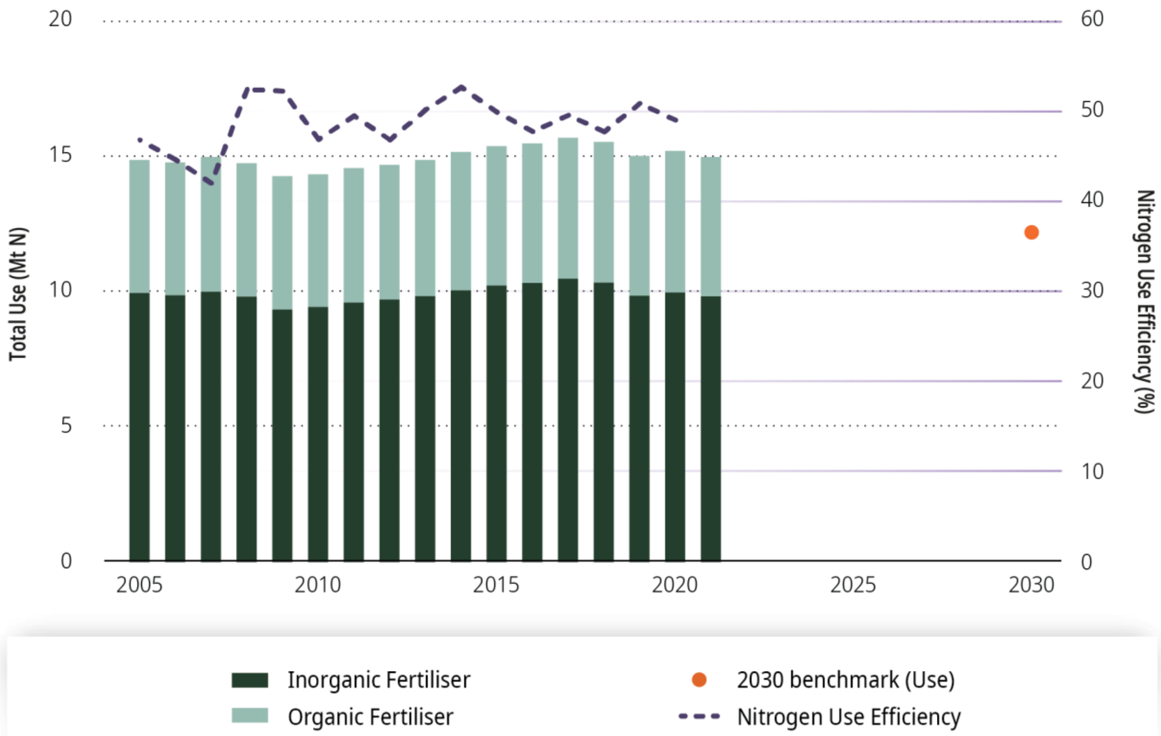
Lever: low-emission crop production

Crop cultivation techniques that use synthetic fertiliser less intensively can reduce emissions as well as enhancing resilience to climate change impacts and improving soil, air and water quality.

N_2O emissions from agricultural soils are the second-highest contributor to GHG emissions from agriculture, accounting for 31 % (EEA, 2023k). In crop cultivation, the use of fertilisers (shown in Figure 58) has been increasing steadily (+ 10 %) between 2009 and 2017. However, since the peak in 2017, fertiliser use has been reducing in absolute volumes (kt N). The efficiency of fertiliser use (measured as the percentage of applied nitrogen that is harvested as crops) varies from year to year but appears to be improving gradually over time.

On average, fertiliser use reduced by 180 kt N per year in 2017–2021. This average rate of decline would need to accelerate by 75 % in absolute value (– 310 kt N per year) in 2022–2030 to achieve the objective of the Farm to Fork Strategy to reduce total fertiliser use by 20 % by 2030 (EC, 2020f). The shares of inorganic and organic fertilisers have remained relatively stable since 2005, at 66 % and 34 % respectively.

Figure 58 Indicator A3 – total fertiliser use (left axis) and nitrogen use efficiency (right axis) in the EU agriculture sector



Notes: 2030 objective based on the European Commission's Farm to Fork Strategy.

Sources: EU CRF tables (EEA, 2023h) (Fertiliser Use), Ludemann et al. (2023) (Nitrogen Use Efficiency), Farm to Fork Strategy (EC, 2020f)

([51]) GHGs in Pérez Dominguez et al. (2020) are expressed using the 100-year global warming potential from the IPCC Fourth Assessment Report (IPCC, 2007a).

Improved crop nutrient management could lower N_2O emissions from fertiliser use in the agricultural sector. At the EU-28 level, JRC modelling estimates that 65 Mt CO_2e of mitigation can be achieved at a carbon price of EUR 100/t CO_2e through measures including fallowing histosols, growing winter cover crops and using nitrogen inhibitors (Pérez Dominguez et al., 2020)[52]. More broadly, options mentioned by the IPCC (2022a) include improved crop rotation practices increasing biological nitrogen fixation by legumes used as main crops (grain legumes, alfalfa) or as cover crops, optimised fertiliser application rates and timing (including precision application technologies), improved manure-spreading machinery, the reduction of inorganic fertiliser use by better utilising the nutrients in organic fertilisers, the application of nitrification and urease inhibitors, and better overall efficiency in crop production (e.g. reduced soil compaction and degradation, optimised irrigation, improved crop health).

Potential co-benefits are emission reductions in other sectors (due to lower mineral fertiliser production and increased carbon sequestration in agricultural soils), improved soil, air and water quality (due to less nitrate leaching, eutrophication and ammonia emissions), and better climate resilience due to increased water-holding capacity of the soil (if soil carbon is increased). In addition to improving biological nitrogen fixation, improved cropping systems with a higher share of grain legumes could also provide plant-based proteins for supporting the shift towards more sustainable diets, or replace soybeans that are imported for feed from non-EU areas undergoing tropical deforestation. Trade-offs relate to the potential reduction in yields in specific circumstances, which could therefore lead to negative impacts from ILUC either within or outside the EU, if the food, feed and bioenergy crop demand is not reduced simultaneously.

8.5 Outcome 2: reduced production and consumption of GHG-intensive agricultural products

While Outcome 1 focused on the intensive margin (reducing the GHG intensity of each product), Outcome 2 focuses on the extensive margin (reducing the production and consumption of GHG-intensive products).

As noted in the subsection 'Towards a whole-system approach' above, production and consumption need to be addressed jointly, otherwise emission reduction efforts risk being offset by increased imports (displacing emissions to other countries) or exports (maintaining EU emissions in spite of consumption changes). Several food and agricultural products are internationally traded commodities. For example, the EU is a net exporter of beef, pig meat, dairy products and cereals.

Lever: reduced livestock production

Agricultural emissions in the EU come predominantly from livestock production (two thirds of emissions) and N_2O emissions associated with growing crops (over half of which are used for feed purposes (JRC, 2023)).

The main contributors to emissions from livestock production are dairy cattle (40 % of total), non-dairy cattle (36 % of total) and pigs (10 % of total) (EEA, 2023h). Over the past 10 years, data on production and consumption of these products (summarised in Figure 59) indicates an increasing production to consumption ratio. The EU is a net exporter of beef, dairy products and pig meat (FAO, 2023), and since 2005 exports of each have grown by more than imports (although both have increased). Slight decreases in consumption of pig meat and beef have therefore not led to a similar reduction in production volumes, and the increase in dairy consumption has been outpaced by dairy production. Overall, increases in

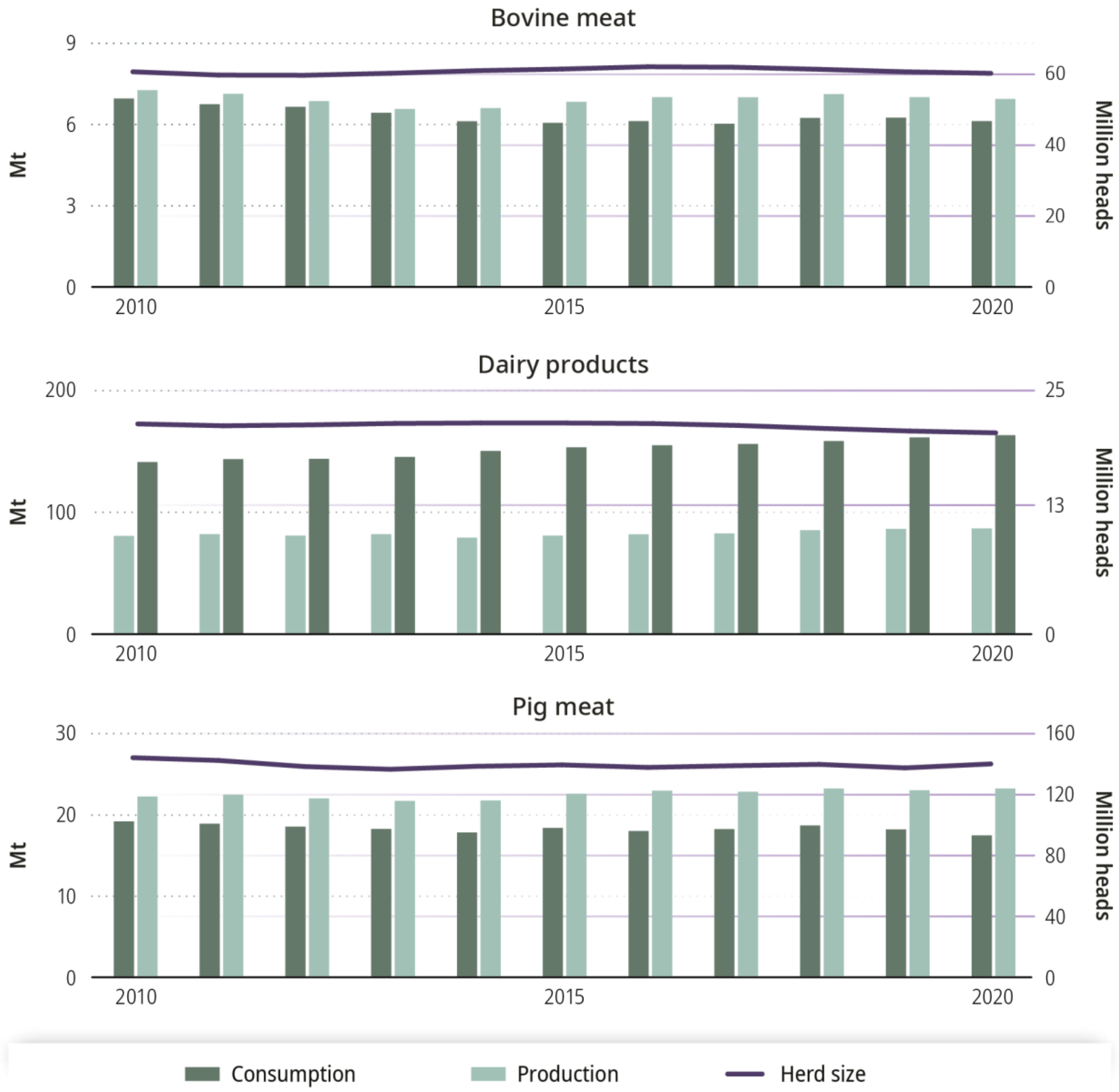
[52] GHGs in Pérez Dominguez et al. (2020) are expressed using the 100-year global warming potential from the IPCC Fourth Assessment Report (IPCC, 2007a).

production have been achieved through improved productivity, with the total herd size declining for dairy cattle and pigs (stable since 2013) and relatively stable for non-dairy cattle.

Total beef consumption decreased in 2010–2020 (by 1 Mt). Production decreased in line with consumption until 2013, but then decoupled from consumption and started to increase again. The herd size fluctuated slightly and was 1 % lower in 2020 than in 2010. The ratio between production and herd size might be explained by a shift towards slaughtering cattle at a later age, which is also supported by the lower ratio of slaughtering to herd size observed in the United Nation's Food and Agriculture Organisation (UN FAO) Corporate Statistical Database (FAOSTAT) data.

The consumption of dairy products increased by 6 Mt between 2010 and 2020 but was outpaced by an increase in production of 22 Mt. Production increases were mainly driven by improved productivity due to genetic selection (larger animals with higher milk production per head), while the total herd size decreased by 1 million head.

Figure 59 Indicator A4 – total production and consumption of livestock products (left axis) and herd sizes (right axis)



Sources: EU CRF tables (EEA, 2023h) (Herd Size), FAO Food Balances (2023) (Consumption & Production)

Despite a reduction in pig meat consumption (by 2 Mt in 2010–2020), production levels increased by 1 Mt. This increase in production was achieved through higher productivity, as the total herd size decreased only slightly in the same period, by 3 %.

To be beneficial for the global climate, lower production of GHG-intensive products will have to be matched by a shift to more sustainable, plant-based diets (addressed in the next section). Such a change should be possible given that agricultural production in the EU is supported by the CAP, which could be reformed to become more ambitious on climate change and provide greater support to low-emission production and environmental stewardship (see subsection 'Common agricultural policy' above).

Lever: sustainable, healthy diets

The health and environmental benefits of sustainable diets are recognised in the EU Farm to Fork Strategy. EU policies to encourage sustainable diets focus primarily on information provision and voluntary codes of conduct, but these measures are not sufficient by themselves.

Despite the heterogeneity of production practices, it is generally true that meat from ruminant animals has the highest GHG emissions (20–50 kg CO_2e per 100 g of protein), followed by other meat and fish (5–8 kg) and dairy (3–11 kg) (Poore and Nemecek (2018), Figure 1) ([53]). For ruminant livestock, a large share of emissions come from CH_4. However, meat (in particular, beef) has higher emissions than other products even when CH_4 emissions are excluded (Ritchie, 2020).

As mentioned above ('Towards a whole-system approach'), shifting to healthier, sustainable, more plant-based diets is important both because of the health and environmental benefits, and because an exclusively supply-side approach risks being undermined by trade-related leakage effects. According to data from the UN FAO shown in Figure 60 ([54]), the average consumption of beef and pig meat per capita has fallen over the last 10 years, although the trend seems to have stagnated and even slightly rebounded in the second half of the period. The observed average reduction in bovine meat consumption in 2016–2020 of 0.01 kcal per person per day would have to accelerate to 0.14 kcal per person (a more than 18-fold increase) to align with a linear trajectory towards the 2050 benchmark. On the positive side, the reduction of pig meat consumption (– 1.3 kcal per person per day on average in 2016–2020) is well on track towards the 2050 benchmark of 0.6 kcal per person per day in 2021–2050.

In contrast to the consumption of meat, the average consumption of dairy products has been increasing in the last 10 years.

The benchmark used for this assessment is the most ambitious ('diet 5') of five possible diet scenarios included in the in-depth analysis supporting the European Commission's 2018 LTS. This scenario could deliver reductions of around 100 Mt CO_{2e} in 2050, reduces animal-based calorie intake by around a third between 2013 and 2050, and would be consistent with reaching meat consumption in line with recommended diets by 2070 (EC, 2018e). Therefore, even though it is the most ambitious of all the scenarios assessed, it still reaches recommended diets only 20 years after the EU's deadline to achieve climate neutrality. The benchmark should therefore be considered as a strict minimum, and further (and faster) reductions in animal product consumption would be recommended. This would not only contribute to further GHG emission reductions but also be recommendable from a health perspective. For example, the World Cancer Research Fund has issued a recommendation to limit the consumption

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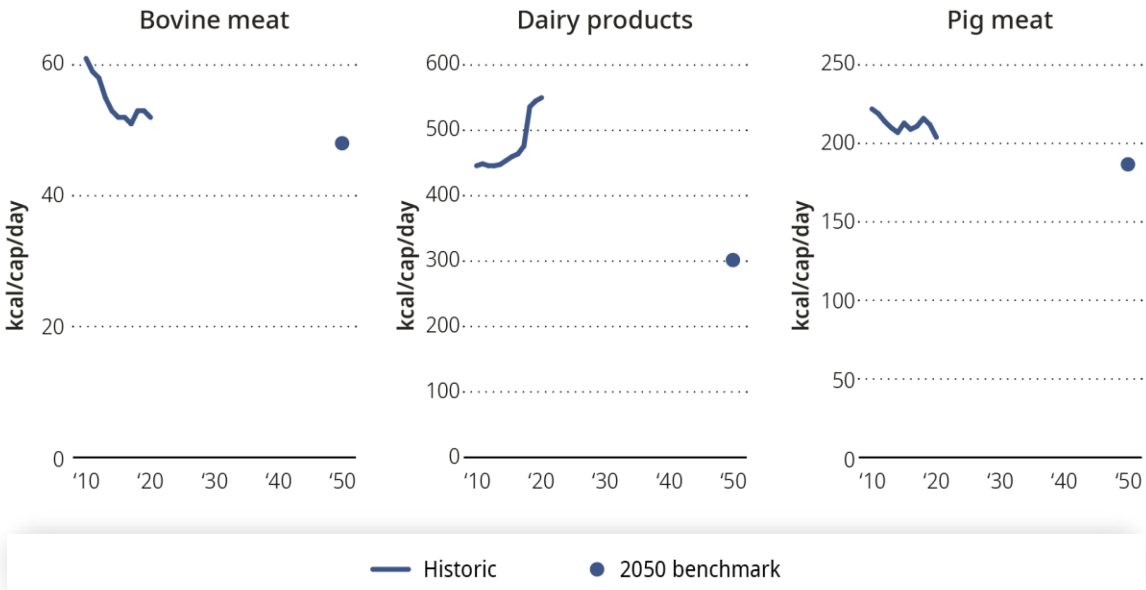
([53]) Figures refer to mean values. For dairy, the low value refers to milk and the high value to cheese.

([54]) The UN FAO database provides information on average animal product consumption per capita in different countries and regions, including for the EU-27. This data is based on consumer surveys, and the values are therefore estimates with some degree of uncertainty.

of red meat ([55]) to a maximum of 525–750 g per week to reduce cancer risks (WCRF, forthcoming). This would imply a reduction of 30–50 % compared with the average red meat consumption in the EU-27 of 1.1 kg per person per week in 2020 (FAO, 2023).

Figure 60 Indicator A5 – average animal product consumption



Notes: 2050 benchmarks based on 'Diet 5' from the in-depth analysis accompanying A Clean Planet for All.

Sources: FAO Food Balances (2023) (historic), In-depth analysis accompanying A Clean Planet for All (EC, 2018e) (Figure 76) (benchmark).

Looking at the issue of sustainable and healthy diets more broadly, the European Commission's Farm to Fork Strategy states that current EU food consumption patterns are unsustainable on both health and environmental grounds, citing evidence that 950 000 deaths a year and 16 million lost healthy life-years can be attributed to unhealthy diets. The strategy therefore calls for promoting sustainable food consumption and facilitating the shift to healthy, sustainable diets.

To this end, it proposes empowering consumers to make healthy and sustainable food choices, improving the availability and price of sustainable food and putting in place tax incentives to encourage healthy diets.

One criticism of the Farm to Fork Strategy is that it **remains vague on definitions and lacks quantified objectives for the shift towards sustainable and healthy consumption patterns**. It uses several general concepts such as 'food sustainability', 'sustainable (agri-)food system' and 'sustainable agricultural practices' without being specific about what they mean. This absence of clear definitions can lead to diverging interpretations, lack of a clear and common vision of the desired end goal, and therefore an increased risk of policy inconsistencies. This is evidenced by the EEA's analysis of the consultation responses to the Sustainable food system framework initiative, which found that stakeholders have different understandings of what a sustainable food system would look like (EEA, 2022h). Similarly, the strategy lacks quantified objectives for its demand-side ambitions (with the

([55]) Under World Cancer Research Fund International's interpretation of red meat, this includes beef, pork, lamb, mutton, horse and goat.

exception of reducing food waste by 50 % by 2030) which makes it difficult to track progress and hold policymakers accountable for the delivery of the objective (EEA, 2022h).

Overall, consumer choices are constrained by food product availability, accessibility and affordability, marketing strategies, and psychological (e.g. habits) and sociocultural (e.g. norms) factors. **Pricing policies could be among the most effective tools but are largely absent from the Farm to Fork Strategy.** The advisory bodies' reports found that pricing policies can be effective to steer consumer demand and ensure that food prices reflect their true costs of production and consumption (EEA, 2022h; EC, Group of Chief Scientific Advisors, 2020; SAPEA, 2023). The Farm to Fork Strategy acknowledges the importance of **tax incentives**, stating they 'should also drive the transition to a sustainable food system and encourage consumers to choose sustainable and healthy diets' (EC (2020f), p. 14). It refers to the ability of Member States to differentiate value added tax (VAT) levels to support specific types of more sustainable foodstuffs. However, the 2022 EEA report found that, at the national level too, there is an almost complete absence of favourable taxation schemes for sustainable consumer food products (EEA, 2022h).

One possible way to address this at the EU level while taking into account the EU's limited powers in the field of taxation is to apply **emission pricing** to the agri-food system (see Chapter 10 'Pricing emissions and rewarding removals' for a discussion of this). The European Commission is considering this option, and launched a survey in June 2023 to gather expert views on how such a system should be organised (EC, 2023bd). In order to have an impact on consumer behaviour, an emission-pricing regime would have to ensure that price incentives favouring low-emission food choices are eventually passed through to the end consumer.

There is a general consensus that introducing emission pricing for food would be regressive, because low-income households spend a larger share of their income on food (Kehlbacher et al. (2016), Klenert et al. (2023) and a number of studies reviewed by Temme et al. (2020)). Temme et al. (2020) suggest that a combination of taxes and subsidies could reduce regressive effects and may enable consumers to change to a more healthy and sustainable diet without additional cost. Modelling by Klenert et al. (2023) supports this conclusion, estimating that a EUR 50/t CO_2e tax on meat would cost the lowest quintile of consumers EUR 72 per year (around 0.6 % of total food expenditure), that recycling the revenue into reduced VAT for fruit and vegetables would reduce this cost to EUR 15, and that recycling the revenue as a lump sum transfer would reduce inequality by returning EUR 13–350 to the lowest income quintile (the range depending on whether the transfer goes to all households or only the poorest quintile).

Pricing policies promoting healthier diets (while ensuring access to healthy food for all) can also be justified on health grounds, with Temme et al. (2020) suggesting that this rationale may increase public acceptability. Predominantly plant-based diets such as the EAT-Lancet diet (Willett et al., 2019) have been designed with objective of improving both health and sustainability outcomes.

Given the evidence outlined above, policies based on emission pricing can in principle incentivise shifts from red to white meat, and to more plant-based diets, while achieving positive outcomes for health, climate and inequality. However, the use of emission pricing or taxes without complementary policies could lead to unintended health outcomes. For example, it could encourage consumers to switch to lower-quality meats, or to sugary products that are not emission-intensive (Kehlbacher et al., 2016; Klenert et al., 2023).

The Farm to Fork Strategy places a great emphasis on **improved information provision** as a key driver of consumer behaviour change (although the European Commission has not yet published the announced proposals at time of writing). The overall approach focuses on providing better information to consumers (e.g. through labelling), in the expectation that they will make well-informed and rational choices towards more healthy and sustainable diets (EEA, 2022h; SAPEA, 2023). According to a number of recent reports by EU advisory bodies (EEA, 2022h; EC, Group of Chief Scientific Advisors, 2020; SAPEA, 2020, 2023), soft policies such as information provision, sensibilisation and choice architecture ('nudging') can support the required shifts in consumer behaviour but are insufficient on their own to drive the required change. As discussed above ('Towards a whole-system approach'), the EU code of conduct on responsible food business and marketing practices has had mixed results so far in facilitating a shift towards healthy and sustainable diets.

Regarding the **social, cultural and behavioural aspects of food consumption**, SAPEA (2023) and other studies such as those by Eker et al. (2019) and Wendler and Halkier (2023) point to the importance of the social environment (i.e. the fact that dietary change is not merely carried out by isolated individuals). Wendler and Halkier go further, arguing that the social aspect (essentially whether a plant-based diet is considered more or less normal) could have a greater influence on meat consumption than an individual's intention to change their diet. In this respect, measures such as improving the sustainability of public procurement (suggested in the Farm to Fork Strategy) can also have an important role to play.

In conclusion, the introduction of price-based policies to encourage healthy and sustainable diets appears to be the main element missing from the EU's farm to fork policy. If well designed, it could be introduced with a modest regressive effect, or even be a financial benefit to low-income consumers. Therefore, the introduction of more binding measures such as regulations and financial incentives appears necessary but should be combined with further efforts to enhance information provision and education about sustainable and healthy diets as part of a broad policy mix.

Lever: reduced food loss and waste

EU policies to reduce food waste are in preparation, and the recent establishment of a monitoring system is an important first step. However, the proposed targets are less ambitious than the aims of the Farm to Fork Strategy.

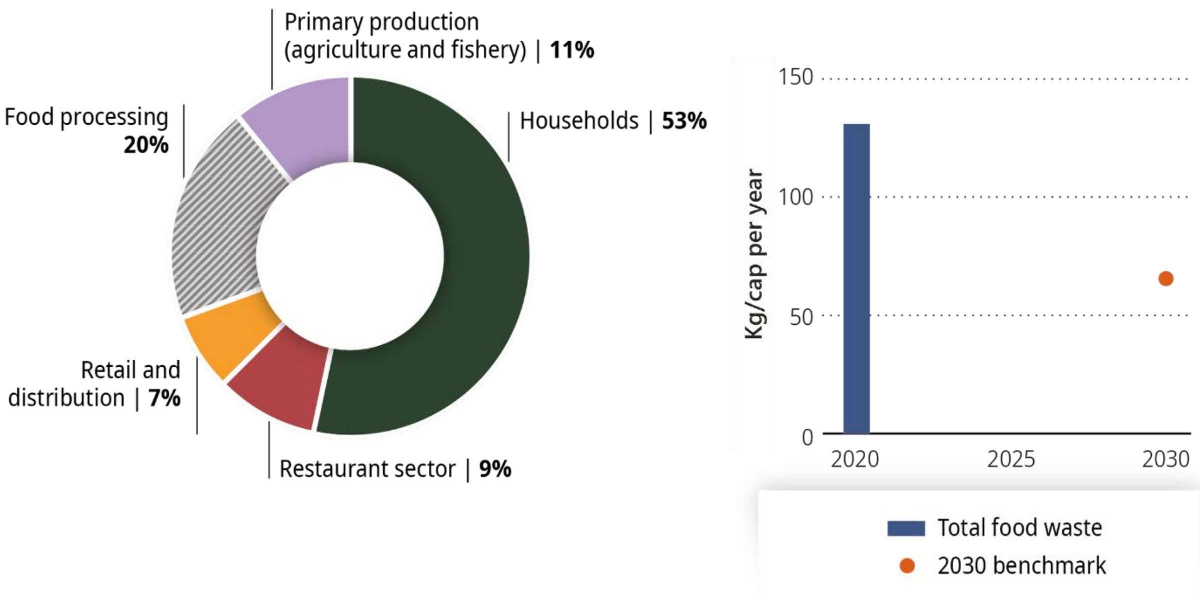
Reducing food loss and waste could deliver considerable emission reductions. Currently, food waste represents approximately 15 % of the total GHG footprint of the EU food system (EEA, 2022h). Reducing food losses and waste could reduce emissions both directly (by reducing agricultural production, food processing and transport) and indirectly (by making land available that could be used for biomass production or carbon sequestration). Food loss and waste take place across the entire agri-food value chain, and in particular the distribution and (post-)consumption stages. Options to reduce them include incentives to reduce business- and consumer-level waste, active marketing of cosmetically imperfect products, improved information provision and regulation of unfair business practices. Potential co-benefits are reduced environmental stress and improved food security.

Before the adoption of the Farm to Fork Strategy, food waste was already considered in a number of EU-level policies and strategies. The European Commission proposed a series of actions under the 2015 Circular Economy Action Plan (EC, 2015a), and the 2018 Waste Framework Directive (EU, 2018a) included obligations for Member States to reduce food waste (without any quantified objective), to measure food waste levels and to report on progress made. To this end, in 2019 the European Commission adopted a common food waste measurement methodology (EC, 2019a) to ensure harmonised food waste monitoring and reporting across Member States.

The Farm to Fork Strategy puts forward a concrete, quantified objective of reducing food waste per capita by 50 % by 2030. Recently, it also published a proposal to revise the Waste Framework Directive (EC, 2023aq), which sets legally binding objectives for Member States to reduce food waste. Under the proposal, food waste in processing and manufacturing would need to be reduced by 10 % by 2030, and food waste in the retail, distribution, restaurant and food services and households would need to be reduced by 30 % by 2030 (both compared to 2020, in kilograms per capita). No objective is set for primary producers, which accounted for 11 % of total food waste in 2020. Given that the objective does not cover all food waste and sets targets below the overall 50 % reduction objective, it is highly uncertain that it will be sufficient to meet that objective. The European Commission acknowledged this ambition gap but argued that lower targets were needed to ensure feasibility, and that targets can be revised upwards in the event of sufficient progress.

Data collected under the common food waste measurement methodology in Figure 61 shows that in 2020 the EU wasted on average 131 kg of fresh food per capita, most of it during the consumption phase: 53 % of the total waste was generated by households and 9 % in the restaurant sector. Under its Farm to Fork Strategy, the European Commission is committed to halving this by 2030, in line with sustainable development goal 12.3 (EC, 2020f). Data for 2021 will bring further clarity about whether the EU is moving in the right direction and at an adequate pace to achieve this objective.

Figure 61 Indicator A6 – food waste in the EU in 2020, per source (left) and compared to the 2030 benchmark (right)



Notes: Food waste during the primary production of foods excludes pre-harvesting food losses. 2030 benchmark based on the European Commission's Farm to Fork Strategy.

Sources: Eurostat (2023i) (2020 data), Farm to Fork Strategy (EC, 2020f) (benchmark).

Lever: minimise demand for biofuel crops

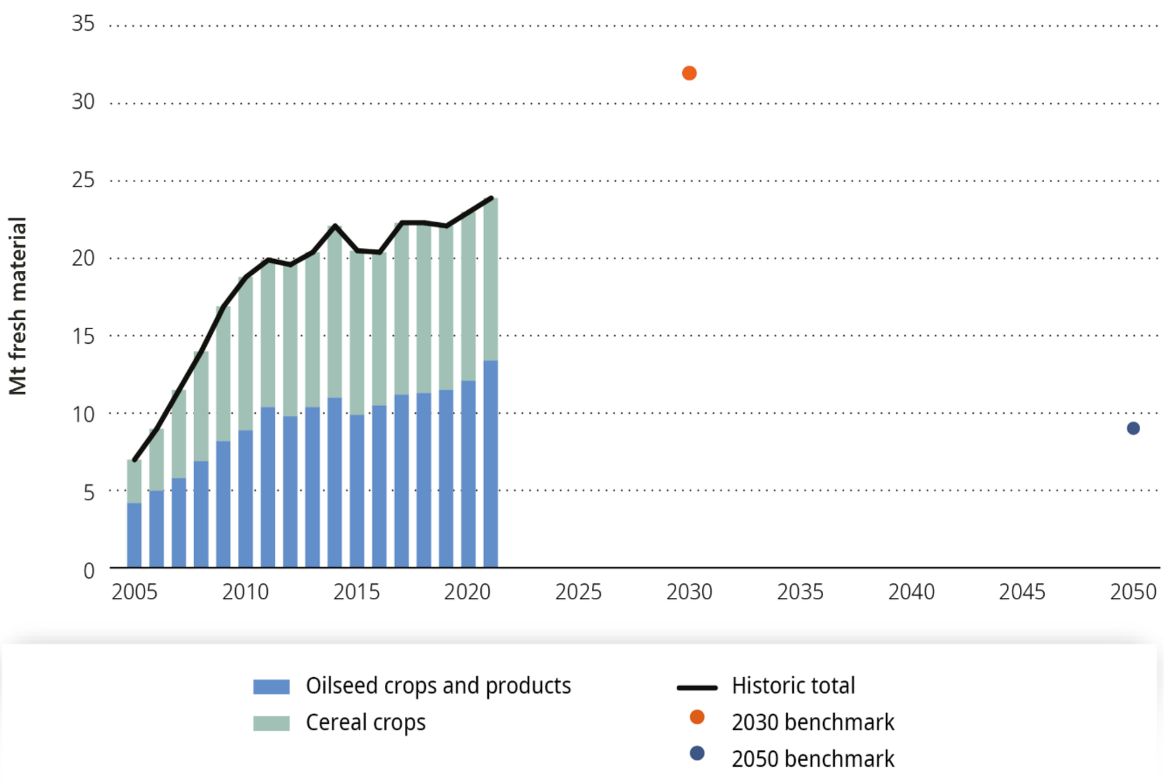
In the long term, use of food crops for first-generation biofuels is expected to decline thanks to advances in electric vehicles and second-generation biofuel technology. However, first-generation biofuel production may continue to grow in the short term as a result of renewable fuel mandates.

The use of bioenergy can lead to either increased or reduced emissions, depending on the scale of deployment, the conversion technology, what fuel it displaces and how/where the biomass is produced (IPCC, 2022i). In particular, some of the GHG emissions and other sustainable development impacts associated with demand for bioenergy cannot be observed or measured directly, because it is entangled with a large number of other changes in agricultural markets at both the global and local levels (Valin et al., 2015). This chapter considers the influence of bioenergy markets on the EU agricultural sector, while Chapter 6 (on transport) examines EU bioenergy policies in general.

The use of agricultural crops as feedstock for biofuels has been increasing since 2005 as the result of EU policies promoting the use of biofuels to decarbonise the transport sector (see Section 6.4, under 'Lever: fuel switches'). The increase was strongest in 2005–2010, after which it slowed down. Nevertheless, by 2021 the absolute volumes of cereal crops and vegetable oils used as biofuel feedstocks more than tripled compared with 2005. Whereas the share of cereal crops used for biofuel production is relatively small (4 % of total), a large minority (40 %) of the total vegetable oil use in 2021 in the EU was linked to biofuel production.

Under the European Commission's MIX scenario underpinning the 55 % reduction objective, the use of food crops for biofuel production would continue to increase up to 2030 at a rate of 0.9 Mt fresh material per year, faster than the observed trend in 2016–2021 (0.4 Mt fresh material per year). After 2030, the MIX scenario envisages continued growth in production of bioenergy feedstocks overall, but largely from non-food crops (lignocellulosic grass) and agricultural residues. Total food crop use for biofuel production should be 66 % below 2021 levels by 2050. Given recent declines in the cost of both batteries and variable renewable generation technologies (IPCC, 2022g), more up-to-date scenarios may find that EU climate targets can be met with lower production and bioenergy use than that set out in the MIX scenario.

Figure 62 Indicator A7 – use of agricultural products as bioenergy feedstocks



Sources: JRC Medium-term outlook commodity flows (Gurría Albusac et al., 2021) (historic), Climate Target Plan impact assessment MIX scenarios (EC, 2020s) (Figure 79) (benchmarks).

8.6 Summary tables

Table 12 Progress summary - agriculture

Indicator	Reference period	Historical progress	Required up to 2030	Required in 2031–2050
A1: GHG emissions	2005–2022	– 1 Mt CO_2e/yr	– 3.5 Mt CO_2e/yr	– 4 Mt CO_2e/yr
A2: livestock GHG intensity				
A2a: beef	2016–2020	– 73 kg CO_2e/kg/yr	No benchmark	No benchmark
A2b: dairy products	2016–2020	– 9 kg CO_2e/kg/yr	No benchmark	No benchmark
A2c: pig meat	2016–2020	+3 kg CO_2e/kg/yr	No benchmark	No benchmark
A3: total fertiliser use	2017–2021	–179 kt N/yr	– 313 kt N/yr	No benchmark
A4: livestock production				
A4a: beef	2016–2020	Stable	No benchmark	No benchmark
A4b: dairy products	2016–2020	+ 2 Mt/yr	No benchmark	No benchmark
A4c: pig meat	2016–2020	Stable	No benchmark	No benchmark
A5: livestock product consumption				
A5a: beef	2016–2020	– 3 kcal per person y^{-1}	No benchmark	– 50 kcal per person/yr
A5b: dairy products	2016–2020	+ 7 777 kcal per person/yr	No benchmark	– 2 970 kcal per person/yr
A5c: pig meat	2016–2020	– 468 kcal per person/yr	No benchmark	– 204 kcal per person/yr
A7: food waste	2020	131 kg per person/yr ([a])	– 7 kg/cap/yr	No benchmark
A7: bioenergy feedstock crops	2017–2021	+ 0.4 Mt FM/yr	+ 0.9 Mt FM/yr	– 1.2 Mt FM/yr

Legend

On track	The required change ([b]) is ≤ 1.
Almost on track	The required change ([b]) is between 1 and 1.5.
Somewhat off track	The required change ([b]) is between 1.5 and 2.
Considerably off track	The required change ([b]) is ≥ 2.
Wrong direction	The required change ([b]) is < 0.

([a]) Only data for one year available; not possible to compare with required progress.
([b]) See Section 2.2 for more details on how the required change is calculated.

Table 13 Policy consistency summary – agriculture

Policy inconsistencies	– Support to emission-intensive agricultural practices such as livestock production continues under the CAP through area-based and, in some cases, production-linked payments. – EU energy policy continues to promote first-generation biofuels.
Policy gaps	– GHG emissions from agriculture are not covered by an emission-pricing system. – Several initiatives announced in the Farm to Fork Strategy have not yet been adopted as final legislation. In some cases, the initial proposal from the European Commission has not been published.
Ambition gaps	– Emission reduction targets and objectives under the CAP are combined with general agri-environmental objectives and are largely qualitative. – Emphasis on mitigation in Member States' CAP CSPs is largely discretionary. Expected mitigation outcomes are difficult to quantify. – The Farm to Fork Strategy lacks delivery mechanisms and relies on non-binding measures (such as information provision). – The impact of recent food and agriculture initiatives such as the EU Code of Conduct on Responsible Food Business and Marketing Practices, food waste reduction targets in the Waste Framework Directive revision proposal and the revised industrial emissions directive are expected to be low.

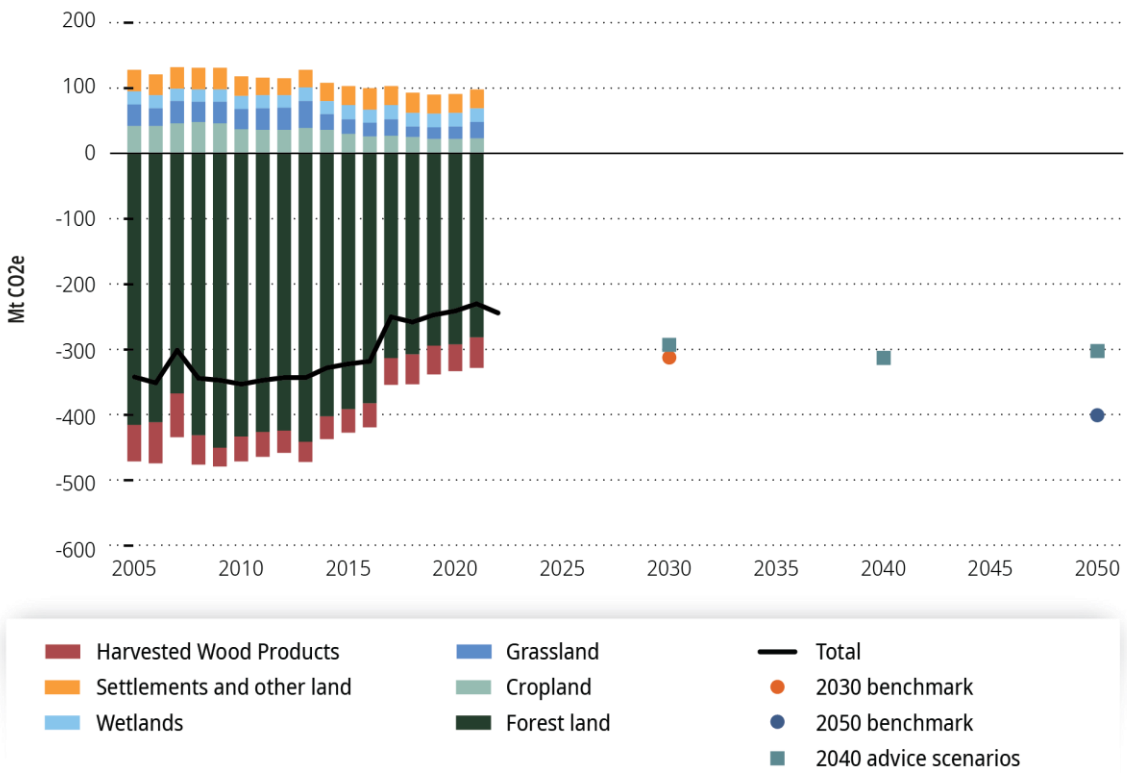
9 Land use, land use change and forestry

Key messages

The observed decrease in the net carbon sink in the LULUCF sector needs to be reversed to be consistent with the EU climate objectives. Several complementary options are available to achieve this.

Figure 63 displays the overall levels of emissions and removals from the LULUCF sector. The net sink in the LULUCF sector has been in decline since 2010 and was a third lower in 2021 than in 2005. The decline was predominantly caused by reduced CO_2 removals by EU forests, driven by slower forest growth, natural disturbances and increased demand for woody biomass (see indicator L6 for more details). The carbon sink has declined, removing on average 6 Mt CO_2 less every year in 2005–2022. This trend needs to be reversed so that the sink will remove on average an additional 8 Mt CO_2 each year in 2023–2030 to meet the legally binding target of 310 Mt CO_2e net removals per year by 2030, and to be consistent the European Commission scenarios underpinning the 2050 climate neutrality objective.

Figure 63 Indicator L1 – overall progress in reducing emissions (positive values) and increasing removals (negative values) in the LULUCF sector



Sources and Notes: See Figure 65 for detailed sources and notes.

The Advisory Board has explored four possible pathways to reverse the downward trend in the LULUCF sink: maintain and expand forests and wetland areas, increase the carbon sink in existing forests, reduce GHG emissions and increase removals in crop- and grasslands, and improve the resilience of ecosystems to current and projected climate change impacts. These solutions are not mutually exclusive, and a combination of all four might be required to achieve the required net removals in 2030 and beyond. The conclusions of the assessment for each pathway are summarised below.

The potential to maintain and expand the area of forests and wetlands is undermined by EU policies on agriculture and biofuels, which are driving land use for agricultural production.

Needs. Maintaining and expanding the area of forests and wetlands has substantial potential to increase the net sink in the LULUCF sector. Its potential is constrained by land availability, which is largely determined by demand for other competing land uses such as human settlements and agricultural production. More efficient spatial planning (see also Section 7.5), lower production of livestock products (which accounts for approximately 65 % of total agricultural land use), reduced food waste and lower production of biofuels made from feed and food crops are all enabling conditions that can reduce demand for these land uses and therefore increase the land available for carbon sequestration.

Gaps. Even if the total area of agricultural land in the EU has slightly decreased, several EU policies are putting upward pressure on demand for agricultural land, which undermines the potential to maintain and expand forest and wetland areas. As described in Chapter 8 'Agriculture', the current CAP continues to financially support livestock production **(policy inconsistency)**, which drives demand for land for feed production. Similarly, the CAP continues to financially support the cultivation of organic soils and marginal lands, which might be better suited to carbon sequestration **(policy inconsistency)**. The CAP does have a mandatory requirement to preserve wetlands (good agricultural and environmental condition (GAEC) 2), but over half of the EU Member States have opted to delay its implementation to 2024 or 2025. The CAP also allows support mechanisms (eco-schemes) for the restoration of wetlands, but these are used to only a limited extent by Member States **(implementation gap)**. The objectives of the Farm to Fork Strategy to reduce fertiliser use (by 20 %) and increase the share of organic farming (to 20 %) have direct local environmental benefits, but risk reducing yields and therefore increasing demand for land (either in the EU or abroad) if demand for agricultural products is not reduced in parallel **(policy gap)**. It also includes an ambitious (non-binding) objective to reduce food waste per capita by 50 % by 2030, but the proposed legal objectives under the Waste Framework Directive fall short of achieving this **(ambition gap)**. Finally, as described in Chapter 6 'Transport', EU biofuel policies continue to incentivise demand for specific biofuel types that drive demand for agricultural land **(policy inconsistency)**.

Recommendation L1. EU policies on agriculture and biofuels should better reflect the need to maintain and expand the area of forests and wetlands for carbon sequestration purposes. The upcoming revision of the CAP should reduce support for livestock production, which is a major driver of demand for agricultural land. Similarly, EU biofuel policies should cease to promote the use of biofuels with high ILUC risks, and in particular first-generation biofuels (see also Chapter 6 'Transport'). Finally, the EU should leverage its competence to support more efficient spatial planning at the (sub)national level (see also Section 7.5).

The carbon sink in EU forests is under pressure from multiple factors, including wood demand. To keep aggregate demand for biomass within sustainable limits while ensuring sufficient supply, incentives for bioenergy use should be better targeted towards end use sectors with limited other mitigation options.

Needs. The decline in the EU forest carbon sink is driven by several, interlinked factors including forest age, climate change impacts and harvesting practices (which affect carbon sequestration both in living biomass and in forest soils). There is an ongoing scientific debate on the role of EU biomass policies in driving the observed decline in the carbon sink (through increased harvesting), and the climate mitigation impact of (forest) biomass use in general. This impact strongly depends on the source and end use of forest biomass, but there is also a need to limit the aggregate demand to the sustainably available supply of forest biomass.

Gaps. Subsequent revisions of the Renewable Energy Directive have made incentives for biomass use for energy conditional on increasingly stringent sustainability criteria, minimum GHG savings thresholds and adherence to the cascading principle. Furthermore, the incentives for bioenergy use are expected to be counterbalanced by the incentive coming from the LULUCF Regulation, and Member States will have to report on the compatibility of their bioenergy policies with their targets under the LULUCF Regulation. Nevertheless, some reasons for concern remain. Firstly, specific exemptions **(ambition gap)** and monitoring and compliance issues (including fraud) **(implementation gap)** risk undermining the effectiveness of the sustainability criteria and provisions on the cascading principle under the RED III. Secondly, so far, Member States have provided insufficient information for the European Commission to assess the compatibility between projected bioenergy demand and sustainably available supply **(implementation gap)**. Furthermore, the incentives for using forest biomass for energy purposes versus maximising the LULUCF carbon sink continue to be unevenly distributed in the absence of a financial incentive for land managers to reduce emissions and increase removals in the LULUCF sector **(policy gap)** (see also Chapter 10 'Pricing emissions and rewarding removals'). Finally, the aggregate demand for biomass is currently projected to (substantially) exceed sustainably available supply. As a result, the EU risks either increasing biomass harvesting levels beyond what is sustainable (thereby undermining the LULUCF net sink) or increasing the import of biomass from regions outside the EU (thereby exporting environmental pressures to outside the EU). This risk could be mitigated by better targeting incentives for biomass use to sectors that have limited other mitigation options. However, key EU policies such as the RED III ([56]) do not differentiate incentives for bioenergy use as a function of other available mitigation options for each end use **(policy gap)**.

Recommendation L2. EU policies should better target incentives for bioenergy use towards end uses with limited mitigation options, to reduce the risk that aggregate demand will exceed sustainably available supply.

Recommendation L3. The EU should start preparations now with the view to introduce a GHG pricing instrument in the LULUCF sector, as to provide a financial incentive for forest managers to reduce emissions and increase removals. This would counterbalance current price incentives for biomass use (see also Chapter 10 'Pricing emissions and rewarding removals').

The potential of reducing CO2 emissions and emission removals in other land use categories (mainly agricultural land) remains under-addressed by EU policies.

Needs. Reducing net CO_2 emissions in non-forest land use categories (e.g. through sustainable soil carbon management practices and agroforestry) can contribute to increasing the overall LULUCF net sink, which is particularly important given the challenges in increasing the forest carbon sink. Whereas net emissions from these non-forest land use categories have reduced by 24 % compared to 2005, they have partially rebounded in recent years. To be consistent with the European Commission's scenarios that underpin the 2030 – 55 % objective, their net emissions need to be reduced by 12 % by 2030 and 75 % by 2050 compared to 2021.

Gaps. The CAP is the strongest policy driver of agricultural land use decisions. It includes both mandatory (e.g. GAECs 1 and 2 on wetland and grassland preservation) and voluntary (e.g. eco-schemes to support 'carbon farming' ([57]) and agroforestry) provisions that aim to reduce emissions from and increase

([56]) The exception is electricity-only generation, which cannot receive new or renewed support except when used in specific just-transition regions with high dependence on solid fossil fuels, as a temporary measure in outermost regions and territories, or in combination with CCS.

([57]) See (EC, 2021u) for an overview of the different practices covered under this term.

emission removals in agricultural soils. However, there are reasons for concern about the effectiveness of these measures. The mandatory requirement on the maintenance of grasslands (GAEC 1) does not prevent agricultural practices that lead to high soil carbon emissions from grasslands **(ambition gap)**. Whereas most Member States have set targets on carbon storage in soil and biomass, only eight of them included voluntary eco-schemes to incentivise carbon farming, often with low levels of ambition **(implementation gap)**. The assessment result is more positive for agroforestry, with a majority of Member States supporting it either directly or indirectly under the CAP. However, the effectiveness of these national support schemes is still suboptimal owing to their limited scope (which relates to a more general concern about the expected effectiveness of eco-schemes; see also Chapter 8 'Agriculture') **(implementation gap)**.

The agriculture and LULUCF sectors are currently still excluded from the EU GHG-pricing regime, which also implies a lack of an overall financial incentive for farmers and land managers to enhance CDR **(policy gap)**. The Carbon Removal Certification Framework, which is currently under development, might create such an incentive, but only to the extent that it creates a voluntary market.

Recommendation L4. Overall, EU policies should provide stronger incentives to trigger emission reductions and removals in all land use categories, including agricultural soils. This could be achieved by making better use of the potential of the CAP, and by pricing GHG emissions and rewarding removals in the LULUCF sector (see also recommendation L3 above and Chapter 10 'Pricing emissions and rewarding removals'). The Advisory Board will publish a dedicated report on the topic of CDR in 2024, including more detailed recommendations on how they should be governed and incentivised at the EU level.

Climate adaptation is crucial to maintain and possibly even increase the net sink in the LULUCF sector. At the same time, even with increased adaptation efforts, the future of the net sink is uncertain.

Needs. The LULUCF sink is increasingly under pressure from natural disturbances, which are exacerbated by climate change, a trend that is projected to worsen in the future. This highlights the need for increased adaptation efforts, such as (in many places) shifting conifer monocultures to mixed-species or broadleaf forests. Such adaptation efforts might decrease the sink in the short term (as maladapted species are harvested) but would increase it in the future (as newly established trees grow and losses from natural disturbances are reduced). Furthermore, it highlights the need to account for uncertainty when relying on removals in the LULUCF sector to achieve overall climate objectives.

Gaps. The assumptions that underpin the LULUCF objective for 2030 did not account for the uncertain effects of climate change and related natural disturbances on the development of the sink **(policy gap)**. The European Climate Risk Assessment will include an assessment of the potential impacts of climate change on the forestry sector, which can provide a good knowledge basis for the future.

Recommendation L5. To cope with the uncertainties of climate change, the EU and its Member States should increase efforts on adaptation.

Recommendation L6. In parallel, the EU should develop a contingency strategy to manage the potential impacts of climate change on the LULUCF net sink. The contingency strategy should include an assessment of the potential development of the LULUCF sink under different climate change scenarios and explore the potential for further reductions in residual emissions or increases in technological emission removals to cope with a further decline in the LULUCF sink.

9.1 Scope and sectoral assessment framework

Scope

This chapter covers all GHG emissions and removals by the EU LULUCF sector, as reported to the UNFCCC under CRF category 4. It focuses particularly on emissions and removals by forests (afforestation, deforestation and forest management), which is by far the largest land use category in terms of net GHG removals, but also the main driver behind the observed decline in the net sink observed over the last decade (see Section 9.2 below). Emissions and GHG removals in other land use categories (crop-, grass-, wet- and peatlands) are also covered under this chapter, but in less detail. The Advisory Board will publish a separate, dedicated report on CDR in 2024, which will cover the topic in more detail, as well as the removal of CO_2 from the atmosphere through novel technologies such as BECCS and direct air carbon capture and storage (DACCS).

Emissions and removals in the LULUCF sector are governed by the LULUCF Regulation (EU, 2023j), which allocates binding targets to Member States. Each Member State will have to implement policies at the national level to achieve these objectives. If a Member State does not achieve its national objective, it can make use of several flexibilities set out in the regulation. Achieving the regulation's objective depends on policies to be defined by each Member State. The European Commission's assessment of the draft updated NECPs found that the majority of those draft updated do not show sufficient ambition and action on the LULUCF sector, with only very few Member States showing a concrete pathway to reach their national net removal targets (EC, 2023p). In aggregate, Member States' action in the sector would still lead to a gap of -40 to -50 Mt CO_2e compared to the 2030 target.

Whereas ambitious national action will be crucial for achieving the 2030 LULUCF objective, the policy consistency assessment in this chapter focuses on to what extent other EU policies facilitate or hamper the achievement of this objective.

Greenhouse gas emission reductions and removals required in the LULUCF sector to reach climate neutrality

Achieving overall climate neutrality requires a balance between anthropogenic GHG emissions ('residual emissions') and the removal of GHGs from the atmosphere. Currently, CDR in the LULUCF sector is the only available option to remove GHGs from the atmosphere at a large scale. In the future, this is expected to be complemented by CDR technologies such as BECCS and DACCS (IPCC, 2018).

The LULUCF sector in the EU is a net sink, removing 230 Mt CO_2e from the atmosphere in 2021 (EEA, 2023f). The EU has set a legally binding objective under the LULUCF Regulation to reach an annual net sink of 310 Mt CO_2 by 2030 (EU, 2023j). The impact assessment for that regulation states that, in order to achieve overall climate neutrality by 2050, net removals in the LULUCF sector should increase to 400 Mt CO_2e by 2050 (EC, 2021r). This corresponds to the 400 Mt CO_2e upper limit of the range of GHG removals in the LULUCF considered to be feasible under the Advisory Board's advice on the EU's 2040 reduction objective (ESABCC, 2023b), considering future impacts of climate change. Under those scenarios where net reductions reach 90–95 % by 2040, the LULUCF sink increases to approximately 300 Mt CO_2e by 2030, with a slight further increase by 2040 (325 Mt CO_2e), after which it levels off by 2050.

Assessment framework for the LULUCF sector

The following building blocks were identified to achieve the required net GHG removals in the LULUCF sector by 2050.

Outcomes. IPCC AR6 has identified several mitigation pathways (see mitigation levers below) that can reduce GHG emissions and increase GHG removals in forests and other ecosystems (IPCC, 2022a). Overall, these pathways aim to achieve either of the following goals, which have been selected as outcomes for the assessment in this chapter.

— **Maintain or expand the surface area of carbon-rich land use categories**, that is, land use categories with high carbon stocks or carbon sink ([58]) potential, primarily forests and wetlands.
— **Reduce emissions and increase emission removals** within each land use category.

Mitigation levers. To achieve these outcomes, five main levers were identified ([59]), which largely correspond to the main mitigation pathways included in Sections 7.4.2 and 7.4.3 of Working Group III's contribution to AR6 (IPCC, 2022a).

1. **Reducing deforestation and forest degradation** can reduce GHG emissions in the LULUCF sector on a short timescale (IPCC, 2022a). Whereas globally the highest potential lies in tropical forests, deforestation is still occurring in the EU-27 as well, causing approximately 30 Mt of CO_2e emissions each year (EEA, 2023h).
2. **Afforestation, reforestation and forest ecosystem restoration** can increase GHG emission removals. The level of emission removals per hectare is relatively low in the initial years, but then increases over time as trees start to grow. In the longer term, removals decrease again as forests reach maturity (EEA, 2023o).
3. **Avoiding conversion and degradation of wetlands and other organic soils** avoids high emissions per hectare on a short timescale, whereas **restoring** these land types can increase removals over a longer timescale (Humpenöder et al., 2020; IPCC, 2022a).
4. **Improved forest management** can increase the carbon stocks in existing managed forests, through a variety of practices such as longer rotations, less intensive harvests, continuous-cover forestry, change of species and provenances, and increasing resilience to avoid the risk of hazards (e.g. fires, windfall, pests and diseases) (IPCC, 2022a).
5. Certain agricultural practices can increase carbon sequestration on agricultural lands, both in the soil and in above-ground biomass. These include **sustainable agricultural soil management practices** (e.g. cover crops, reduced tillage, residue retention and improved water management) and **agroforestry** (the integration of woody vegetation on agricultural land used for grazing or crop production) (IPCC, 2022a; Kay et al., 2019; Sykes et al., 2020).

In addition to increasing the carbon stock in living biomass, some of the practices under levers 1, 2 and 4 can also increase carbon stocks in forest soils (see Box 5).

Enabling conditions. In addition, the following enablers were identified, which could support the various levers. This list is not exhaustive.

— The availability of land determines the potential for the expansion of land use categories with high carbon sequestration potential such as forests and wetlands (Searchinger et al., 2022b). It can be increased by **more efficient spatial planning** to reduce land take and urban sprawl (Metternicht,

([58]) A carbon stock is the total amount of carbon stored in an ecosystem, either in biomass or in soils. A carbon sink is the annual increase in the total carbon stock, in other words the amount of carbon that is removed from the atmosphere and added to the biosphere carbon stock in a certain year.
([59]) The conservation and restoration of grasslands is included as a mitigation pathway in the IPCC AR6, but not included as a mitigation lever in this chapter. This is because most of Europe's climate is suitable for forest ecosystems, which have a higher carbon sequestration potential than grasslands. Whereas reducing the conversion of grasslands to croplands can reduce emissions (and conversely the restoration of croplands to grasslands can increase removals), the conversion of crop- or grasslands to forests has an even higher GHG mitigation potential.

2018). Similarly, **reduced livestock production** (which require large amounts of land for feed production) (Leip et al., 2015) and **reduced food waste** (Philippidis et al., 2019) can reduce the area of land required for agricultural production.

— Keeping the **demand for biomass for GHG mitigation purposes** ([60]) **within sustainable limits** can support the mitigation levers in two ways. Keeping demand for woody biomass within sustainable limits avoids overharvesting of managed forests, which would lead to a decrease in the forest carbon sink (and even risking turning it into a source). Reduced demand for crops for biofuel production can reduce the land required for agricultural production, thereby increasing the land available for, for example, afforestation.
— **Price signals and financial incentives** can influence decisions on land use and land management (Kim and Langpap, 2015).
— **Enhancing climate adaptation/resilience** is key to maintaining the carbon stock and sink activity in EU forests and ecosystems, which are currently already under pressure from climate change impacts (Forzieri et al., 2022; Patacca et al., 2023). For example, the decrease in the forest carbon sink observed in recent years is partly due to natural disturbances such as pest outbreaks (bark beetles), storms and wildfires, all of which are projected to become more frequent and more intense as a result of climate change. Improving the resilience of forest and ecosystems against such disturbances can mitigate future carbon losses.

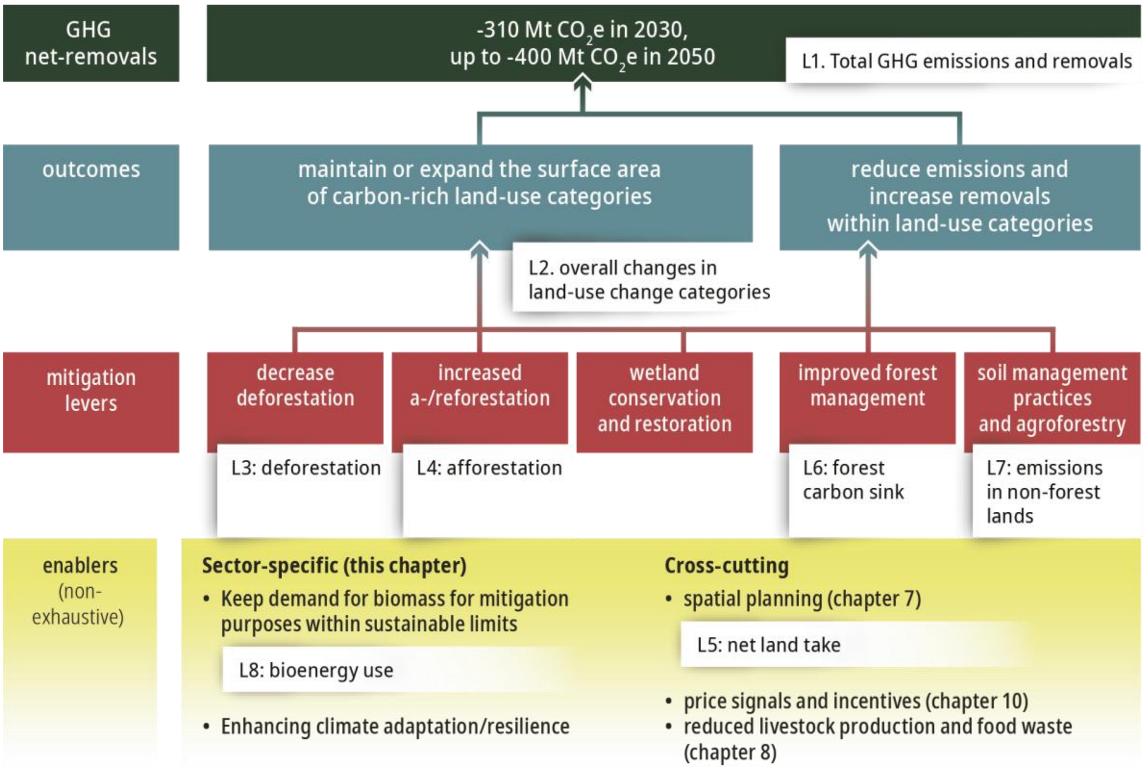
There are strong links between climate mitigation, climate adaptation, and biodiversity preservation and restoration. In most cases, there is potential for strong synergies. For example, maintaining and restoring carbon-rich ecosystems such as forests and wetlands contribute to climate mitigation, climate adaptation and biodiversity objectives. However, in some cases trade-offs might also occur; for example, rewetting afforested land might be beneficial from a nature and biodiversity perspective, but would reduce the carbon sink in the LULUCF sector. Although a detailed assessment of such potential synergies and trade-offs is beyond the scope of this report, it is important to taken them into account when developing policies affecting the LULUCF sector.

Finally, it is important to note that all land use categories are subject to carbon saturation, which means their potential to serve as a carbon sink will decrease over time and finally reach zero (EEA, 2023o). When this will occur depends on the type of land use, the point of departure and the specific measures taken to increase the carbon sink. From a policy perspective, this means that, whereas the LULUCF sector can contribute to climate neutrality by 2050, it cannot continue to offset residual emissions forever, and therefore provides only a temporary solution for residual emissions.

The assessment framework for the LULUCF sector – including the indicators selected to track progress for this sector (see white boxes) – are shown in Figure 64.

([60]) That is, demand for biomass to replace fossil fuels and feedstocks and other GHG-intensive materials.

Figure 64 Assessment framework for the LULUCF sector



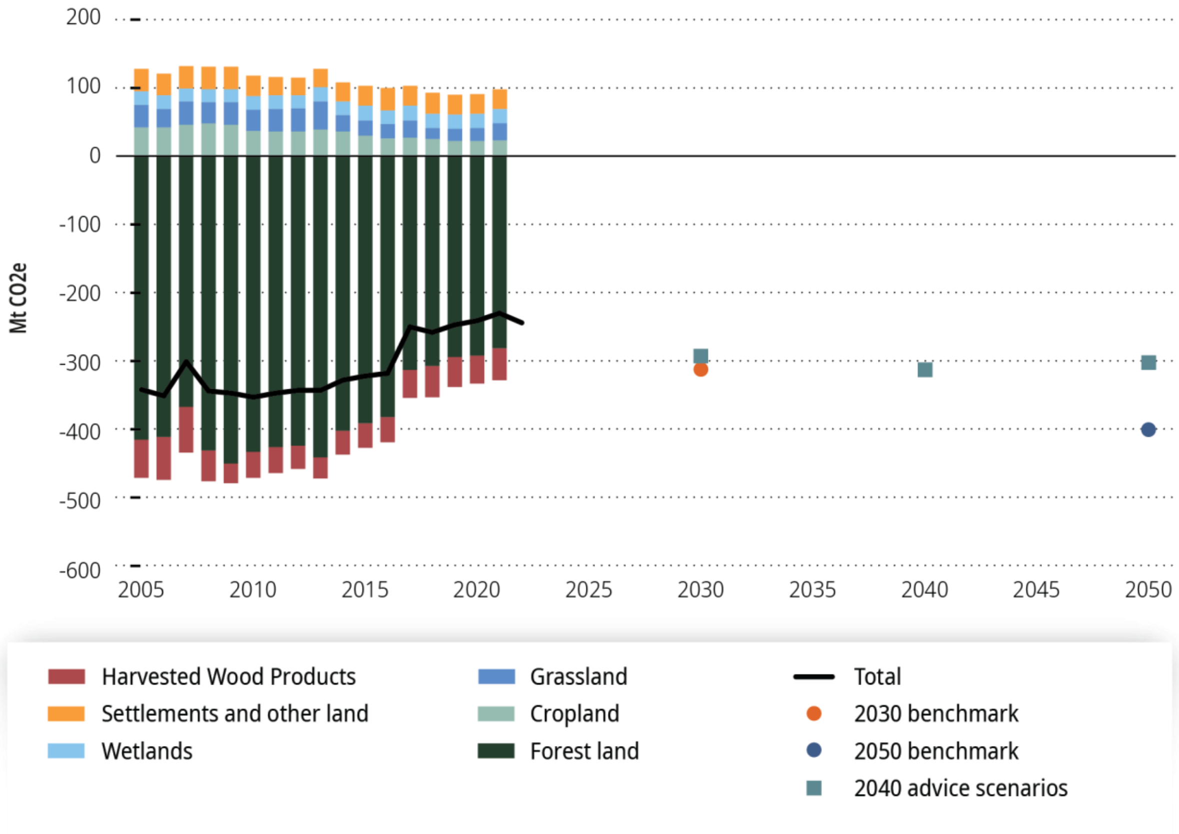
Source: Advisory Board (2024).

9.2 Emission reduction progress

As shown in Figure 65, the EU LULUCF sector is a net sink of GHG emissions, with gross emission removals in forest lands and in harvested wood products larger than the GHG emissions from other land use categories. However, after relative stability in 2005–2013, the net sink has been declining rapidly in the last 10 years, and in particular since 2016. By 2021, the total net sink had decreased by approximately one third (removing 112 Mt CO_2e less) compared to 2005. The reduction in the net sink was predominantly caused by a reduced carbon sink in EU forests (removing 134 Mt CO_2e less in 2021 than in 2005), which was driven by slower forest growth, natural disturbances and increased harvesting (see Figure 69 for more details). Proxy data for 2022 indicates a slight increase in the net sink compared to 2021.

The trend observed in the last decade would need to be reversed for the EU to meet the legally binding objective for 2030 (310 Mt CO_2e net removals). After 2030, the sink should be further increased to align with the European Commission scenarios underpinning the 2050 climate neutrality objective, and the scenarios underpinning the Advisory Board's advice on a 2040 reduction objective and the 2030–2050 GHG emission budget.

Figure 65 Indicator L1 – overall progress in reducing emissions (positive values) and increasing removals (negative values) in the LULUCF sector



Notes: Historic data from the EU GHG inventory, with 2022 data based on proxy data reported to the EEA. 2030 benchmark based on the legally binding objective under the LULUCF regulation, while 2050 benchmark based on the impact assessment accompanying the revised LULUCF regulation. 2040 advice values are based on the scenarios that underpin the Advisory Board's 2040 advice.

Sources: EU GHG inventory (EEA, 2023f), LULUCF regulation impact assessment (EC, 2021d), Advisory Board 2040 advice scenarios (ESABCC, 2023b).

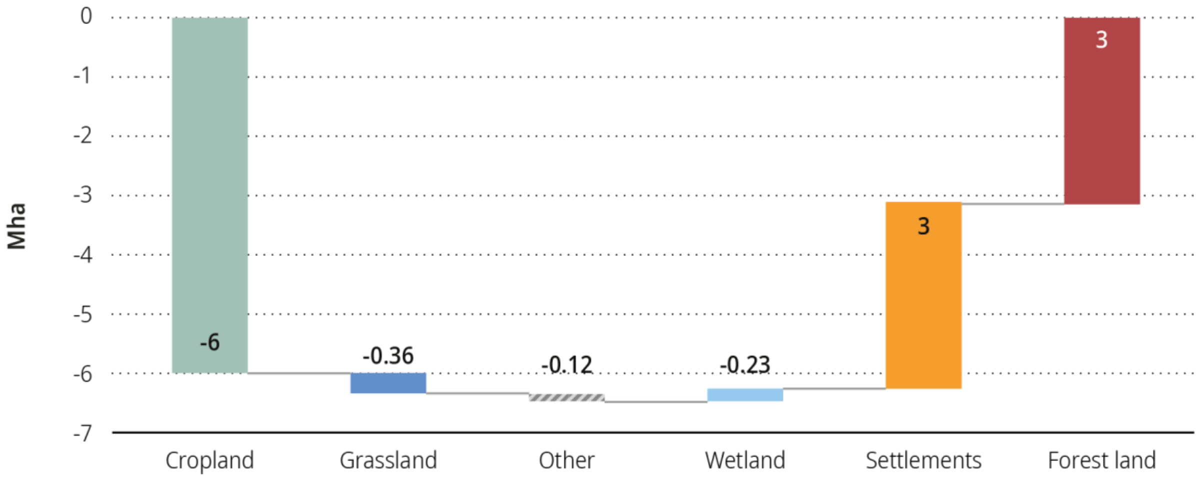
9.3 Outcome 1: maintained or expanded surface area of carbon-rich land use categories (forests and wetlands)

Progress on expanding forest and wetland areas

There have been limited changes in total area for each land use category since 2005.

As shown in Figure 66, there have been relatively limited changes in the total area for each land use category since 2005. The most noticeable change has been a decrease in cropland (– 6 million ha, or – 5 % compared to 2005) and an equal increase in settlements (+ 3 million ha, or + 13 % since 2005) and forest land (+ 3 million ha, or + 2 % compared to 2005). The area of wetlands has also increased, but to a lesser extent (+ 0.2 million ha, or + 1 % compared to 2005).

Figure 66 Indicator L2 – change in surface area per land use category (2021 compared with 2005)



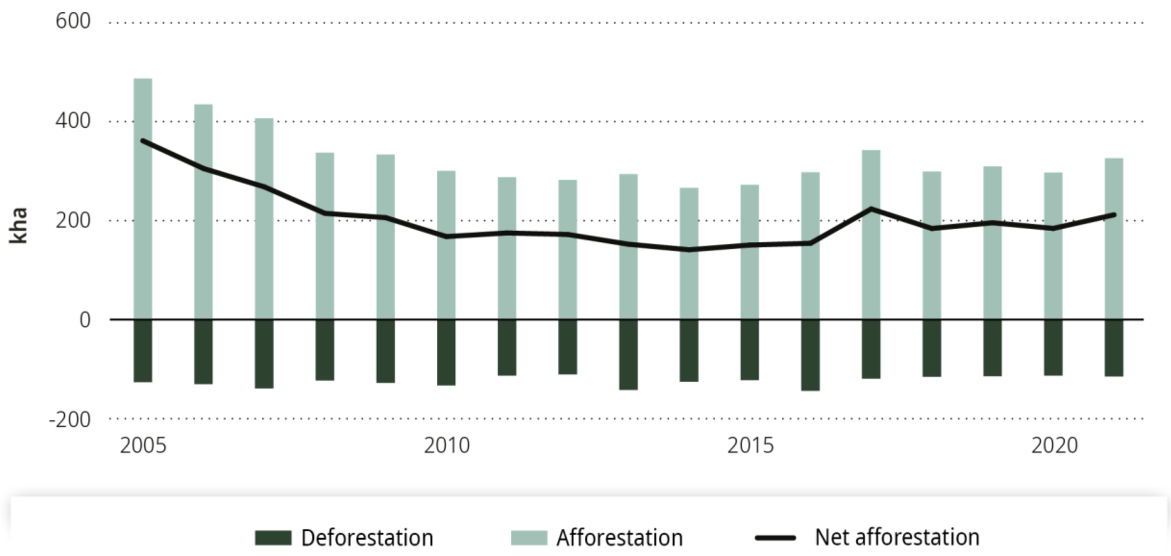
Notes: No benchmarks were found for 2030 or 2050.

Source: EU CRF tables (EEA, 2023h)

Net afforestation declined in 2005–2010 and has remained relatively stable since, driven by declining afforestation in combination with stable deforestation.

Whereas the total surface of forest land has increased since 2005, the rate at which it increased (the net afforestation rate) declined in 2005–2010 as a result of decreasing afforestation and stable deforestation, as shown in Figure 67. Both afforestation and deforestation have been relatively stable since.

Figure 67 Indicators L3 and L4 – afforestation and deforestation in the EU



Notes: No benchmarks were found for 2030 or 2050

Source: EU CRF tables (EEA, 2023h)

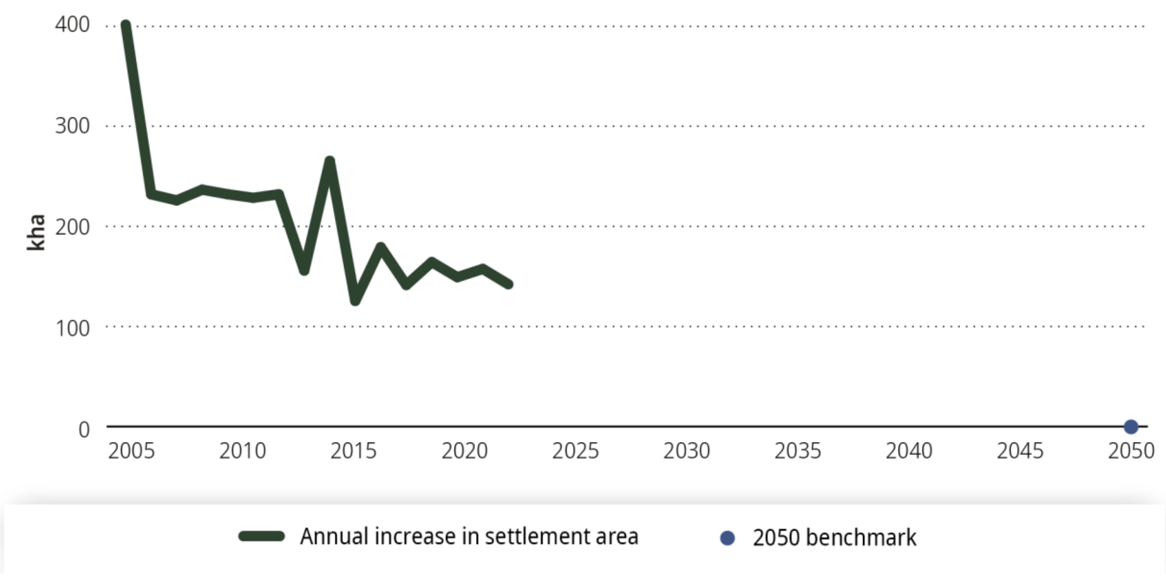
The EU Biodiversity Strategy includes a pledge to plant 3 billion additional trees by 2030, for which a roadmap was included under the Forest Strategy (EC, 2021n, 2020e). To achieve this objective, the EU would need to plant on average 333 million additional trees per year in 2022–2030. However, 2 years after the pledge only 12.5 million additional trees have been reported as planted, which is far below the required rate (EEA, forthcoming). The Advisory Board has not been able to assess whether this low figure is due to lack of planting or lack of reporting. Furthermore, even if the objective is achieved, it will only make a modest contribution to the LULUCF sink, generating 15 Mt CO_2e of additional removals by 2050 (Korosuo et al., 2023).

A faster reduction of deforestation would be a quick win to increase the LULUCF carbon sink in the short term, whereas increased afforestation increases the carbon sink gradually over time, as it takes time for young forests to sequester carbon (Korosuo et al., 2023). About half of the deforestation observed in 2005–2021 is driven by the expansion of settlements (EEA, 2023h). Decreasing net land take (see indicator L5) could therefore be expected to contribute to decreasing deforestation.

The decrease in net land take for settlements has slowed down in recent years.

As shown in Figure 68, the total surface of settlement area increased by 13 % in 2005–2021, but the rate at which it did so fell between 2005 and 2017 (EEA, 2023h). However, since then the rate has been relatively stable. The downward trend over the longer term needs to be continued to put the EU on track towards achieving no net land take by 2050, in accordance with the ambition of the 7th Environmental Action Programme (EU, 2013a). An even faster decrease could support the overall LULUCF objective by reducing deforestation (see indicator L4 in Figure 67) and increase the surface land available for carbon sequestration.

Figure 68 Indicator L5 – annual increase in settlement area (as proxy for net land take)



Sources: EU CRF Tables (EEA, 2023h) (historic), 7th Environment Action Programme (EU, 2013a) (benchmark)

Consistency of EU policies

EU policies are driving land use for agricultural production, thereby reducing the potential for maintaining and expanding forests and wetlands.

Section 9.1 identified several enabling conditions that could reduce the demand for land for settlements and agricultural production, thereby reducing pressure on carbon-rich land use categories and increasing the amount of land available for their expansion.

Whereas spatial planning is predominantly a (sub)national competence, there are some areas where EU policies can facilitate more efficient spatial planning, which could, among other effects, reduce land demand for human settlements. These are further discussed in Section 7.5.

The EU has more competences in other areas such as agriculture, transport and energy, which could be used to limit land for agricultural production (including for biofuel crops) and therefore increase the amount of land available for carbon sequestration. However, as further detailed below, there are some EU policies in these policy domains that put upward pressure on land demand for agricultural production.

For example, livestock production is particularly land-intensive: animal feed accounts for 61 % of the EU's total cereal production (EEA, 2023o), and livestock systems (including feed production) occupy around 65 % of total agricultural land (or 28 % of the EU's total land surface) (Leip et al., 2015). Reducing livestock production would not only reduce emissions directly (less GHG emissions from enteric fermentation and manure) and indirectly (less fertiliser use for feed crop production) but could also free up substantial amounts of land that could be used for carbon sequestration (e.g. afforestation). However, there are few EU policies in place that aim to reduce demand for livestock products, and the current CAP continues to financially support livestock production (see also Chapter 8 'Agriculture').

The CAP does include a number of provisions to maintain and increase the area of grass-, wet- and peatlands (EU, 2021d). Firstly, the minimum environmental requirements under the CAP include the mandatory requirement to maintain permanent grassland (GAEC 1) and the protection of wet- and peatlands (GAEC 2). Secondly, Member States can (financially) support the rewetting of wet- and peatlands, and the establishment, maintenance and extensive use of grasslands, through eco-schemes and agri-environmental measures. However, there are several elements of the CAP that undermine its effectiveness at expanding or even maintaining the area of carbon-rich land use categories. Firstly, the overall approach of the CAP is to provide payments per hectare of land cultivated. This approach incentivises farmers to continue to cultivate organic soils, which causes high CO_2 emissions, and to cultivate less productive land, which might be more suitable for afforestation and the restoration of grasslands and wetlands (EEA, 2022h). Furthermore, the majority of EU Member States have chosen to delay the implementation of GAEC 2 (on the conservation of peatlands) to 2024 or 2025 (EC, 2022aa). Finally, some peatland-rich Member States have not included any voluntary support schemes for rewetting peatlands, and in those that have done so the schemes are not expected to lead to substantial changes in land management practices (Birdlife Europe and EEB, 2022; Midler et al., 2023).

As further described in Chapter 8 'Agriculture', the Farm to Fork Strategy includes a range of objectives to reduce local environmental pressures from agricultural production, such as increasing the share of organic farming and reducing the use of mineral fertilisers. However, whereas such measures can reduce environmental impacts (including GHG emissions) locally, they are also expected to result in lower yields (JRC, 2021b). Therefore, unless they are complemented by policies to reduce demand for agricultural products (which are largely missing regarding reduced livestock consumption; see Chapter 8 'Agriculture'), they risk increasing overall land demand for agricultural production either in the EU or abroad.

Finally, EU policies in the domain of transport fuels continue to incentivise the demand for (and therefore production of) crop-based biofuels, which contribute further to land demand for agricultural production (see also Section 6.4, under 'Lever: fuel switches', and Section 8.5, under 'Lever: minimise demand for biofuel crops').

Even if there has been a slight decline in the total area of croplands in the EU (– 5 % since 2005; see Figure 66), the abovementioned policies put upward pressure on the area of land required for agricultural production. Changes to these policies could reduce this pressure, freeing up larger areas of land available for carbon sequestration through afforestation/reforestation and wetland restoration.

9.4 Outcome 2: reduced emissions / increased removals within land use categories

Progress on increasing removals in EU forests

Despite the increasing forest area, the net carbon sink in EU forests is declining. The decline needs to be reversed to be consistent with the scenarios underpinning the EU climate objectives.

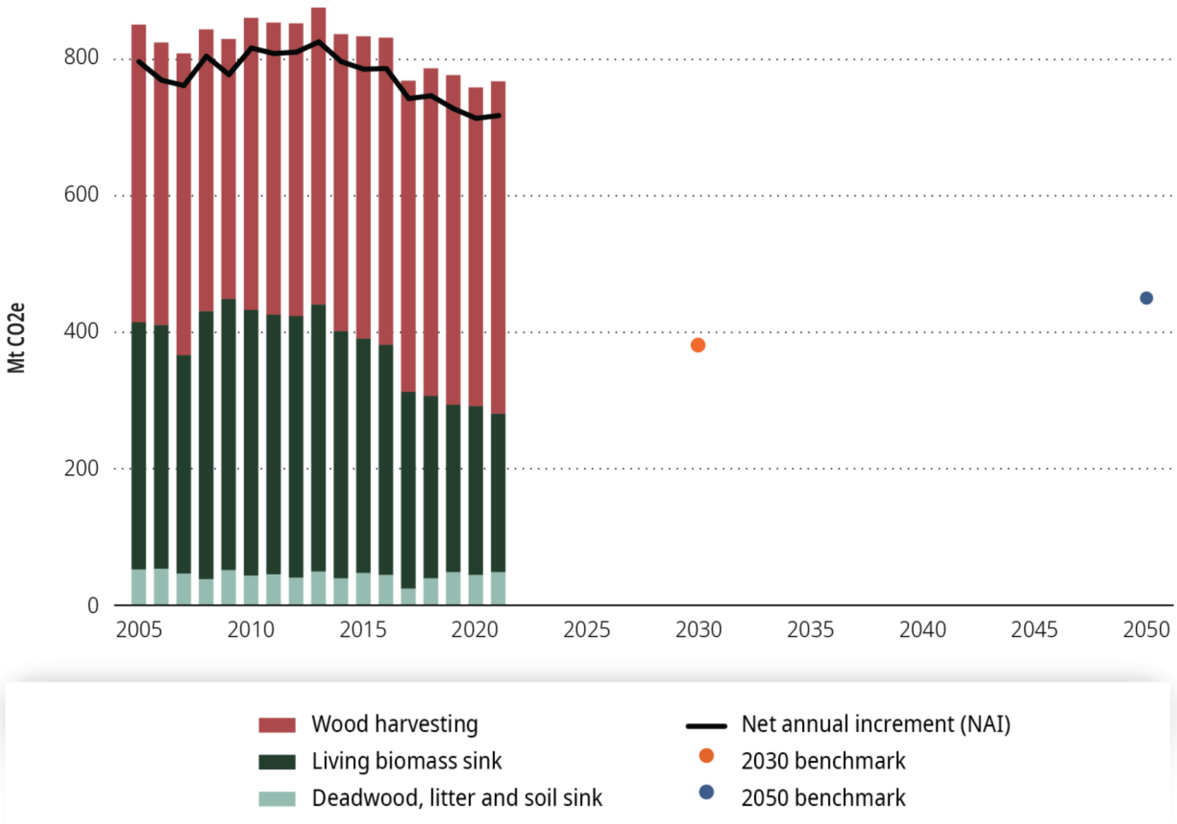
Despite the net afforestation occurring in the EU (see indicators L3 and L4 in Figure 67), the forest carbon sink has been declining rapidly, primarily because of a slowing down of the annual growth in living biomass which accounts for > 80 % of the total forest carbon sink (see Figure 69). In the last 5 years, the net carbon sink in forests declined by on average 8 Mt CO_2e per year. This trend would need to be reversed to be consistent with the scenarios underpinning the EU climate objectives. Under the MIX scenario of the Climate Target Plan, the forest carbon sink would need to increase to 380 Mt CO_2e by 2030 and 450 Mt CO_2e by 2050.

Box 5 The role of forest soils in the carbon sink and stock

As shown in Figure 69, growth in living biomass accounts for the large majority (between 80 % and 90 % in 2005–2021) of the total forest carbon sink, with deadwood, litter and soils accounting for the remaining 10–20 %. However, forest soils represent the largest carbon stock in forests, with a total carbon content estimated to be 2.5 times larger than the carbon stock in tree biomass (see footnote 58 for the difference between the carbon sink and the carbon stock) (De Vos et al., 2015). Furthermore, the role of forest soils as a carbon sink and stock can be further increased through forest management practices.

The French National Research Institute for Agriculture, Food and Environment launched a study (Augusto and Boča, 2022) to identify the characteristics of forests that would optimise carbon sequestration in soils. It found that it is important to have a significant amount of tree biomass in forests, which would produce a lot of debris (leaves, needles and dead roots) that contributes to the carbon stock in the soil. Furthermore, forests made up of a mixture of two species can store more carbon than forests with a single species, provided that the mixed forests grow faster than the single-species ones. But it is the characteristics of the dominant tree species in combination with the climate zone and soil type that most control the capacity of forests to store carbon in soils. Even though some questions remain to be further explored in more detail, the results of the study show that encouraging a significant biomass of trees, through extensive management or a mixture of species, is a practice that should be encouraged provided that the environmental risks to which the forest is exposed are carefully assessed (fires, drought, etc.). Above all, it is important to choose the species of trees carefully, favouring species ecologically adapted to the climate and soil of the region where they are planted.

Figure 69 Indicator L6 – changes in the forest carbon sink



Notes: Wood harvesting data converted from m^3 to Mt CO_2e based on standard conversion factors. The Net Annual Increment was approximated as the sum of the forest carbon sink and wood harvesting. 2030 and 2050 benchmarks are based on the MIX scenario from the Climate Target Plan impact assessment.

Sources: EU GHG inventory (EEA, 2023h). FAO Statistics on Forestry Production and Trade (2020), Climate Target Plan impact assessment (EC, 2020s) (Figure 10).

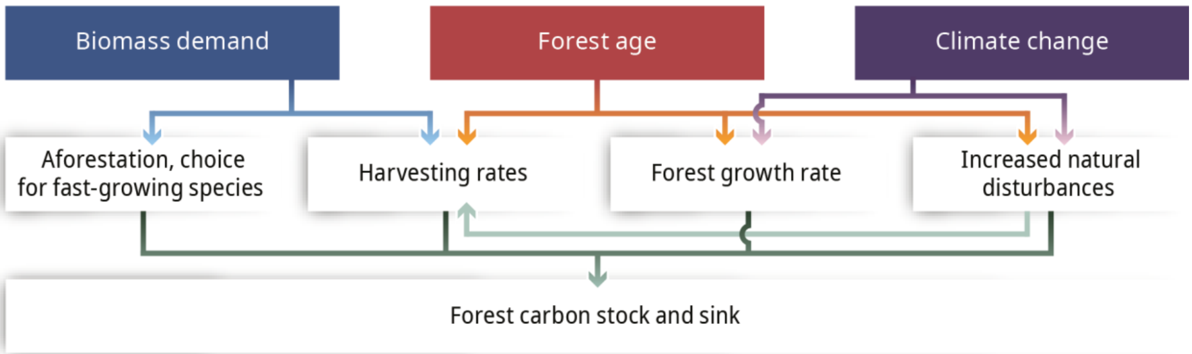
The decline in the forest carbon sink is driven by multiple, interlinked drivers, including forest age, biomass demand and climate change impacts.

Forests have long production cycles (from 15 to more than 250 years), which means that changes in the forest sink over a few years could be (but are not necessarily) compatible with long-term sustainable forest management. The observed decline in the carbon sink in the last 10 years is caused by several underlying trends, including a slowdown in net afforestation (see indicators L3 and L4 in Figure 67 above), a decrease in gross annual increment (that is, forest biomass growth before taking into account natural mortality and harvesting), increased mortality (worsened by natural disturbances) and increased harvesting (Korosuo et al., 2023). This is also illustrated in Figure 69, which shows a declining net annual increment (NAI) ([61]) since 2013, and an increase in wood harvesting. These trends are driven by multiple, interlinked drivers.

([61]) The NAI is defined as the gross annual increment (gross forest growth) minus the natural mortality. Part of the NAI is harvested; the remaining biomass growth represents the net carbon sink. See Figure 2 in (Korosuo et al., 2023) for more details. Natural disturbances have an impact on both natural mortality (e.g. if a tree is burned in a wildfire) and harvesting

- **Forest age** determines the forest growth rate (EEA, 2023o). Trees grow slowly when they are young, resulting in a small annual carbon sink. The growth rate then accelerates as they grow older (which increases the carbon sink), after which it starts to slow down again as the tree reaches maturity. As a result, the average age of a forest determines the forest growth rate and consequently the carbon sink. Furthermore, forest age also influences harvesting rates, as forest managers are likely to harvest trees when they reach a certain size. Finally, forests with older trees are also more vulnerable to natural disturbances, which could result in carbon stock losses and related emissions both directly and indirectly (see Figure 70). As forests in the EU do not have even age structures, there will be fluctuations in the carbon stock and sink, even if management and growth conditions are unchanged.
- **Biomass demand** is a driver of harvesting rates (De Oliveira Garcia et al., 2018), and increased biomass demand could therefore lead to a net decrease in the forest carbon sink and even a net decrease in the carbon stock (in which case it would result in net emissions). On the other hand, it is argued by some that biomass demand could also incentivise afforestation and forest management practices that improve forest productivity, which would increase the carbon sink (Berndes et al., 2022), although other research found no or only weak evidence to support this claim (Giuntoli and Searle, 2019). It is also suggested that biomass supply could be increased through forest management practices without affecting long-term carbon storage (Gylling et al., 2023) but, again, the aggregate effect necessarily depends on the specifics.
- **Climate change** is expected to increase the frequency and intensity of natural disturbances that undermine the sink potential of EU forests either directly (increased mortality) or indirectly (increased sanitary or salvage logging) (Korosuo et al., 2023; Seidl et al., 2017). Forest management practices to adapt forests to projected climate change impacts can increase resilience against such disturbances but might require increased harvesting in the shorter term (see also Section 9.5 for more details).

Figure 70 Overview of drivers affecting the forest carbon sink and carbon stock



Source: Advisory Board (2024).

Increasing the forest carbon sink is possible only by reducing the share of the NAI that is harvested, either by increasing the NAI more than the increase in harvested woody biomass or by decreasing harvesting compared with the NAI. This would require more effort than the traditional concept of sustainable forest management, which is understood as ensuring that harvesting does not exceed the NAI (Korosuo et al., 2023).

(when a tree is cut for sanitary or salvage purposes). There is an inverse correlation between natural mortality and harvesting, as the non-harvesting of trees will eventually increase natural mortality and vice versa. In its assessment, the Advisory Board has assumed a constant natural mortality for simplicity.

Consistency of EU policies with the aim of increasing the forest carbon sink

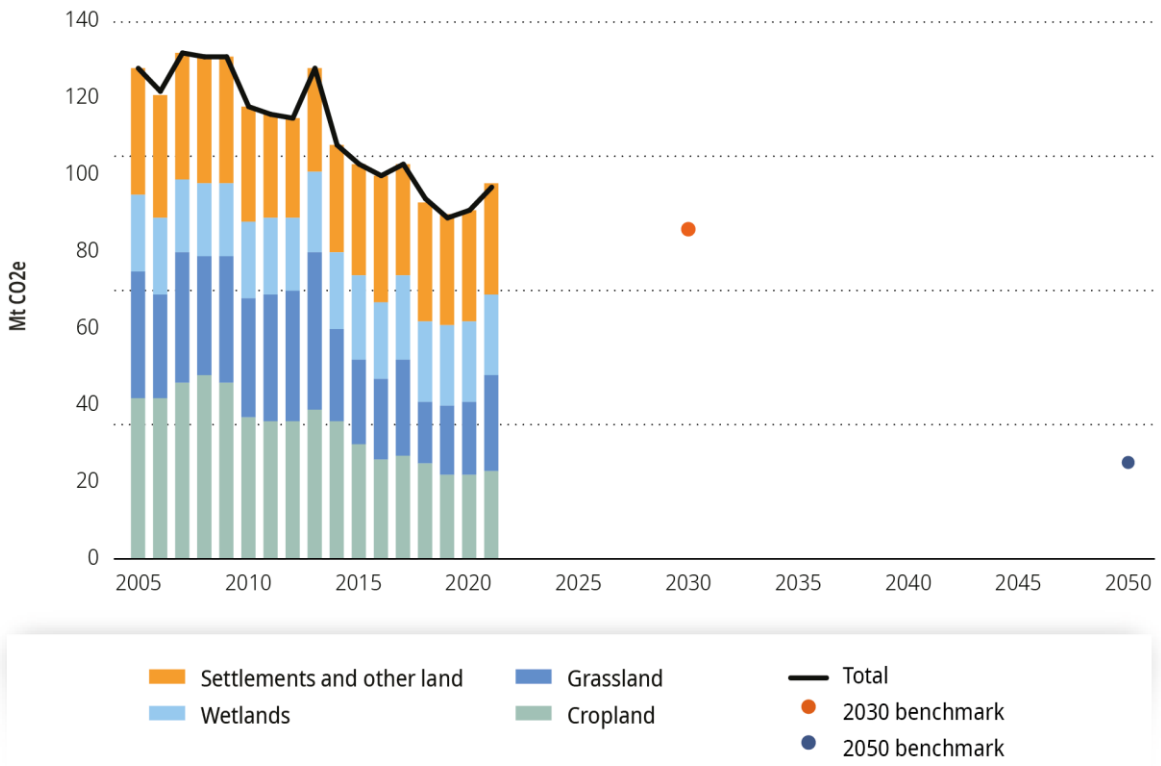
The observed decrease in the forest carbon sink has been linked to EU bioenergy policies and the increasing occurrence of natural disturbances, exacerbated by climate change. These topics – including the role of EU policies – are assessed in more detail in Section 9.5 below, as they are relevant to the overall LULUCF sector.

Progress on reducing emissions and increasing removals in other land use categories

Net emissions are decreasing, but the pace needs to double beyond 2030.

Although forests make up the largest share of the LULUCF sector, reducing net emissions in other land use categories can contribute to enhancing the overall sink. Between 2005 and 2021, net GHG emissions in these other land use categories decreased by 24 %, as shown in Figure 71. This was mainly achieved by reductions of soil carbon emissions in croplands (– 46 %, – 19 Mt CO_2e), grasslands (– 23 %, – 8 Mt CO_2e) and settlements (– 14 %, – 5 Mt CO_2e), whereas emissions from wetlands increased slightly (+ 5 %, + 1 Mt CO_2e). However, reported data show a rebound in emissions in recent years. The average pace of reductions in the last 5 years (1.5 Mt CO_2e) would need to be maintained until 2030, and then double (to 3 Mt CO_2e per year) to be consistent with the European Commission scenarios underpinning the EU climate objectives.

Figure 71 Indicator L7 – net GHG emissions in non-forest land use categories



Notes: 2030 and 2050 benchmarks are based on the MIX scenario from the Climate Target Plan impact assessment.

Sources: EU GHG inventory (EEA, 2023h), Climate Target Plan impact assessment (EC, 2020s) (Figure 10).

Consistency of EU policies with the aim of reducing emissions from other land use categories

The EU has few policies to incentivise carbon sequestration in crop- and grasslands.

Whereas there are several agricultural practices to enhance carbon sequestration in crop- and grasslands, there are currently only a few EU policies to incentivise this. The CAP does allow Member

States to support such measures under eco-schemes, but only eight Member States have chosen to do so (EC, 2022aa). Furthermore, permanent grasslands are defined in such a way that the mandatory requirement on the maintenance of permanent grasslands (GAEC 1) does not prevent ploughing and tilling, which are agricultural practices that lead to high soil carbon emissions from grasslands. Regarding agroforestry, some positive policy developments can be observed compared with the pre-2020 CAP. From 2007 to 2020, direct payments under the CAP were conditional on a maximum tree density (50 trees/ha in 2007–2013, 100 trees/ha in 2014–2020), which incentivised farmers to remove trees from arable land in order to receive such payments. This condition was removed in the CAP after 2020, which is positive for the promotion of agroforestry (Mosquera-Losada et al., 2023). Furthermore, the amount of national support schemes for agroforestry under the CAP has also increased. In 2007–2013, only five Member States supported agroforestry under the CAP, which increased slightly to eight Member States in 2014–2020. Under the latest CAP, 17 Member States have included eco-schemes to support agroforestry in their CSPs, either directly (4 Member States) or indirectly through support for landscape features (13 Member States), making it one of the most widely employed schemes (Buratti-Donham et al., 2023). Nevertheless, some room for improvement remains, as the national support schemes do not cover all types of agroforestry or support all phases (preservation of traditional systems, implementation of new systems and management of those new systems) (Buratti-Donham et al., 2023; Mosquera-Losada et al., 2023).

Furthermore, there is currently no (financial) incentive at the EU level for the agriculture and LULUCF sectors to enhance CDR. The European Commission recently took initiatives to start addressing this gap, including a proposal for a Union certification framework for carbon removals (EC, 2022w), and steps to explore the possibility of establishing a mandatory, separate emissions trading system for GHG emissions and removals in the land sector (EC, 2023bd). Both initiatives are described in more detail in Section 10.6.

The Advisory Board's upcoming report on CDR will provide a more detailed assessment and policy recommendations to enhance CDR, including in agricultural soils.

9.5 Enabling conditions

Keep biomass demand within sustainable limits

Biomass use can be an important mitigation lever, but can also have a negative impact on ecosystems, including on the net sink in the LULUCF sector.

According to IPCC AR6 (IPCC, 2022g), biomass has the potential to be a high-value and large-scale mitigation option, and could be particularly valuable for sectors with limited alternatives to fossil fuels (e.g. aviation, energy-intensive industry), for the production of chemicals and other products, and, potentially, in CDR by means of BECCS or biochar. However, the long-term role of bioenergy in low-carbon energy systems is uncertain because of sustainability concerns about traditional biomass and first-generation biofuels – which can have far-reaching impacts on food production, forestry, water use, land use and overall ecosystems – and cost-effectiveness concerns about more advanced biofuels.

In line with the IPCC guidelines for GHG inventories (IPCC, 2006), when biomass is harvested this is counted as an emission under the LULUCF sector. When the harvested biomass is then combusted for energy purposes, it is 'zero-rated', meaning that it is assigned an emission factor of zero, although biogenic GHG emissions are still reported as a memo item. This means that, whereas bioenergy can contribute to GHG emissions in other sectors, it can at the same time undermine the sink in the LULUCF sector (and thus achievement of the LULUCF objective). This is less of a risk when the harvested biomass is used as a material instead of being combusted (in which case it is reported as a sink under the harvested wood product" category) or when bioenergy is combined with CCS (BECCS, in which case it should be accounted as a removal under CRF category I.C).

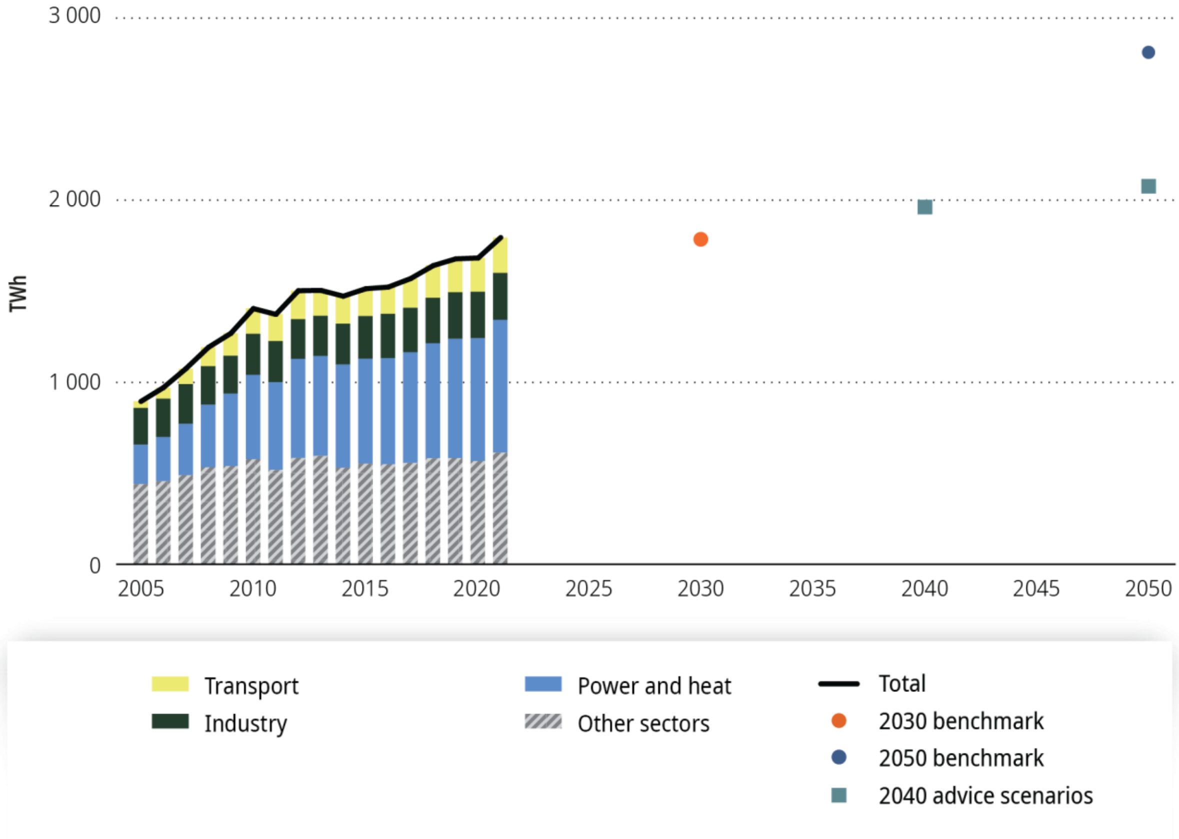
Bioenergy use in the EU has doubled since 2005 and is projected to more than double again by 2050 under the European Commission's decarbonisation scenarios.

The EU started to promote the use of biofuels in the electricity and transport sectors in the early 2000s (EU, 2001, 2003), and has continued to do so under the renewable energy directives, the EU ETS and the ESR.

Since 2005, bioenergy use has doubled from about 900 TWh in 2005 to 1 800 TWh in 2021 (see Figure 72). This was mainly driven by increased use for electricity and heat production (+ 512 TWh) and in 'other sectors' (mainly building heating, + 178 TWh), followed by the transport (+ 158 TWh) and industry sectors (+ 55 TWh). Based on the most recent data (2021), it is mainly used as input for electricity and heat production (41 %), followed by building heating (34 %), transport (14 %) and industry (11 %). Bioenergy is the main source of all renewable energy in the EU, accounting for 59 % of all renewable energy use in 2021 (EC, 2023bh).

As shown in Figure 72, the European Commission's scenarios underpinning the EU climate objectives assumed that bioenergy use could increase by 10 % between 2015 and 2030. However, in reality this increase was already exceeded in 2021. After 2030, the scenarios assumed, bioenergy use would again increase substantially, to double by 2050 compared with 2030, driven mainly by increased use in the power and heat sector combined with CCS (about 500 TWh more than in 2021) and in the transport sector (about 325 TWh more than in 2021, mainly for aviation and maritime transport). The total bioenergy use by 2050 under the European Commission's scenarios (> 2 800 TWh) would exceed the 20 EJ (or 2 500 TWh) ' high feasibility' threshold used for the Advisory Board's advice on the 2040 target (which is based on the High availability scenario from Ruiz et al (2019)).

Figure 72 Indicator L8 - bioenergy use



Notes: Historic data refers to final energy use in the industry, transport and other sectors, and transformation input for the power and heat sector. The "other sectors" is primarily dominated by residential buildings (ca. 85% of "other sectors'" bioenergy use in 2021), but also includes the tertiary and agriculture sector. 2030 and 2050 benchmarks are based on the MIX scenario of the Climate Target Plan impact assessment. 2040 advice range refers to the average bioenergy use in the scenarios which underpin the Advisory Board's advice for a 90-95% emissions reduction by 2040.

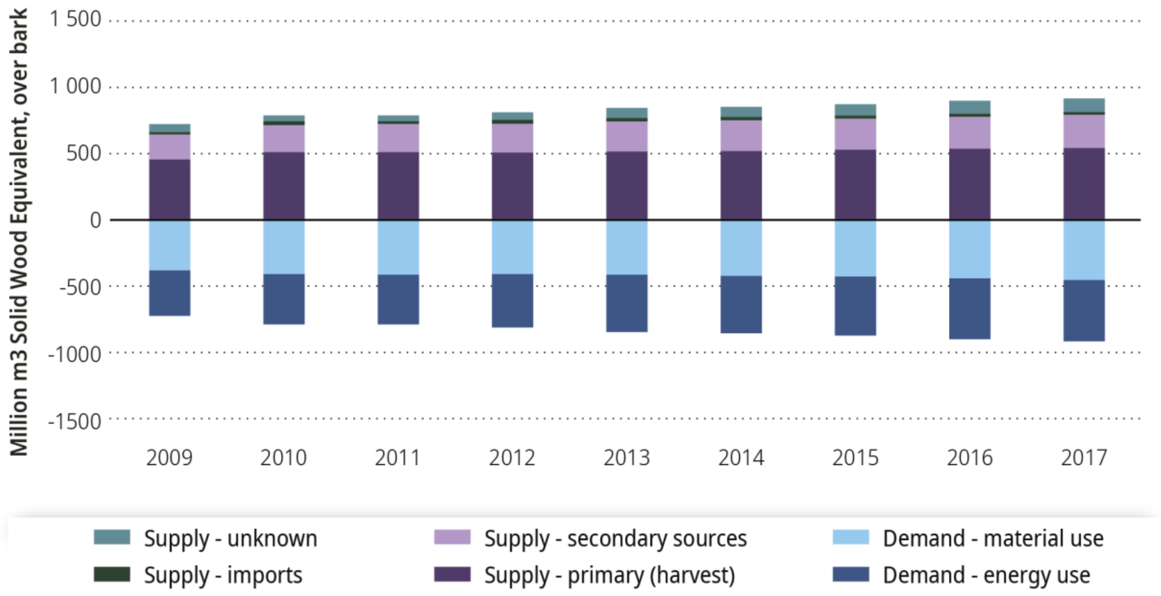
Sources: Eurostat energy balances (2023b), Climate Target Plan impact assessment (EC, 2020s) (Figure 77), Advisory Board 2040 advice scenarios (ESABCC, 2023b).

The increase in bioenergy contributed to an increase in forest biomass demand. At least 45 % of the increased forest biomass demand was met by increased harvesting.

The JRC has published data on woody biomass supply and demand for 2009 until 2017 (JRC, 2022b), which is shown in Figure 73. In that period, demand for woody biomass increased by more than 25 % (193 million m^3), primarily owing to an increase in demand for energy use (121 million m^3). At least 45 % of the increased demand in 2009–2017 was met by increased harvesting, with another 22 % being met through additional supply from unknown sources (which could also include harvesting). Only one third of the additional demand is known to have been met from additional secondary supply, which includes residues from wood-processing industries and post-consumer wood. The available data therefore shows a correlation between increased demand for woody biomass – primarily for energy purposes – and an increase in harvesting, which in its turn has contributed to the reduction of the forest carbon sink (see indicator L6 in Figure 69).

Whereas the JRC data covers only the period up to 2017, UN FAO data indicates that harvesting continued to increase, with volumes 8 % higher in 2021 than in 2017 (FAO, 2020). Similarly, Eurostat data indicates that the consumption of solid primary biofuels have increased with an additional 13 % by 2021 compared to 2017 (Eurostat, 2023b).

Figure 73 Supply (shown as positive values) and demand (shown as negative values) for woody biomass



Source: Wood Resource Balances (JRC, 2022b)

The scientific debate on the consistency of EU bioenergy policies with the EU's overall climate objectives is ongoing.

There is an ongoing debate about the role of EU biomass policies in driving the observed decline in the LULUCF carbon sink (in particular in the forest carbon sink), and the mitigation impact of bioenergy in general. The most critical voices within the scientific community (see e.g. EASAC 2017; Blattert et al. 2023; Norton et al. 2019; Searchinger et al. 2022; Brack 2017) argue that the promotion of bioenergy by EU policies is the main culprit of the decreasing carbon sink and will put the EU climate targets for 2030 and 2050 out of reach. They argue that the use of primary woody biomass for energy production often increases atmospheric GHG concentrations in the short to medium term, and it can take up to decades or even centuries before it has a net mitigation effect. Finally, they have also warned that the promotion of bioenergy puts the EU biodiversity targets at risk. They have therefore called for a halt to policy support for the use of bioenergy from primary woody biomass, including stepping away from the zero-rating approach for bioenergy.

On the other side of the debate, there are scientific researchers who are more supportive of the promotion of bioenergy (see e.g. Berndes, Cowie, and Pelkmans 2022; Berndes et al. 2016). They emphasise that, in many cases, bioenergy can already make a substantial net contribution to climate mitigation in the short term and will continue to be necessary for the EU to achieve its climate objectives for 2030 and 2050. Their main arguments are that bioenergy often uses waste streams from value chains that use biomass as material in which carbon is stored for a longer time (e.g. sawnwood, pulp and paper). Furthermore, they point out that forest management has a greater climate benefit than forest conservation, as regular harvesting and replanting of trees contributes to maintaining the forest carbon sink in the longer term, whereas the sink would saturate over time under the conservation approach. Related to this, they argue it is more appropriate to assess the mitigation impacts of forest harvesting at the landscape level instead of at the level of a specific forest stand, as under sustainable management practices it is appropriate to harvest specific forests stands when the trees reach maturity. Furthermore, they counter-argue that bioenergy use is in fact not zero-rated in GHG inventories, as the emissions are counted in the LULUCF sector, and that counting emissions at the point of combustion would therefore result in double counting. Finally, harvesting might also be appropriate from a climate adaptation perspective, for example to replace maladapted species, to reduce the amount of biomass at risk of being lost in natural disturbances or to remove wood after such disturbances (Korosuo et al., 2023).

It is highly likely that a trade-off is needed between, on the one hand, maintaining/increasing forest harvesting and biomass supply and, on the other, maintaining/increasing the forest carbon sink.

In an ideal world, the EU would be able to increase the net emissions sink in forests, while maintaining or even increasing current harvesting levels to supply other sectors with forest biomass to substitute for fossil fuels and other GHG-intensive materials. This would require the NAI in EU forests to outpace the increase in harvesting levels (see indicator L6). However, current forest management practices are projected to increase harvesting while decreasing the NAI (both of which are driven by ageing forests), and as a result the forest carbon sink is projected to decrease to 240 Mt CO_2 in 2030 and 207 Mt CO_2 in 2050 (Korosuo et al., 2023; Pilli et al., 2022). It is therefore highly unlikely that the EU can achieve its LULUCF objectives for 2030 and 2050 without major and immediate changes to current forest management practices.

There are several options possible to increase the NAI, including decreasing deforestation, increasing afforestation, specific management practices to increase gross annual increment and increasing the resilience of forests against natural disturbances. However, the impact of these options will only materialise over decades, with only modest impacts in the timeframe up to 2050. Reducing harvesting is therefore one of the rare options to maintain or increase forest carbon sinks in the short to medium term. However, this also has its downsides, as forest biomass supply supports mitigation in other sectors, allows stronger forest growth in the future and might be required in the context of climate adaptation (JRC, 2021a; Korosuo et al., 2023).

It is therefore highly likely that the EU will have to make a trade-off between maintaining/increasing current harvesting levels and maintaining/increasing the forest carbon sink. The first option would increase biomass supply to other sectors, increase the forest carbon sink in the longer term (provided that harvested trees are replanted) and possibly also contribute to climate adaptation (if harvested trees are replaced with better-adapted species). However, it might also cause the EU to miss its 2030 LULUCF target, result in a smaller sink in 2050 and undermine the EU's biodiversity objectives. The second option would enhance the carbon sink in the short to medium term and is also preferable from a biodiversity perspective. However, it would reduce the carbon sink in the longer term (as the forest carbon stock saturates) and would reduce domestic supply to other end use sectors. In certain cases, it might also make forests more vulnerable to natural disturbances. The different options are also likely to have different socioeconomic impacts, which would need to be taken into consideration, but these have not been assessed within the scope of this report.

Recent literature suggests that, in the short to medium term, limiting harvesting is a more effective climate change mitigation action than increasing harvests to produce more bioenergy and wood-based materials (partly because wood is currently mainly used in short-lived products such as packaging and paper) (JRC, 2021a; Korosuo et al., 2023). The climate benefit of biomass use can be strengthened if wood is used in longer-lived products such as construction materials, which would diversify the income stream and increase the harvested wood products sink in the LULUCF sector. Nevertheless, even for such uses, the majority of studies conclude that within a short to medium time frame (up to 2050) the mitigation potential provided by the material substitution effect is unlikely to compensate for the reduction of the carbon sink in forests affected by increased harvesting (JRC, 2021a).

The EU has taken steps to mitigate the potential adverse impacts of bioenergy, but concerns remain. In particular, there is a high risk that biomass demand (driven by EU policies) will exceed sustainably available supply.

The EU strives to address the potential adverse impacts of bioenergy production, for example through sustainability criteria and minimum GHG emissions savings for biomass set out in Renewable Energy Directive in 2009, which became increasingly stringent under the RED II and the RED III. Only biomass use that adheres to these criteria can contribute to the EU's renewable energy objectives and be eligible for financial support mechanisms (including the exemption from surrendering allowances under the EU ETS). The RED III has further strengthened this sustainability framework, by expanding it to more (smaller) installations, by excluding biomass from areas that were previously old-growth forests, and by excluding biomass harvested in a way that exceeds maximum thresholds for large clear-cuts. Although this sustainability framework is certainly useful to prevent the worst adverse impacts of biomass use, its overall effectiveness remains uncertain because of monitoring and compliance issues, including risks of fraud (Mai-Moulin et al., 2021; Mather-Gratton et al., 2021; Sikkema et al., 2021). Furthermore, as described in more detail in Chapter 6 'Transport', despite this framework, EU policies continue to promote certain types of biofuels that have a high risk of negative spillover effects.

In addition to the sustainability criteria framework, the RED III also requires Member States to design support mechanisms for bioenergy in line with the cascading principle and prohibits direct financial support for the use of specific, high-value wood types for bioenergy production. However, several implicit and explicit exemptions from these rules (e.g. the possibility of continuing to provide non-direct financial support such as tax cuts for the use of high-value wood for energy production) risk undermining their effectiveness.

The RED III also aims to improve the consistency of the EU's bioenergy policies and the objective of the LULUCF Regulation to increase the carbon sink. It does so by introducing a requirement for Member States to ensure that the domestic production of biomass for energy is consistent with their targets under the LULUCF Regulation. To this end, Member States need to assess in their NECPs the compatibility of overall projected forest biomass energy use with their respective targets under the LULUCF Regulation, and a description of the national measures and policies put in place to ensure compatibility with those targets. Member States are also required to report on those policies and measures in their biennial national energy and climate progress reports submitted under the Governance Regulation. These provisions are generally a step in the right direction to improve the consistency between the RED III and the LULUCF Regulation, but their effectiveness will depend on implementation by Member States. The European Commission's 2023 Bioenergy sustainability report (EC, 2023bh) – a biennial requirement under the Governance Regulation – found that so far Member States have not provided sufficiently granular information to allow a comprehensive insight on projected bioenergy demand and sustainably available supply. Similarly, the assessment of the draft updated NECPs found that most of them don't include information on the domestic supply of forest biomass for energy purposes, nor the projected use of forest biomass for energy purposes in 2021-2030 (EC, 2023p).

Furthermore, there continues to be an uneven distribution of incentives for the different possible uses of forest biomass. The current EU policy framework provides a direct, financial benefit for certain private actors to use bioenergy (e.g. operators that are exempted from surrendering allowances under the EU ETS or benefiting from national biomass support schemes). However, in the absence of an emission-pricing mechanism in the LULUCF sector (see also Section 10.6), the financial cost of the biomass use (in the form of a reduced carbon sink) is solely at the expense of the Member State. As a result, the climate benefit of bioenergy use is privatized, whereas the climate cost (in the form of a reduced carbon sink) is socialised.

Finally, the EU policy framework on bioenergy does not consider its potential impact on the aggregate demand for biomass compared with the sustainably available supply. Some researchers have questioned the feasibility of the European Commission's scenarios with regard to potential sustainable biomass supply (Searchinger et al., 2022a), and several assessments have cautioned that biomass demand – driven by climate and energy policies – is projected to exceed sustainably available domestic supply (EEA, 2023o; Material Economics, 2021). This could result in three outcomes, each of which is to be avoided:

— the EU would harvest more biomass than is sustainable, with negative impacts on, among other things, biodiversity and the LULUCF net sink;
— the EU would not be able to meet demand for biomass, and therefore specific sectors with limited alternative mitigation options would risk being unable to reduce their GHG emissions enough to be compatible with the overall climate neutrality target;
— the EU would meet the increased demand by substantial increases in biomass imports, thereby exporting environmental pressures (including GHG emissions) associated with biomass production.

To avoid these outcomes, the aggregate demand for biomass needs to stay within ecological boundaries, while ensuring that end uses with limited mitigation options have sufficient access to sustainably sourced biomass to decarbonise by 2050 at the latest. This could be achieved by targeting incentives for bioenergy towards end uses that have limited other mitigation options, and by promoting the efficient and circular use of biomass overall. However, EU policies do little to target bioenergy towards demand centres with limited alternatives to fossil fuels (Malico et al., 2019). Whereas the RED III (EU, 2023f) does prioritise material use over biomass use for energy, regarding end uses it only excludes (new or renewed) support for electricity-only installations. It does not further differentiate between end uses based on the availability of other renewable energy or climate mitigation options. A better-targeted use of biomass could be achieved by putting a price on emissions in the LULUCF sector at a level similar to the carbon prices in other sectors (the EU ETS and the EU ETS 2). This would create an incentive to use biomass where its value is highest, that is, where it is hardest to replace.

Enhance climate adaptation

Climate change is projected to undermine the LULUCF sink by increasing the frequency and intensity of natural disturbances.

Research has found that – despite strong interannual variation – natural disturbances are increasingly damaging EU forests ([62]), thereby undermining their climate mitigation potential (Forzieri et al., 2022; Patacca et al., 2023; Seidl et al., 2017; Senf and Seidl, 2020). There is growing evidence that climate change is one of the underlying drivers of this trend and is expected to worsen it in the future (Forzieri et al., 2022; Patacca et al., 2023); there is some evidence that climate change has increased maximum wind speeds during extreme wind events, and models predict that such events will occur more frequently in the future. Whereas improved fire suppression policies have reduced damages from forest fires in recent decades, climate change is expected to increase the intensity and frequency of extreme fire events. Finally, climate change is increasing the damage expected from bark beetle outbreaks, both by increasing the bark beetle population and by reducing the resistance of trees to beetle infestations (e.g.

([62]) Expressed as volume of forest biomass loss per year.

due to droughts). Further increases in disturbance-caused mortality risk further undermining the net sink in EU forests and could even transform them into a net source of emissions.

Whereas climate change is expected to increase the frequency and intensity of natural disturbances, it might also improve carbon sequestration in some regions and forest types through warming and CO_2 fertilisation (Forzieri et al., 2022). The overall impact is expected to be mainly negative in arid and temperate forests (southern and central Europe) whereas it might be overall positive for boreal forests (northern Europe). Pilli et al. (2022) expect climate change to lead to an overall increase in forest growth in broadleaved forests (in particular in northern European regions) and an overall decrease in coniferous forests, but concludes that the overall impact of climate change on the aggregate EU forest sink is highly uncertain and could be either positive or negative. For example, assuming continuation of current management practices, the EU forest carbon sink could range between 100 and 400 Mt CO_2e by 2050 (compared to 280 Mt CO_2e in 2021) depending on climate change impacts.

Forests' resilience can be enhanced by changing forest management practices, but, even then, the future of the LULUCF net sink remains uncertain.

The findings above highlight the need for climate adaptation efforts to safeguard the net sink in the LULUCF sector. Several forest management options exist that could improve the resilience of EU forests against climate change impacts. One recommended option is to shift from conifer monocultures to mixed forests and broadleaved species. Such practices might decrease the LULUCF sink in the shorter term (as maladapted tree species are harvested, to be replaced by more resilient species) but would enhance the sink over the longer term (as the newly planted trees grow and future losses from natural disturbances are reduced (Korosuo et al., 2023). However, even if improved forest management practices can increase the mitigation potential and resilience of EU forests, their effect might still be outpaced by increased damage caused by natural disturbances (Patacca et al., 2023).

The importance of climate adaptation – but also of accounting for uncertainty induced by climate change – is illustrated by the sudden drop in the forest carbon sink in the late 2010s, which was driven by natural disturbances, among other causes ([63]). In its impact assessment regarding the revised LULUCF Regulation (EC, 2021r), the European Commission had assumed that the LULUCF net sink could be maintained at the average 2016–2018 level (268 Mt CO_2e) until 2030 without substantial additional efforts. Moreover, it assumed around 40 Mt CO_2 of additional removals could be achieved through a range of relatively inexpensive near-term actions including improved forest management and set-aside of organic soils, which formed the basis for the 310 Mt CO_2e objective. Whereas the impact assessment acknowledged the potential exacerbation of natural disturbances by climate change and biodiversity loss, it did not account for this in its scenarios that underpinned the proposed objective. Since the assumptions were made, net removals in the LULUCF sector have dropped drastically, to only 230 Mt CO_2e in 2021. As a result, the additional effort required has almost doubled (from 42 Mt assumed in 2021 to 80 Mt CO_2e today).

This highlights the need to account for the uncertainties from climate change when setting climate reduction objectives for the LULUCF sector. This could be based on the European Climate Risk Assessment, which is currently under development and expected to be published in spring 2024.

([63]) Pattaca et al. (2023) estimate that the loss of forest biomass due to natural disturbances was on average 50 million m^3/yr in 2010–2015, and then started to increase to on average 100 million m^3/yr in 2018–2020, mainly due to increased extreme wind events and bark beetle outbreaks. Based on standard conversion factors (between 0.8 and 1 t CO_2 per tonne of forest biomass, depending on the tree species), this would have decreased the forest sink by 40–50 Mt CO_2e in 2018–2020 compared to 2010–2015. According to the EU GHG inventory, the total forest carbon sink decreased from on average 420 Mt CO_2e/yr in 2010–2015 to on average 300 Mt CO_2e/yr in 2018–2020. Natural disturbances would thus be responsible for a large minority (33–40 %) of the decrease in the carbon sink.

Furthermore, it shows that the > 400 Mt CO_2e net removals by 2050 under the European Commission's scenarios might not be achievable. In that case, more technological removals of emissions or further reductions in residual emissions will be required to achieve overall climate neutrality.

9.6 Summary tables

Table 14 Progress summary - LULUCF

Indicator	Reference period	Historical progress	Required up to 2030	Required in 2031–2050
L1: GHG emissions and removals ([a])	2005–2022	+ 6 Mt CO_2e/yr	– 8 Mt CO_2e/yr	– 5 Mt CO_2e/yr
L2: land-use changes				
L2a: forests	2005–2021	+ 194 kha/yr	No benchmark	No benchmark
L2b: wetlands	2005–2021	Stable	No benchmark	No benchmark
L3: deforestation	2017–2021	– 3 kha/yr	No benchmark	No benchmark
L4: afforestation	2017–2021	– 4 kha/yr	No benchmark	No benchmark
L5: net land take	2017–2021	Stable	No benchmark	– 5 kha/yr
L6: forest carbon sink ([a])	2017–2021	+ 8 Mt CO_2e/yr	– 11 Mt CO_2e/yr	– 4 Mt CO_2/yr
L7: emissions in non-forest lands ([a])	2017–2021	– 1.5 Mt CO_2e/yr	– 1.3 Mt CO_2e/yr	– 3.1 Mt CO_2e/yr
L8: bioenergy use ([b])	2017–2021	+ 56 TWh/yr	Stable/no further increase	+ 52 TWh/yr

Legend

On track	The required change ([c]) is ≤ 1.
Almost on track	The required change ([c]) is between 1 and 1.5.
Somewhat off track	The required change ([c]) is between 1.5 and 2.
Considerably off track	The required change ([c]) is ≥ 2.
Wrong direction	The required change ([c]) is < 0.

([a]) Positive values represent an increase in emissions or a reduction in removals. Negative values represent a decrease in emissions or an increase in removals.

([b]) Given the expected adverse impacts if bioenergy use exceeds sustainably available supply, indicator L8 is considered to be on track if bioenergy use remains below a linear trajectory to the benchmark values, and off track if it risks exceeding that linear trajectory.

([c]) See Section 2.2 for more details on how the required change is calculated.

Table 15 Policy consistency summary – LULUCF

Policy inconsistencies	– EU policies (CAP support for livestock production and the cultivation of organic soils and marginal lands, EU biofuel policies) put upward pressure on the demand for agricultural land, reducing land available for afforestation/reforestation and wetland restoration.
Policy gaps	– The objectives of the Farm to Fork Strategy to reduce fertiliser use (– 20 %) and increase the share of organic farming (to 20 %) have direct local environmental benefits, but risk reducing yields and therefore increasing demand for land (either in the EU or abroad) if demand for agricultural products is not reduced in parallel. – Agriculture and LULUCF are currently still excluded from the EU carbon-pricing regime. Therefore there is no EU-wide (financial) incentive for farmers and land managers to reduce GHG emissions and enhance CDR. It also implies that the incentives for using forest biomass for energy purposes versus maximising the LULUCF carbon sink continue to be unevenly distributed between private and public actors. – There is a genuine risk that aggregate biomass demand will exceed sustainably available supply. Key EU policies such as the RED III do not target incentives for bioenergy towards end uses that have limited alternative mitigation options. – The assumptions that underpin the LULUCF objective for 2030 did not account for the uncertainty of the effects of climate change and related natural disturbances on changes in the sink.
Ambition gaps	– Specific exemptions risk undermining the effectiveness of the sustainability criteria and provisions on the cascading principle under the RED III. – Under the CAP, the mandatory requirement on the maintenance of grasslands (GAEC 1) does not prevent agricultural practices that lead to high soil carbon emissions from grasslands
Implementation gaps	– So far, Member States have provided insufficient information in their NECPs and national energy and climate progress reports to assess the compatibility between projected bioenergy demand and sustainably available supply. – The CAP does include a mandatory requirement to preserve wetlands (GAEC 2), but over half of EU Member States have opted to delay its implementation to 2024 or 2025. It allows support mechanisms (eco-schemes) for the restoration of wetlands, but these are used to only a limited extent by Member States. Similarly, whereas most Member States have set targets for carbon storage in soil and biomass, voluntary eco-schemes to incentivise carbon farming have been implemented by few Member States, often with low levels of ambition. – Monitoring and compliance issues (including fraud) risk undermining the effectiveness of the sustainability criteria and provisions on the cascading principle under the RED III.

10 Pricing emissions and rewarding removals

Key messages

Achieving climate neutrality requires a policy mix with a sufficiently high, credible and consistent price signal for GHG emissions.

By internalising the externalities of GHG emissions in the market (making the polluter pay), carbon pricing is an effective tool to incentivise producers and service providers to shift towards lower-emission processes, and to incentivise consumers to reduce their consumption of GHG-intensive products and services. It also enables emission reductions to occur where they are most cost-effective. Carbon pricing therefore achieves predefined climate policy goals at the lowest cost ([64]).

Carbon pricing also needs to be complemented by measures to address social impacts and other market failures and to support investments in infrastructure and innovative new technologies, as well as action to prevent carbon leakage (where production and emissions relocate to places not subject to ambitious climate policies). The appropriate complementary measures are different for each sector and policy issue, and are discussed in the other chapters of this report.

In the EU ETS, the carbon-pricing signal needs to be credible so that producers and consumers are empowered to make long-term investments to reduce emissions.

Needs. Carbon pricing systems' efficiency hinges on a stable, long-term regulatory environment to incentivise low-emission investments. Interventions should therefore aim to stabilise expectations about future renegotiations of rules and targets for the carbon market (e.g. price caps, market stability reserve (MSR)), and ideally be based on clear rules.

Gaps. Successive revisions of the EU ETS have increased both the level of the carbon price and its resilience to economic shocks (such as the COVID-19 pandemic). By further accelerating the decline in emissions, the latest (Fit for 55) revision of the EU ETS Directive brings forward the end of the supply of allowances for stationary installations to 2040.

However, there is not yet a clear strategy to prepare the carbon market and relevant sectors for this **(policy gap)**. EU ETS governance, including the existing stability mechanisms, is yet to be adjusted to account for such scarcity of allowances and their effects on allowance price volatility, and ultimately the producers and consumers concerned. The potential contribution of carbon capture and utilisation (CCU) and CDR as well as international linking under the EU ETS is also unclear ([65]).

Recommendation C1. Discussion on carbon pricing in the sectors covered by the EU ETS needs to begin urgently, given the need to provide certainty for long-term investments.

Questions that need to be clarified include the amount and timing of allowances to be issued after 2030; the future design of the MSR; the relationship between EU ETS and other carbon markets, such as the EU ETS 2 and potentially third-country carbon markets; and the appropriate way to incorporate CDR. A very low, or net zero, cap does not require the replacement of a cap-and-trade system when permits for carbon removal can compensate for residual emissions. However, net negative emissions might require

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([64]) In this chapter, 'carbon pricing' refers to the pricing of GHG emissions (including non-CO_2 emissions).

([65]) The revised ETS directive (Article 30(5)) requires the European Commission to produce a report on these matters, accompanied by a legislative proposal where appropriate, by 31 July 2026.

new incentive schemes for sustainable removals. The Advisory Board will consider this issue further in future work, including a report on carbon removal, which is planned for publication in 2024.

The risk of carbon leakage needs to be addressed, without undermining the incentive to reduce emissions.

Needs. Successive reviews of the EU ETS have increased the carbon price (to about EUR 90/t CO_2e in recent years), which is projected to increase further towards and beyond 2030. This increases the incentive for emission reductions, but also the **risk of carbon leakage**. EU policies need to adequately address this risk, while maintaining a strong incentive to reduce emissions.

Gaps. The EU's traditional response has been to issue free allowances to sectors considered exposed to the risk of carbon leakage**.** However, several assessments raise concerns that free allocation creates distortions and complexities, and there is uncertainty concerning its overall impact on the carbon market. Free allocation can also reduce the incentive for mitigation action by consumers and downstream industries (see Chapter 5 'Industry', Chapter 6 'Transport' and Chapter 7 'Buildings'). Replacing it with auctioning of allowances, combined with a carbon border adjustment mechanism (CBAM), would restore this incentive. Ultimately, free allocation cannot be sustained in the longer run, as the ETS cap – and therefore the number of allowances available for free allocation – will decline rapidly to reach zero before 2040.

The CBAM is superior to free allocation, as it applies carbon pricing to both domestic and imported products (thereby also maintaining a stronger incentive for demand-side measures), and does not conflict with the projected decline in the ETS cap. However, the CBAM will be only phased in gradually (from 2026 to 2034), does not yet cover all ETS sectors or address the risk of carbon leakage for EU exporters, and might be circumvented switching imports from raw materials to more refined products (which are not covered by the mechanism). Continued issuing of free allowances for some sectors up to 2030 and beyond represents an **ambition gap**.

Recommendation C2. The EU should further develop alternatives to free allocation for addressing the risk of carbon leakage, to maintain adequate protection even when the cap reduces further. To this end:

— the European Commission should monitor the introduction of the CBAM carefully, with a view to expanding it to more products and sectors, as stipulated in the CBAM regulation;
— the EU should in parallel engage in diplomatic efforts to introduce comparable carbon pricing in the EU's major trading partners.

The European Commission should also conduct or encourage further research into the extent of carbon leakage in recent years, the effectiveness of successive EU ETS reforms in preventing it, and potential policy options other than those mentioned above.

The EU ETS 2 (covering fuel use in buildings, transport and additional sectors) will need to be reformed to provide a stronger, more predictable price signal and greater convergence between the two emission trading systems.

Needs. The EU ETS 2 needs to put a price on emissions of GHGs that is high enough and credible enough to spur a target-consistent trajectory of emission reductions in the relevant sectors.

Gaps. While the original EU ETS appears to have reached a sufficiently high carbon price and ambitious trajectory, **it is unclear whether the EU ETS 2 will be stringent enough to meet its target** of reducing emissions by 43 % below 2005 levels by 2030. Modelling studies suggest that the carbon price in these sectors could reach well in excess of the EUR 45/t CO_2e soft price cap agreed in the revised EU ETS Directive. This would cause additional allowances to be released on to the market, thereby de facto weakening the emissions cap and jeopardising achievement of the target **(ambition gap)**.

Decarbonising these sectors while keeping the carbon price low will require additional measures by the EU and Member States, such as addressing non-market barriers in the transport and buildings sectors (see key messages of Chapters 6 'Transport'and 7 'Buildings'). The coverage of the EU ETS 2 overlaps with the sectors covered by individual Member State targets under the ESR. Therefore, the potential release of new allowances (in response to the soft price cap) will increase the reliance on Member States implementing additional policies (in these or other sectors) in order to achieve their ESR targets (potential **implementation gap**) (see Chapter 14 'Climate governance').

Maintaining two separate emissions trading systems creates distortions and perverse incentives. The EU ETS and the EU ETS 2 have different carbon prices, caps and governance regimes. In the short term, this difference can be justified for pragmatic reasons. The EU ETS has been developing continuously for nearly 20 years, while actors in the buildings and road transport sectors will experience emissions trading for the first time under the EU ETS 2. However, maintaining multiple prices and systems weakens the cost-effectiveness of carbon pricing as a way of encouraging emission reductions where they are least expensive **(policy inconsistency)**. One example of this is electrification of the buildings and transport sectors, which is both encouraged by subjecting fossil fuels in heating and road transport to the EU ETS 2 carbon price and discouraged by subjecting electricity to a (higher) carbon price under the EU ETS.

Recommendation C3. The EU ETS 2 should be reformed for after 2030 to give greater certainty regarding the overall quantity of allowances and strength of the emission price signal associated with fuel use in transport, buildings and the other sectors covered. Including these sectors in the EU ETS (or other options for linking the two systems) should also be considered.

The EU ETS 2 will operate only from 2027 (potentially 2028). Hence, its initial years should be used as a trial period to inform design choices in later trading phases after 2030. Key parameters to monitor will include the level and volatility of the allowance price, the amount of additional allowances released in response to potentially high prices, the functioning of the auctioning, monitoring and reporting systems, the impact on carbon prices and energy taxes at the Member State level, and the system's effect on the uptake of emission reduction measures.

After 2030, the EU ETS 2 should, at a minimum, feature a carbon price high enough to achieve an emission reduction target consistent with the EU's climate neutrality goal, and enhanced credibility so that it is clear to participants whether it will resemble a traditional cap-and-trade system (in which quantity is fixed and prices could be high) or a carbon tax (in which prices are predictable but there is less certainty over the resultant emission reductions).

The European Commission should also propose options for increasing convergence between the two emissions trading systems. Options include creating a single emissions trading system (with a single emissions cap, carbon price and set of governance arrangements ([66])), and more gradual options such as allowing trading between the two systems so that their prices converge over time.

([66]) The ETS Directive (Article 30i) requires the European Commission to report on the implementation of EU ETS 2 by January 2028, and to assess by October 2031 the feasibility of integrating its sectors into EU ETS 1.

Expand coverage of emission pricing to missing sectors, including agriculture and land use.

Needs. All major sources of GHG emissions and opportunities for removals need to be covered by a price incentive to reduce emissions and increase removals.

Gaps. Although the recent Fit for 55 package more than doubles the scope of EU carbon-pricing policies, **some sectors are still not covered by explicit emission pricing (ambition gap / policy gap)**. Plans to include or expand the coverage of carbon pricing (including pricing of non-CO_2 GHG emissions) are at different stages of maturity. There is no EU-level price on emissions in **agriculture/food, forestry** and **land use**, which suffer from an overall lack of incentives to reduce emissions and increase removals (see Chapter 8 'Agriculture' and Chapter 9 'Land use, land use change and forestry'). The European Commission is currently studying ways of introducing some form of emission-pricing mechanism in these sectors. Municipal **waste** incineration may be incorporated into emission trading (in accordance with the ETS Directive), taking into account the risk of diverting waste streams to landfill or third countries. In **aviation**, intra-EU flights are covered by the EU ETS; expansion to extra-EU flights is dependent on further legislation and the development of the international carbon offsetting and reduction scheme for international aviation **(implementation gap)**.

Recommendation C4. The EU should start preparations now with a view to introducing pricing instruments in the agricultural/food and LULUCF sectors, in order to incentivise emissions reductions and carbon removals. These instruments need to take into account the technical complexity of measuring emissions and removals, and attributing them to land management and mitigation actions, as well as differences in the permanence of various natural removals. Discussions on the development of carbon removal certification for land, and pricing of non-CO_2 emissions in agriculture, should therefore explore these complexities, focus on solutions that are scientifically robust and feasible, and convert the solutions into concrete legislative proposals for after 2030. Policymakers will need to pay particular attention to whether land-based carbon removal should be rewarded as part of a system for pricing of non-CO_2 emissions in agriculture, or whether non-CO_2 emissions and carbon removal should be treated separately. They should also take account of the possibility that such carbon-pricing efforts will be affected by emission leakage through international trade (see also Chapters 8 'Agriculture' and 9 'Land use, land use change and forestry').

For international aviation, the EU should ensure that the same carbon price applies to all outgoing flights (including to third-country destinations), whether through the EU ETS, the carbon offsetting and reduction scheme for international aviation (CORSIA) or a combination of the two (see also Chapter 6 'Transport').

Reform energy taxation so that relative price signals are consistent with climate goals.

Needs. Effective carbon prices in the EU today can vary from zero to over EUR 100/t CO_2e, depending on the Member State, activity and fuel use. This can mean that some cost-effective options for reducing emissions are not pursued, while costlier options may need to be considered instead.

A lot of the difference in effective carbon prices is due to implicit carbon pricing (meaning taxes levied for other reasons, such as excise duties). While differences are justifiable (because climate policy is not the only goal of taxation), instances where the tax system actively encourages climate-damaging activities need to be removed.

Gaps. The current ETD permits energy tax differentials that are inconsistent with climate goals. For example, fossil fuels can be taxed less than electricity. In some cases, activities that are not covered by explicit carbon pricing (such as agriculture and extra-EU flights) can also be exempted from energy taxation entirely **(policy inconsistency)**.

Recommendation C5. The EU should adopt the proposed reform of the ETD and consider further options for aligning taxation and incentives to reduce emissions.

Adoption of the revised Fit for 55 ETD proposed by the European Commission would go a long way towards addressing inconsistencies between energy taxation and climate policy. It would remove exemptions (the ability to tax energy use below established minimum rates), tax fuels based on energy content (rather than volume) and establish a hierarchy whereby carbon-intensive fuels are taxed the most.

Further improvements could be introduced, such as taxing electricity based on the carbon content of the energy used to produce it (this is an option for Member States but not an obligation in the European Commission's proposal).

Carbon-pricing policies need to be complemented by redistributive policies to mitigate adverse social impacts, and by measures to address market failures and support investments in infrastructure and innovative new technologies.

Needs. Carbon pricing provides social benefits by reducing the impacts of climate change and fossil fuel consumption, as well as reducing dependence on fossil fuel imports. However, in most cases carbon pricing is regressive (a heavier burden falls on people with low incomes and certain vulnerable groups). Therefore, it needs to be accompanied by complementary or compensation measures that can alleviate its burden without undermining its effectiveness. These include targeting non-market barriers to reducing emissions (thereby lowering abatement costs and hence the carbon price needed to achieve a given level of emission reduction) and recycling revenues from carbon pricing to make low-emission substitutes available, accessible and affordable for vulnerable groups (see Chapter 11 'Whole of Society Approach'). Carbon-pricing revenues should also continue to fund the development and deployment of innovative new technologies with the aim of bringing their prices down to the point where they would be competitive at the prevailing carbon price.

Gaps. Under the revised ETS Directive, Member States must spend all the revenue they receive from auctioning ETS allowances for climate and energy-related purposes, including the decarbonisation of energy and transport, RD & D of innovative new technologies, energy efficiency, providing support to vulnerable households and compensating sectors exposed to carbon leakage. Nevertheless, **ambition gaps** exist. While the potential revenue from carbon pricing will expand once the CBAM begins to collect payments from 2026, there is no requirement to spend these proceeds on climate- and energy-related purposes. Replacing the remaining free ETS allowance allocations with auctioning would further increase revenues earmarked for energy and climate purposes.

Recommendation C6. Resources for climate and energy-related expenditure should be expanded by ending the free allowance allocation in the EU ETS and requiring revenues collected by the CBAM to be spent for climate- and energy-related purposes.

10.1 Scope and overview

This chapter provides an overview of the role of carbon prices in the EU climate policy mix, and assesses the consistency of the main policies that affect the pricing signal. Carbon pricing in this sense refers to the collection of economic measures that affect the cost of emitting GHGs. It includes both explicit measures designed to reduce emissions (such as the EU ETS) and implicit measures that act as de facto carbon prices (such as taxes on energy).

Other forms of regulation that affect GHG emissions are considered in Chapter 13 on governance, as well as in earlier sectoral chapters. The distributional consequences of carbon pricing (and of climate policies in general) are considered in Chapter 9 on whole-of-society approaches.

10.2 The role of carbon pricing in the policy mix

Carbon pricing as climate policy

There is a consensus in the relevant literature that a sufficiently high carbon price plays an important role in reducing GHG emissions and achieving climate neutrality (ECB, 2022; IEA, 2022e; IMF, 2019; Koch et al., 2022; OECD, 2021). Carbon pricing can incentivise reductions cost-effectively, since it enables the market (both producers and consumers) to identify and exploit the most cost-effective way to reduce emissions. It also incentivises investment in low-carbon technologies, and generates additional fiscal revenues, which can be recycled to finance complementary policies or compensation measures, alongside decarbonisation.

Carbon pricing as fiscal policy

The tax system can be used as a means to correct externalities, hence providing (dis)incentives to induce behavioural change, for example by discouraging smoking, or by encouraging innovation and investment.

When it comes to influencing GHG emissions, some policy measures price emissions explicitly, while others, such as excise taxes on fuel, act as implicit carbon prices. The latter are typically not designed to control GHG emissions in the first place, and are not calculated as a price per tonne of CO_2 equivalent, but nevertheless put a price on emissions at the margin.

Carbon pricing is therefore capable of raising revenue to compensate low-income households or finance green infrastructure while aligning price incentives with climate goals. However, by reducing GHG emissions, successful carbon prices run the risk of undermining their own revenue base in the long term as the economy decarbonises (EEA, 2022g). Therefore, carbon pricing should not be understood as a traditional fiscal instrument, feeding national budgets sustainably with revenue streams. However, carbon pricing can be used together with other fiscal instruments to reduce horizontal and vertical inequality (Hänsel et al., 2022).

Carbon pricing within the EU

In the EU today, carbon pricing is applied through several overlapping measures at both the European and national levels.

The EU ETS is an EU-wide cap-and-trade system, which was created in 2005 following several failed attempts to establish an EU-wide carbon and energy tax (Delbeke and Vis, 2019). At the time (and still today) decisions on taxation required unanimity among Member States, whereas environmental measures such as a cap-and-trade system required only qualified majority approval.

Environmental taxes are not set at the EU level, although they are subject to some common rules as part of the EU's single market, including the minimum tax rates set out in the ETD. However, the ETD has not been revised since 2003, in part because any reforms need to be approved unanimously (EP, 2021).

According to Eurostat data, environmental taxes in the EU consist primarily of energy taxes, although explicit carbon taxes also exist in 14 Member States (Eurostat, 2022a). Environmental taxes represent 5.5 % of government revenues from taxation and social contributions in the EU. While the vast majority of this share (78 % in 2021) comes from energy taxes, revenue from the auctioning of EU ETS allowances represented 6.4 % of total energy tax revenue in 2020. However, the share of environmental taxation in total tax revenue has been falling since 2009 (i.e. revenues have risen more slowly than GDP and overall tax revenue). Environmental taxes are most often levied per unit of physical consumption and are fixed in nominal terms. Hence, their real value tends to fall over time unless adjusted for inflation or gradually adapted (EC, 2021q; Eurostat, 2013).

Carbon pricing combined with complementary policy instruments

While carbon pricing is traditionally acknowledged as the cost-effective way to achieve an emission reduction objective (Jenkins (2014) citing earlier literature), there is an ongoing debate about how ambitious climate targets are best achieved by including carbon pricing within a wider policy mix (Goulder and Parry, 2008; Jaffe et al., 2005; Koch et al., 2022).

Such research indicates that the theoretically cost-optimal solution is not always feasible or sufficient because of market failures, which justify complementing emission pricing with other policy instruments such as standards, bans or subsidies ([67]). Market failures hindering the uptake of potentially cost-effective mitigation options include imperfect information, split incentives ([68]), principal–agent relationships, network externalities or insufficient R & D investments (see Hood (2011) for a more complete overview). Addressing these market failures though complementary measures can therefore improve the effectiveness and reduce the cost of a carbon-pricing regime, by improving the uptake of theoretically low-cost mitigation measures. Examples of other instruments include minimum efficiency standards and labelling, building codes, or policies and incentives for expanding vehicle charging infrastructure.

The need to bring forward and reduce the cost of immature technologies is also often cited as a justification for supplementing carbon pricing with other measures (Kalkuhl et al., 2012). A policy combination can be justified because current societies are locked in to high-emitting technologies in terms of infrastructure, institutions and markets. Furthermore, incumbent emitting technologies have been able to reach very low costs through decades of learning, economies of scale and increasing returns through network effects, which place new technologies at a competitive disadvantage at the beginning of their lifetimes. For example, Stiglitz (2019) points out that high carbon prices may be needed to switch to low-emission technologies, but maintaining them may not require such high carbon prices once these same effects take hold for the new technologies.

Combining carbon pricing with complementary measures can also be justified when there are multiple market failures to be addressed simultaneously (e.g. reduce GHG pollution, encourage innovation,

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([67]) 'Market failure' means when decisions based on market prices do not generate an efficient allocation of resources because of market distortions such as externalities. Externalities are costs or benefits incurred by third parties by production or consumption. Pollution is an example of a negative externality. Education is an example of a positive externality (because it benefits society as well as the individual student).

([68]) 'Split incentives' means when the costs and benefits of an action accrue to different people, for instance in the building sector, where renovations would be the responsibility of the landlord, but the benefits in terms of energy savings would accrue to the tenant.

address distributional concerns, raise revenue). For example, Kalkuhl et al. (2013) demonstrate a second-best situation in which carbon pricing is effective in reducing emissions, while a complementary renewable energy subsidy limits the resultant energy price increase. Some authors (e.g. Stiglitz, 2019) raise concerns about the level of carbon prices because of their political consequences. Some command-and-control regulation can lower the level of explicit carbon tax required to achieve a given emission reduction, and thereby reduce the adverse distributional consequences of the tax. However, the overall economic costs – often hidden – will increase and have to be paid by consumers or producers.

Use of revenues from carbon pricing

Targeting the use of carbon-pricing revenues is one way to combine the price-incentive effect of carbon pricing with other objectives (such as redistribution to low-income groups, or funding innovation). This is also a core feature of the EU ETS. In the Fit for 55 revision of the ETS Directive, Member States are required to spend their share of the revenues from allowance auctioning on climate- and energy-related purposes, which can include investing in decarbonisation of energy and transport, R & D and energy efficiency, providing support to vulnerable households or transport users, and compensating sectors exposed to carbon leakage (EU, 2023c) ([69]). In addition, a share of allowances is managed at the EU level (rather than by Member States) for improving energy efficiency and modernising energy systems in lower-income Member States (Modernisation Fund), and supporting innovation in low- and zero-carbon technologies (Innovation Fund). The new EU ETS 2 features a Social Climate Fund to be spent by Member States on similar purposes (including temporary direct income support for vulnerable households and transport users), funded by a combination of auctioning revenues and national co-financing.

Following the revision of the ETS Directive, there are two remaining opportunities for increased revenue recycling in EU carbon-pricing policies. Firstly, there is currently no requirement for Member States or the EU to spend CBAM revenues on energy and climate-related purposes (although a recital in the CBAM regulation mentions the need for the EU budget to support adaptation in least developed countries) (EU, 2023n). Legislation on the use of the EU's own resources ([70]) created by the CBAM is still being debated but, at the time of writing, does not contain such a requirement (EP, 2023). Secondly, replacement of free allocation in the EU ETS by auctioning, would create additional revenues to be used for climate- and energy-related purposes.

Data covering 2013–2020 indicates that Member States spent 75 % of their auctioning revenues on climate- and energy-related purposes between 2013 and 2020. However, five Member States did not meet this requirement individually (EEA, 2023q).

Carbon pricing under Fit for 55

The de facto approach to carbon pricing in the EU and its Member States has also been to integrate explicit carbon pricing into a broader portfolio of climate and non-climate policies, taxes and subsidies. With the proposals of the European Green Deal, the EU is attempting to expand carbon pricing to areas not already covered. The rest of this chapter considers carbon pricing under the Green Deal, in particular the EU ETS, the EU ETS 2 and the reform of the ETD.

([69]) 'Carbon leakage' refers to the displacement of emissions to regimes outside the EU where climate governance is laxer. According to the directive, Member States must seek to limit compensation to leakage-exposed sectors to 25 % of the revenues or below (and provide justification if this share is higher). The list of eligible spending areas is in Article 10(3) of the ETS Directive.

([70]) EU 'own resources' are sources of revenue for the EU budget (as opposed to carbon-pricing revenues that can be spent by Member States).

10.3 EU Emissions Trading System (energy supply, industry, international transport and maritime)

The EU ETS has been the EU's climate flagship policy since 2005. Since then, it has been revised multiple times, resulting in an extended scope, a more ambitious emission cap, more stringent allocation rules and increased recycling of auctioning revenues for climate purposes. The latest revision of the EU ETS was concluded in 2023, based on the European Commission's proposal under the Fit for 55 package. It had the following key outcomes.

— **Extension of the system to the maritime sector, to be concluded by 2026.** Furthermore, the European Commission is mandated to consider the extension of the system to waste incineration by 2026, with a view to include the sector as of 2028.
— **Further tightening of the emissions cap.** This is to be done both by increasing the annual linear reduction factor (from the current 2.2 % to 4.4 % by 2028) and by imposing two one-off reductions in 2024 and 2026. As a result, the current directive would reduce the cap to zero by around 2040.
— **Adjusting the MSR**. The MSR consists of ETS allowances that have been withdrawn from the market but can be released back into it under certain conditions. The latest adjustments include maintaining the current ('accelerated') rate at which allowances enter the MSR, capping the maximum size of the MSR at 400 million allowances from 2024, and gradually invalidating excess MSR allowances above that level (EU, 2023b).
— **Gradual transition from free allocation to a carbon border adjustment mechanism (CBAM) for specific sectors.** The aim is to shield the relevant sectors against the risk of carbon leakage.
— **More rapid phase-out of free allocations for the aviation sector.** This is to be implemented by 2026.
— **Changes to the distribution of auctioning revenues.** These include an increase in the volumes of the Modernisation Fund and the Innovation Fund, and a requirement for Member States to spend all of their auctioning revenues (or an equivalent amount) on climate- and energy-related purposes.
— **Creation of EU ETS 2, a parallel emissions trading system for buildings and road transport and other sectors.** This is discussed in Section 10.4.

The progressive tightening of the EU ETS cap, together with other reforms, has caused the carbon price to increase considerably over time, from EUR 5/t CO_2e in the mid 2010s to EUR 80–90/t CO_2e in recent years. It has remained at higher levels despite external shocks such as the COVID-19 pandemic and the energy crisis in 2021–2022 (Bruninx and Ovaere, 2022; Pahle et al., 2023). As a result, the incentive that the EU ETS provides for GHG emission reductions is stronger now than ever before.

Continued effort is needed to combat carbon leakage without undermining the carbon price signal.

While auctioning is the default allocation methodology under the EU ETS, a substantial proportion of EU ETS allowances (48 % of total supply in 2013–2020) are allocated for free, mainly to sectors that are considered to be exposed to the risk of carbon leakage (EC, 2023g).

The rationale behind free allocation is that these sectors are considered unable to pass on the cost of the EU ETS to their customers downstream in the value chain without losing competitiveness and thus market share to non-EU producers that do not face a comparable carbon cost ([71]). As a result, the EU ETS could lead to displacement of production (and related GHG emissions) to outside the EU. To prevent this, ETS firms in certain sectors are given a certain amount of allowance (based on benchmarks) for free.

([71]) This applies both to EU firms that are competing on the EU market with non-EU producers that import their products into the EU and to EU firms that export their products and are competing with non-EU producers outside the EU.

This should reduce the actual carbon cost they face, thereby reducing the need to pass this cost through to their customers.

Free allocation therefore risks weakening the incentive for demand-side mitigation measures (such as improved material efficiency or material substitution) by reducing the need for firms to pass through the ETS cost through to their customers. In addition, several assessments have suggested that free allocation creates distortions in the carbon market, the extent of which continues to be debated in the literature. There is debate over whether or not free allocation affects firms' production and mitigation decisions (Teixidó et al., 2019; Venmans, 2016; Zaklan, 2023), and over the extent to which it has enabled windfall profits through over-allocation of allowances or passing carbon costs on to consumers (Cludius et al., 2020; Neuhoff and Ritz, 2019).

Recent EU ETS reforms extended the use of free allocations into trading phase IV (2021-2030). The revision introduced more dynamic allocation benchmarks by aligning free allowances with actual production levels. Still, substantial free allocations are permitted to continue until 2030. For 2021–2030, sectors that are considered exposed to the risk of carbon leakage (and thus eligible for continued free allocation) account for 94 % of total industrial GHG emissions under the EU ETS (EC, 2019e), and over 40 % of the aggregated ETS cap is projected to be allocated for free (ECA, 2020b) ([72]).

In the first two phases of the EU ETS (up to 2013), the scientific literature did not find significant evidence of carbon leakage caused by the EU ETS (Cludius et al., 2020; Hintermann et al., 2020; Verde et al., 2019). However, studies that include more recent data do find (non-causal) evidence of carbon leakage (while confirming the lack of such effects prior to 2013). A study by the European Central Bank (ECB) (2023a) observes that emission reductions in EU ETS industries within the EU were more than offset by a simultaneous rise in emissions from the same industrial sectors outside the EU, and that sourcing high-emission inputs from within the EU translates into a competitive disadvantage. Similarly, De Beule et al. (2022) found (non-causal) evidence of investment leakage, meaning that multinational enterprises respond to more stringent climate policy by investing outside the EU. The risk of carbon leakage strongly depends on the development of climate policies in other major economies outside the EU. In that respect, it is positive to note that uptake of cap-and-trade systems and carbon taxes is increasing, including in emerging economies (World Bank, 2023). Furthermore, there is some evidence that the adoption of carbon pricing in one country can explain the subsequent adoption of carbon pricing in other countries (Linsenmeier et al., 2023).

To further address the risk of carbon leakage, the EU adopted the CBAM that will start to operate as of 2026. Under this mechanism, a price equivalent to the ETS price is put on imports of certain carbon-intensive products and their precursors ([73]) into the EU. It will be phased in gradually between 2026 and 2034, with a corresponding phase-out of free allocation for the same products under the EU ETS ([74]). For sectors that are exposed to the risk of carbon leakage but not (yet) covered by the CBAM, free allocation will continue. This means that free allocation will coexist with the CBAM, and a substantial share of the allowances under the EU ETS cap is still expected to be allocated for free until at least 2030.

The newly adopted CBAM could reduce carbon leakage by ensuring that both domestic production and imports face a carbon price (meaning that all suppliers to the EU market have an incentive to reduce emissions). Its introduction – combined with a corresponding phase-out of free allocation – would also provide a stronger incentive for demand-side mitigation measures (e.g. material efficiency or substitution), as it would ensure that the carbon cost is passed down the value chain.

([72]) Before taking into account the impact of the CBAM, which is expected to reduce this share.

([73]) Cement, iron and steel, aluminium, fertilisers, electricity and hydrogen.

([74]) For example, in 2026, a carbon price will be levied on imported steel based on 2.5 % of its climate impact, and the amount of allowances allocated to EU steel producers will be decreased by an equal 2.5 %. This share increases to 5 % in 2027, 10 % in 2028, 22.5 % in 2029, 48.5 % in 2030 and so on, to reach 100 % by 2034.

On the other hand, even with the introduction of the CBAM, removing free allocation could place EU exporters at a disadvantage if they are competing in third-country markets against firms that are not subject to a carbon price (Evans et al., 2020). Furthermore, both the European Commission (2023f) and the ECB (2023a) point out that it may be necessary to expand the CBAM's coverage further downstream. Otherwise, there may be an incentive to avoid the carbon price by switching from importing raw materials to importing more refined products. To this end, the product scope will be reviewed during the scheme's transitional phase.

Because of the rapid decline of the ETS cap – which is expected to reach zero before 2040 – the allowances available for free allocation will become more and more scarce. This means that in any case the EU needs to consider further alternatives to free allocation to address the issue of carbon leakage. One option is a further extension of the CBAM, which has the additional advantage that it can sharpen incentives to reduce emissions (Jakob, 2023). However, this would still leave the issue of EU exporters unresolved. This underlines the need for (i) climate policies to encourage innovation, scale-up and cost reduction for zero emission technologies so that they become the more competitive choice; and (ii) the EU to pursue diplomatic efforts to encourage carbon pricing in the EU's trading partners and ensure a level playing field and strong mitigation incentives for both imports and exports.

Preparations must start now to make the EU ETS fit for 2040.

With the Fit for 55 revision of the EU ETS Directive, the emissions cap is expected to reach zero by 2039 ([75]). Specifically, the increase in the emissions cap's annual linear reduction factor, eventually to 4.4 % from 2028 onwards, and the lack of a sunset clause for this provision, combined with the invalidation of allowances held in the MSR above a level of 400 million (equivalent to 31 % of verified EU ETS emissions in 2022) ([76]) are decisive reform elements.

Still, both the European Commission's long-term scenarios and the scenarios underpinning the Advisory Board's 2040 advice indicate considerable residual GHG emissions in 2040 in sectors covered by the EU ETS (in particular in industry and in international aviation and maritime transport), which means demand for allowances will not reduce to zero.

This brings the 'endgame' of the EU ETS in sight, raising questions about how governance and stability mechanisms must be adjusted to account for trade frictions under low liquidity (Pahle et al., 2023).

The possible consequences of the latest revision (assuming there are no further reforms of the EU ETS governance) are explored by Pahle et al. (2023). They include more rapid emission reductions and banking of allowances as participants anticipate the future scarcity of allowances. In an optimistic outcome, this could drive investment in green technologies, thereby reducing the demand for allowances. However, considering potential impacts beyond modelling, the price of allowances could become increasingly high and volatile, calling the political credibility of the ETS into question.

There are numerous options available to policymakers for avoiding the outcome described above. In principle (and without prejudging future advice of the Advisory Board or forthcoming political discussions) these could include the following.

— **Increasing liquidity.** This could be done by expanding the scope of the EU ETS, for example by including smaller operators and other sectors (such as agriculture and waste, or linking with the new

([75]) The 2039 extrapolation excludes aviation.

([76]) The ETS Directive establishes the 'invalidation' of allowances above 400 million, but also stipulates that legislators could revise this in the light of a hypothetical European Commission proposal based on the annual review of the functioning of the European carbon market.

EU ETS 2 covering transport and buildings); or by linking to emissions trading systems elsewhere in the world (FTI consulting, 2023; Ferrari, 2023; Pahle et al., 2023).

— **Incorporating CDR into the ETS.** This will require a governance framework that balances the need to scale up carbon removal technologies against the risks associated with relying on these technologies and the risk of crowding out emission reduction as the primary means for achieving climate neutrality (Strefler et al., 2021) ([77]).
— **Further regulatory changes.** These may include adjustments to the cap or MSR, shifting to a more price-based approach by introducing floor and ceiling prices, or replacing the EU ETS with a carbon tax.
— **Establishment of a carbon central bank.** It could perform some combination of all the above, with the intention of keeping carbon prices or net emissions within a trajectory consistent with EU policy goals (Edenhofer et al., 2023; Rickels et al., 2022).

By agreeing to a steeper, stricter emission reduction path, the latest revision of the ETS Directive has ushered in the endgame of the ETS and placed it within current investment horizons. This in turn increases the urgency of addressing questions around the future of climate governance, in particular the EU ETS, in a credible way (Dolphin et al., 2023). The next scheduled review of several of the abovementioned issues related to the EU ETS Directive and the MSR is due in (July) 2026, and further assessment of the different options for post-2030 governance needs to start now. The Advisory Board will contribute to this in future work, including its upcoming report on carbon removal, which is planned for publication in 2024.

10.4 EU Emissions Trading System 2 (buildings and road transport)

The revised ETS Directive creates a separate EU ETS 2 for buildings and road transport and additional sectors (mainly smaller industry) (EU, 2023c). By introducing an additional emissions trading system, the EU has significantly enhanced its policy architecture; EU carbon pricing, and monitoring and reporting of emissions are expanded to additional sectors; and additional fiscal revenues will be generated by auctioning emission allowances issued under the new system. This in turn enables further spending on climate- and energy-related purposes (including support to vulnerable groups through a dedicated Social Climate Fund). However, design features of the system make it difficult to predict its contribution to achieving the EU's 2030 climate target. Most of this difficulty relates to uncertainties related to the soft price cap set at EUR 45/t CO_2e in the initial years of the system.

The EU ETS 2 expands the coverage of carbon pricing.

The EU ETS 2 will become operational in 2027 (or 2028, in the event of exceptionally high fuel prices), with data collection and reporting starting in 2025. In the impact assessment accompanying the original EU ETS 2 proposal, the European Commission stated that the EU ETS 2 should operate as part of a broader policy mix to decarbonise the transport and building sector, given the existence of non-market barriers such as split incentives, lack of information and lack of access to finance (EC, 2021al). EU co-legislators have therefore decided that, at least until 2030, the sectors covered by the EU ETS 2 will also continue to be covered by the ESR, thereby supporting Member States in meeting their ESR targets.

The implementation of an EU-wide carbon-pricing mechanism in the road transport and buildings sectors is an important step forward, which is expected to drive further GHG emission reductions. As

([77]) CO_2 that is captured and stored geologically is exempt from the requirement to surrender EU ETS allowances (according to Article 12 of the EU ETS Directive). The Fit for 55 revision of the directive extends this exemption to GHGs that have been captured and utilised, mandating the European Commission to develop implementing legislation on how to ensure that the utilised GHGs do not enter the atmosphere.

pointed out by the German scientific platform on climate protection (WPKS, 2022), it strengthens climate governance in several different ways compared to having these sectors are governed only by national measures contributing to ESR targets. Firstly, the EU ETS 2 provides direct incentives to lower emissions by means of the price signal. Secondly, it introduces a compliance mechanism that reduces the reliance on each Member State's bespoke policies and measures as an incentive for reducing emissions, and on the ESR compliance procedure (see Section 14.2).

The EU ETS 2 carbon price is uncertain.

The emissions cap and auctioning of allowances in the EU ETS 2 will be calculated so as to achieve a 43 % emission reduction in regulated sectors (combined) by 2030 (compared to 2005 levels). This is consistent with these sectors' contribution to an overall 55 % emission reduction target as per the European Commission's MIX scenario (EC, 2021c). In the buildings and road transport sectors, there is considerable uncertainty about price elasticities and future market developments, and it is not clear *ex ante* how actual prices may develop. The original European Commission proposal estimated allowance prices of between EUR 48 and EUR 80, with the lower estimate assuming there are more complementary emission reduction measures to accompany the carbon price (EC, 2021c). However, other studies suggest a carbon price of EUR 200–300 in the absence of sufficient accompanying measures (Abrell et al., 2022; Agora Energiewende, 2023; Rickels et al., 2023).

Price formation under the EU ETS 2 is regulated in several ways, either using a rule-based procedure or by direct intervention of the European Commission. To prevent sudden price peaks in the starting phase of the system, auction volumes will be frontloaded (130 % of volumes for 2027). The frontloading mechanism is 'cap neutral', as quantities will be deducted from auctioning volumes between 2029 and 2031. Additional allowances will be released if the allowance price exceeds EUR 45/t CO_2e for two consecutive months (the soft price cap in initial years of the system). These additional allowances will come from a separate MSR, which will be endowed initially with 600 million allowances (equivalent to 80 % of the sectors' target-consistent emissions for 2030 ([78])). Unlike the EU ETS, for which surplus allowances already in circulation were placed in the MSR, the initial reserve for the EU ETS 2 will contain allowances that are additional to the quantity calculated to be consistent with the 43 % reduction target.

It is also not clear how many allowances will be released on to the market if the soft price cap is exceeded. According to the directive, the first triggering of the cap would result in the release of 20 million allowances (equivalent to 3 % of the sectors' target-consistent 2030 emissions[78]). Additional tranches of 20 million, 50 million or 150 million allowances could be released on to the market several times depending on how allowance prices develop (explained in the directive's Article 30h).

There are significant risks to the EU's climate targets and social compatibility.

If the EU ETS 2 fails to meet its 43 % reduction target, there is a considerable risk that the EU will fail to reach its 2030 target under the ESR. This places pressure back on Member States to address the shortfall by adopting further national policies and measures in ESR sectors, either in transport and buildings or in other sectors such as agriculture and land use. The ESR features a flexibility mechanism, which grants Member States the option to sell any surplus of their reductions under the ESR sectors to others to efficiently achieve compliance. However, it is unclear *ex ante* whether sufficient annual emission allocations will be available to fill potential emission gaps, in particular given ESR's slow-acting and relatively weak compliance mechanisms (see Section 14.2).

([78]) See Table 46 of European Commission (2021c).

In this context, Member States that already have ambitious carbon prices covering EU ETS 2 sectors should maintain them, since this would help mitigate the risks of not meeting national obligations under the ESR and increase the predictability of investment decisions. Furthermore, the introduction of the EU ETS 2 will reduce the risk of intra-EU carbon leakage by placing an EU-wide floor on the level of ambition.

If the EU ETS 2 prices reach the higher end of price projections, the distributional impacts of uncompensated carbon pricing can be significant. In the course of the Fit for 55 package, the EU has decided to establish a Social Climate Fund to mitigate adverse effects of the EU ETS 2 on vulnerable groups (see Section 11.4 for a detailed explanation). Each Member State is eligible for a specified maximum share of Social Climate Fund funding based on a 'solidarity' formula (EU (2023l), Annex I). However the size of the fund is capped at EUR 65 billion, irrespective of the value of the carbon price. While the Social Climate Fund has been broadly welcomed by stakeholders (EurActiv, 2023), it remains unclear at this stage whether the combination of the fund and national auction revenues will be sufficient to balance distributional concerns and vulnerability issues in the EU ETS 2 context (Pahle, 2023).

The underlying logic of having two separate emissions trading systems merits revisiting beyond 2030.

As discussed above, the EU will, from 2027, operate two separate emissions trading systems, each with separate carbon prices, caps, allowance allocation methods, and systems for managing the price or quantity of allowances. This appears suboptimal, since the underlying logic of carbon pricing is to allow the market to identify and incentivise the most cost-effective emission reductions wherever they might be. One example of this is electrification of the buildings and transport sectors, which is encouraged on the one hand by subjecting fossil fuels in heating and transport to the EU ETS 2 carbon price, but discouraged on the other hand by subjecting electricity to a (probably higher) carbon price under the EU ETS.

There may be political, economic and administrative reasons for maintaining separate carbon markets at least in the short term. These include the fact that EU ETS is a tried and tested system that has been refined over nearly 20 years, while emissions trading may be new to the participants in the EU ETS 2. Furthermore, price changes in the buildings and transport sectors may be more salient to consumers than in the EU ETS sectors (since consumers purchase both heating and transport fuel directly). This provides a political (and distributional) rationale for policymakers' decision to introduce the EU ETS 2 in a more gradual manner, in particular given uncertainties over the EU ETS 2 carbon price and the likely success of policymakers in reducing it through complementary mitigation measures in these sectors.

However, the case for maintaining separate markets is likely to weaken over time, firstly because policymakers and the public will gain experience of operating the EU ETS 2, and secondly because (other things being equal) the EU ETS cap will shrink towards net zero (or net negative emissions), placing a very high price on some carbon emissions and causing attention to shift to the sectors that continue to emit. Options for merging the two markets include the creation of a single emissions trading system (a single price, cap and set of governance arrangements). Alternatively, policymakers could consider more gradual convergence options involving linking (the possibility of importing allowances from one system to the other under certain conditions) (Edenhofer et al., 2022).

10.5 Energy Taxation Directive

Taxation of the embodied emissions in energy varies across Europe.

Effective carbon prices within the EU (the prices created by fuel excise taxes, carbon taxes and emission allowances combined) can vary widely between Member States and between different sectors and applications. This is mostly because taxation is decided primarily at the Member State level, and partly because taxation serves numerous policy objectives apart from climate policy goals.

While a comprehensive survey of effective carbon taxes within the EU is beyond the scope of this chapter, a number of key characteristics are noted here.

— There are **substantial differences in effective carbon taxation between Member States and between sectors**. Transport fuels (diesel and petrol) face relatively high implicit carbon prices compared with other sectors, ranging between Member States from less than EUR 150/t CO_2 to over EUR 350/t CO_2 (Matthes and Graichen, 2022). These prices consist overwhelmingly of excise duties rather than explicit carbon taxes (OECD, 2023a). However, there are numerous sectoral reductions and exemptions. For example, agriculture and energy-intensive industries pay the least tax relative to the amount of energy they consume (Trinomics, 2020).

— **Explicit carbon taxes are levied in 14 Member States** according to Eurostat (2022a), while the European Commission estimates that 7 Member States have carbon taxes covering the buildings and transport sectors, with prices in 2020 ranging from EUR 19 to EUR 115 per tonne of CO_2 (EC, 2021c)

— **Tax rates sometimes favour carbon-intensive choices.** For example, effective carbon rates for coal are much lower than the rates for gasoline and diesel quoted above. Although most coal uses are subject to explicit carbon pricing under the EU ETS (around EUR 90 at time of writing), excise duties for coal are much lower (ranging from EUR 0 to EUR 25/t CO_2) (OECD, 2023a). Similarly, electricity is taxed more highly than gas per kWh (Rosenow et al., 2023).

The ETD aims to harmonise tax levels but is not aligned with the EU's climate objectives.

The Energy Taxation Directive (2003/96/EC) sets minimum taxation levels across Europe to ensure that the internal market can function effectively. It was introduced in 2003 with one of its main objectives being to harmonise energy taxation, avoid the distortions between different energy carriers (such as gas and electricity) and avoid energy tax competition across Europe. This harmonisation is ultimately aimed at strengthening the internal market by addressing possible distortions from the relocation of energy-intense businesses to beneficial tax regimes.

In 2011, the European Commission proposed to restructure the ETD to reflect both energy content and emissions. Following 4 years of unsuccessful negotiations, the proposal was withdrawn, as Member States were unable to reach a unanimous agreement. In 2019, the European Commission published an evaluation report on the ETD (EC, 2019b), concluding that energy taxation can be an important part of the economic incentives that steer energy transition. Considering the need for an updated ETD, the Council invited the European Commission to analyse and evaluate potential options, with a view to publishing a proposal for a revision.

The European Commission's proposal to update the ETD aims to address this misalignment.

In 2021, as part of the Fit for 55 package, the European Commission proposed a revision of the ETD to 'remove outdated exemptions and reduced rates that currently encourage the use of fossil fuels' (EC, 2021ai). It would introduce a new scale of tax rates based on the energy content and environmental performance of the fuels and broadens the tax base to include more products in its scope, such as electricity, hydrogen and sustainable biofuels. Some of the main changes can be summarised as follows.

— Fuels and electricity would be taxed according to their energy content and environmental performance, rather than their volume. This change aims to help consumers to make more climate-cautious choices.
— A simpler product categorisation would be introduced, to simplify taxation and ensure that the most harmful fuels are taxed in the highest tax band.
— Exemptions for certain fuel uses, such as home heating, would be phased out, and so would the option for Member States to tax agricultural energy use at zero, thereby removing the possibility of taxing fossil fuels below specified minimum rates.
— Fossil fuels used for intra-EU transport by air or sea should no longer be exempt from energy taxation.

The proposal would tax energy use and price GHG emissions with a wider scope than the current ETD. One of the main challenges is to find ways to align EU-wide energy taxation with climate policy objectives. Low tax rates on fossil fuels increase the relative cost of switching to cleaner technologies and can delay the energy transition. According to the proposal, conventional fossil fuels (i.e. petrol, gas, oil) will be subject to the top minimum rate of EUR 10.75/GJ when used as motor fuel and EUR 0.9/GJ when used for heating. The next category applies to fuels such as fossil gas and liquefied petroleum gas, which will be taxed at a lower rate for a transition period of 10 years. In this transition period, a minimum rate of EUR 7.17/GJ will be charged when they are used in transport and EUR 0.6/GJ for heating. After the 10-year transition period, they will be taxed at the same rate as conventional fossil fuels. Electricity will be taxed at the lowest minimum rate, EUR 0.15/GJ, regardless of its use ([79]). Low-carbon hydrogen can also benefit from the same rate for a transition period of 10 years (EC, 2021z).

The European Commission proposal builds on the *ex post* evaluation of the ETD in 2017, which, in line with the better regulation guidelines, assessed the performance of the directive against the basic principles of relevance, effectiveness, efficiency, coherence and EU added value (EC, 2019b). The evaluation identified significant shortcomings in both the directive and its implementation. On effectiveness (i.e. progress made towards achieving policy objectives), the ETD was found to have made only a limited contribution to smooth functioning of the internal market, given the absence of an indexation mechanism and the multiple exceptions granted in certain industries. In terms of relevance and coherence, the ETD shows a gap between the needs of EU climate targets and the objectives the ETD was designed to address back in 2003 (for example, it enables electricity to be taxed more highly than fossil gas). The potential of synergies from the alignment of fiscal polies with policies in the domains of energy and transport remains unexploited. In the meantime, policy gaps and inconsistencies in implementation hamper the achievement of EU climate objectives.

Without a revision, the ETD undermines the effectiveness of the EU's carbon-pricing regime.

At the time of the writing of this report, progress on the revision of the ETD is limited, in part because of the requirement for revision to be approved by unanimity among Member States (as opposed to the qualified majority required for most Fit for 55 legislation). As previous sections of this chapter point out, taxes are not the only type of carbon price signal operating in the EU, and the Fit for 55 package should see a deepening and extension of explicit carbon pricing in several sectors. Nevertheless, the ETD in its current form enables the continuation of energy tax rates that run counter to the EU's climate goals by

([79]) Article 13 of the proposal also permits Member States to adopt a tiered approach to the taxation of energy inputs into electricity production, whereby taxation would reflect the input's relative carbon intensity.

taxing carbon-intensive energy carriers more lightly than low-carbon alternatives or by prolonging disparities in the carbon tax signals between Member States or different sectors of the economy. The ETD should therefore be revised in a manner similar to the European Commission proposal in order to correct these policy inconsistencies.

Additional opportunities for aligning energy taxation with climate goals include taxing electricity differently depending on its source (e.g. coal, wind) and offering preferential tax treatment for electrified transport or shore-side electricity for ships ([80]). The European Commission proposal allows Member States to exploit these opportunities by applying exemptions to these cases but stops short of giving them EU-wide preferential treatment.

10.6 Remaining gaps in the EU carbon-pricing regime

This section discusses emission pricing in agriculture and LULUCF. More general discussions of options for managing emissions and removals in these sectors can be found in Chapters 8 and 9, respectively.

With the most recent revision of the ETS Directive, the EU's carbon-pricing regime is extended to the maritime sector, road transport and fuels for heating in buildings. It might also be extended to (municipal) waste incineration as of 2028, based on an assessment by the European Commission to be carried out by 2026 (see Section 10.3).

As a result, the share of EU emissions and removals that are covered by an EU-wide carbon price will increase from 36 % at the time of writing ([81]) to 73 % in the second half of the 2020s (74 % if the EU ETS is extended to waste incineration) ([82]). However, the remaining 26 % (795 Mt CO_2e emissions and 230 Mt CO_2e removals in 2021) would remain excluded from any EU-wide carbon-pricing mechanism by 2030. Most of this carbon price gap, illustrated in Figure 74, is related to the absence of an EU carbon-pricing mechanism for the agriculture and LULUCF sectors, and the remainder is due to the partial exclusion of certain sectors (international aviation and maritime; non-CO_2 emissions from energy production, transport and combustion; and some smaller sectors including waste landfilling, wastewater treatment, etc.).

As all sectors will need to contribute to the 2050 climate neutrality objective, this gap should be addressed. Applying a carbon-pricing mechanism to the agriculture and LULUCF sectors would provide a clear financial incentive for farmers and forest managers to reduce emissions and increase removals, and for consumers to reduce the consumption of GHG-intensive agricultural products (see Chapter 8 'Agriculture'). It would also reduce the potential for intra-EU leakage ([83]) of emissions related to agriculture, forestry and other land use (Stepanyan et al., 2023), and address the uneven distribution of incentives for biomass use versus carbon removal (see Chapter 9 'Land use, land use change and forestry').

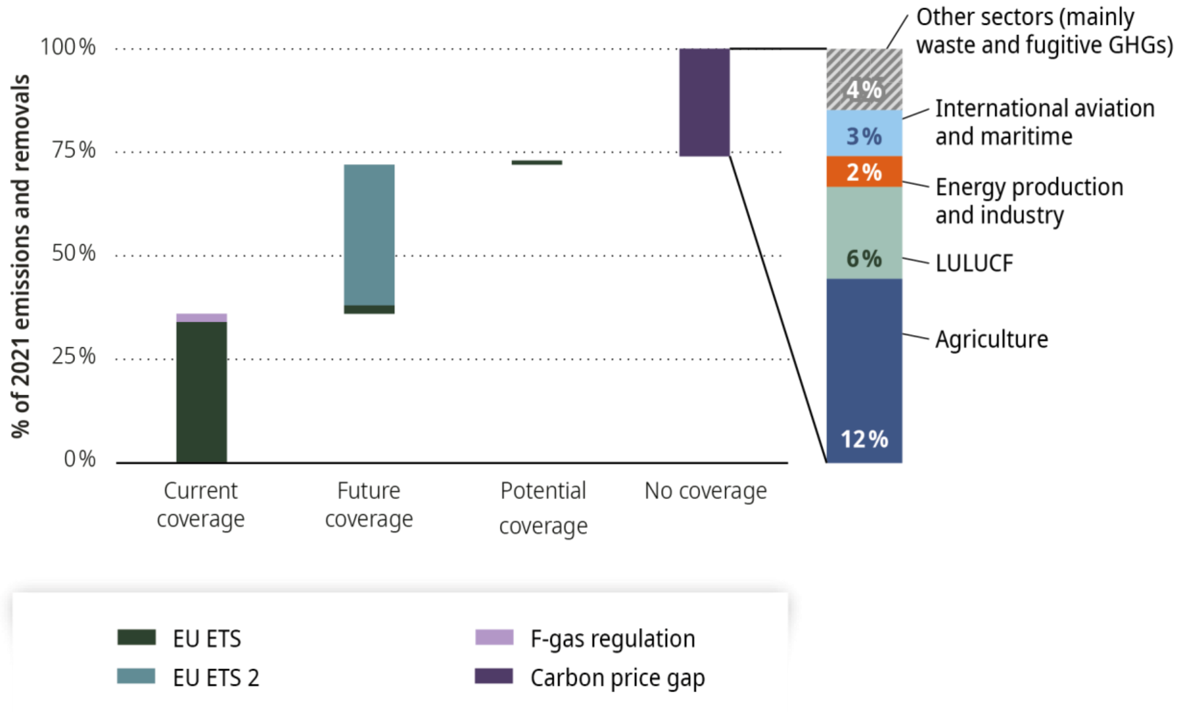
([80]) Shore-side power allows ships to turn off their engines (powered by tax-exempted fossil fuels) and connect to the electricity grid, thereby reducing local air pollution, and potentially GHG emissions, compared with using electricity generated on board the ship.

([81]) Hydrofluorocarbon emissions are currently covered by the F-gas regulation, which is considered to be a cap-and-trade system, and are therefore covered by a carbon or GHG price.

([82]) Based on the latest available data on GHG emissions and removals in 2021.

([83]) displacement of activity to regions with laxer climate policies

Figure 74 Scope of EU-wide carbon-pricing mechanisms (% of 2021 EU-wide GHG emissions and removals)



Notes: Agriculture includes both energy (CRF category I.A.3.c) and non-energy (category 3) GHG emissions. Energy production and industry include fugitive GHG emissions (category I.B). The denominator for determining the share is all EU GHG emissions and removals (both expressed as positive values) in 2021, including emissions from international aviation and bunkers but excluding indirect CO_2 emissions, as reported in the latest GHG inventories.

Sources: For the numerator: current coverage based on verified EU ETS data and the reported emissions from hydrofluorocarbons in the 2023 EU GHG inventory; future coverage under the EU ETS based on intra-EU, 'at berth' and half of extra-EU CO_2 emissions as reported by (EC, 2023k); future coverage under the EU ETS 2 based on the reported GHG emissions under the 2023 EU GHG inventory for road transport (CRF category I.A.3.b), the residential sector (category I.A.4.a) and the commercial/institutional sector (I.A.4.b); potential coverage based on an estimated 52 Mt CO_2e from waste incineration (this is an estimation, as the majority of waste incinerators recover energy and are therefore reported under the broader 'energy production' sector in GHG inventories); breakdown of the carbon price gap based on the 2023 EU GHG inventory data.

For **CDR**, the European Commission has proposed a certification framework based on four "QU.A.L.ITY" criteria (Quantification, Additionality, Long-term storage, and 225ustainability) (EC, 2022w). However, each of these criteria represents a key conceptual challenge to carbon pricing in land use (forestry and agricultural soils), as articles such as those by McDonald et al. (2023) and Wells et al. (2023) point out. It is challenging scientifically to quantify emissions and removals, and even more so to prove causality between management actions and carbon fluxes, due to the heterogeneity of the systems involved. Demonstrating additionality is also challenging because detailed checks may be needed to ensure that changes are the result of mitigation actions that go beyond existing requirements. Long-term storage cannot be guaranteed for land-based mitigation because carbon stored in soils and vegetation is inherently non-permanent and can be released by fire, natural disturbances, and changes in climate conditions or land management. This implies that land-based emission reductions and removals cannot be considered equivalent to other types of mitigation or removal unless sophisticated systems are put in place to ensure that the mitigation continues over time. Sustainability is challenging, since it involves ensuring that carbon-pricing incentives incorporate (or at least do not conflict with) several other environmental and social objectives. Despite these challenges, excluding land-based carbon fluxes from carbon pricing can create a loophole (Isermeyer et al., 2021), for example by incentivising the use of straw for energy (to avoid CO_2 emissions from fossil fuels) while failing to incentivise the carbon sequestration benefits of returning it to the field.

When it comes to pricing **non-CO_2 emissions in agriculture**, some of the same challenges apply – in particular, heterogeneity – and the need for on-site measurement if emissions and mitigation are to be calculated accurately. Isermeyer et al. (2021) provide a review of practical options. For CH_4 emissions associated with livestock, they suggest emission pricing could work by introducing a default emission value per ruminant animal (e.g. cattle, goats and sheep). For N_2O, pricing could be based on the nitrogen surplus calculated at the farm level (the difference between annual nitrogen inputs and outputs) or by subjecting sales of nitrogen fertiliser to a carbon price. When introducing emission pricing in agriculture, the same risks of carbon leakage apply as those discussed in the context of the CBAM above and will need to be taken into account.

Options for designing a carbon tax in agriculture have been considered by the Danish climate council (Klimarådet, 2023), and at the time of writing the government of New Zealand is developing a system to commence mandatory emissions reporting in 2024 and carbon pricing in 2025 (He Waka Eke Noa, 2022; New Zealand government, 2022; O'Connor, 2023). The New Zealand proposal contains a number of interesting design choices that could inform ongoing discussions among the European Commission and European stakeholders. Emission reporting will occur at the farm level, through the use of standardised calculation tools whereby the cost per farm will be a function of estimated CH_4 and N_2O emissions, with discounts awarded for specified mitigation actions. The initial scheme will apply separate emission prices for CH_4 and N_2O, as well as rewarding certain carbon sequestration activities. In this way, the proposal appears to resemble an emissions tax and incentive scheme for encouraging sectoral mitigation, rather than a cap-and-trade market based around tradable tonnes of verified CO_2e emissions and removals. However, the New Zealand government has stated that its eventual aim is to include scientifically validated forms of on-farm carbon sequestration in its national emissions trading system covering other sectors of the economy. Introducing carbon pricing in agriculture also raises issues of international trade and emission 'leakage' (Henderson and Verma, 2021; Zech and Schneider, 2019). The general economic principles of this question are the same as those discussed in Section 10.3 in the context of the EU ETS and the CBAM. However, questions specific to agriculture will also need to be considered and addressed.

At the EU level, the European Commission is currently exploring options for pricing emissions and rewarding removals in the land sector, including through surveying the public (EC, 2023bd), commissioning research (EC, 2023am) and holding discussions in the expert group on carbon removal (EC, 2023af). As part of this effort, a study by Trinomics (2023a) examined a number of options for introducing an emissions trading system in agriculture, exploring the pros & cons of different "points of obligation" including farm-level, upstream (producers and importers of fertilizer and feed), and downstream (meat and dairy processors). It found that an on-farm point of obligation is likely to be the most complex administratively but may provide the most direct incentive to reduce emissions. The study also stressed that "vertical arrangements" could be put in place to incentivise mitigation along the value chain. For example this could incentivise manufacturers and importers to produce and supply low-emission feed and fertilizer, and incentivise food producers to substitute away from the highest emitting animal products. Emissions pricing can also involve action further down the "farm to fork" value chain (such as differentiated VAT rates). These kinds of action are considered in Chapter 8 on agriculture. The Trinomics study also points out that administrative costs, combined with economies of scale, may mean that large farms benefit the most from the opportunity to generate credits from mitigation actions, implying that ways to limit adverse impacts on small farms will need to be identified.

The European Commission's deliberation needs to be followed up by a concrete legislative proposal, with a view to extending carbon pricing to the agricultural and LULUCF sectors after 2030. The Advisory Board will consider this issue further in future work, including a report on carbon removal expected to be published in 2024.

10.7 Summary table

Table 16 Policy consistency summary – pricing emissions and rewarding removals

Policy inconsistencies	– Differences in the carbon price between the EU ETS and the EU ETS 2 introduce discrepancies such as subjecting electricity and fuels to different carbon prices in the buildings and transport sectors. – The ETD allows fossil fuels to be taxed less than electricity.
Policy gaps	– The EU does not yet have a clear strategy to prepare the carbon market and relevant sectors for the era of very low emissions and the prospect of the allowance supply reaching zero by 2040 – Agriculture/food and land use are not covered by explicit carbon pricing.
Ambition gaps	– The latest reform of the EU ETS does not phase out free allowances completely. They continue in industrial sectors not covered by the CBAM. – The EU ETS 2 may fall short of its own 2030 target because of uncertainties concerning the level of the carbon price, and design features that may de facto loosen the cap. – Not all revenue from carbon pricing is allocated to climate action. While EU ETS revenues must be used for specified climate action purposes, a similar requirement for CBAM revenues has not been confirmed at the time of writing. In the EU ETS, replacing free allocation with auctioning would release additional revenue.
Implementation gaps	– Potential gap: the risk of the EU ETS 2 missing its target places pressure on Member States to increase the stringency of national policies and measures in pursuit of national ESR targets. – Legislation enabling the expansion of the EU ETS to extra-EU flights is yet to be proposed.

11 Whole-of-society approach

*The title of this chapter is inspired by the first global stocktake under the UNFCCC, which highlighted that '**carefully designed climate action** can generate significant benefits and can help to minimize disruptions by taking a whole-of-society approach informed by local context. Equity should enable greater ambition and increase the likelihood of meeting the goals of the Paris Agreement' (UNFCCC, 2023, own emphasis).* ***Given that several climate policy measures recommended in this report are likely to have regressive social impacts, at least in the short term, the Advisory Board raises a few points for attention in support of a careful design of the EU climate policies.***

Key messages

EU climate policies should be accompanied by more systematic ex ante and ex post measurements of their distributional and wider socioeconomic impacts in specific contexts. Co-benefits of climate mitigation policy measures such as health, well-being and climate resilience, as well as trade-offs, should be duly considered and better integrated in the EU's policymaking.

Needs. To allow a transition to societies with a high level of well-being in a net zero EU, EU climate policy cycles need to be informed by the distributional and wider socioeconomic impacts of their various measures in specific contexts, such as rural/urban and gender-specific aspects. Identifying climate policy co-benefits ([84]) and unintended harms provides policymakers with a more comprehensive picture of what is at stake, and allows science-based positive framing of policy. By informing and engaging citizens and other stakeholders, consultations can increase public support for climate policies and measures.

Gaps. Despite the better regulation toolbox being equipped with instructions regarding the assessment of distributional and wider socioeconomic impacts, EU climate policies have not always been accompanied by systematic measurement of such impacts **(implementation gap)**. Moreover, the evidence of climate policy co-benefits such as better health, social cohesion and energy security, as well as possible trade-offs, is often overlooked in impact assessments. For that reason, policymakers across the EU often lack sufficient understanding of the socioeconomic impacts of the policies they put forward.

Recommendation W1. More systematic and context-specific impact assessments and *ex post* evaluations (e.g. considering local and national needs) should help reinforce synergies between EU social and climate policies and improve climate policy narratives. Assessments should be transparent and include public consultations. Trade-offs and co-benefits of climate policy measures should be duly considered and better integrated in the EU's policymaking. The European Commission's communication on 'Better assessing the distributional impact of Member States' policies' (2022), provides welcome guidance for the Member States, and should go hand in hand with integrated socioeconomic assessments, including those conducted by the European Commission for all relevant draft EU policies and measures.

Climate policies driving societal and behavioural changes can be supported by better narratives that are tailored to local contexts and built on evidence regarding the expected costs and benefits.

Needs. Many demand-side mitigation measures build on people's willingness to adopt innovative or otherwise disruptive solutions, usually triggered by understanding of the related costs and benefits at

([84]) Climate policy co-benefits are the multiple benefits that are additional to avoided climate change costs.

the household, community, or wider society level. EU climate policies need to leverage behavioural and societal changes in consumption patterns.

Gaps. The narratives surrounding climate policy instruments tend to be focused on GHG emission reduction and cost-effectiveness, without due attention paid to their co-benefits or to local needs and values **(ambition gap)**.

Recommendation W2. EU climate policies across sectors should be better supported by narratives that respond to local needs and values, informed by data on both costs and benefits of climate policy measures.

Regressive impacts of climate policies can be attenuated by well-designed and well-resourced social policy measures.

Needs. Many climate policy instruments carry a risk of disadvantaging lower-income households and vulnerable groups, for instance through green gentrification, restricting access to energy services, higher prices of goods and loss of jobs. Since the perceived fairness of EU climate policies will determine whether they are implemented successfully, EU policies need to address regressive social impacts of climate policy measures, taking into account various dimensions of social inequalities including location (e.g. rural, urban, remote), income, gender, ethnicity, race, age and (dis)ability.

Gaps. EU climate and social policies are not sufficiently complementary so far. Few EU climate policies are informed by *ex ante* assessments of their possible socioeconomic impacts **(policy gap)**. This may affect the design and funding of social compensation instruments; for example, it is uncertain if the Social Climate Fund will be sufficient to offset the expected regressive impacts of the EU ETS 2. Adequate targeting of compensation measures is attracting increasing attention within the EU, linked to the risk of perverse incentives in fossil fuel consumption; for example, the recent energy subsidies deployed across the EU in response to high energy prices to protect consumers accounted for EUR 195 billion in 2021–2022, with the lion's share categorised as fossil fuel subsidies (for the need to phase out fossil fuel subsidies, see Section 12.3). The risks of such policy responses were flagged by the Advisory Board in its previous contribution (ESABCC, 2023a).

Recommendation W3. Synergies between EU social policies and climate policies should be strengthened, and the measures compensating for regressive impacts of climate policy instruments, such as the Social Climate Fund and Just Transition Fund, should be adequately targeted and resourced. At the national level, the European Commission's recommendation of October 2023 should be followed by all Member States, as it provides a welcome basis for defining and tackling energy poverty, calling on Member States to ensure coherence across policies, in particular between energy and social policies.

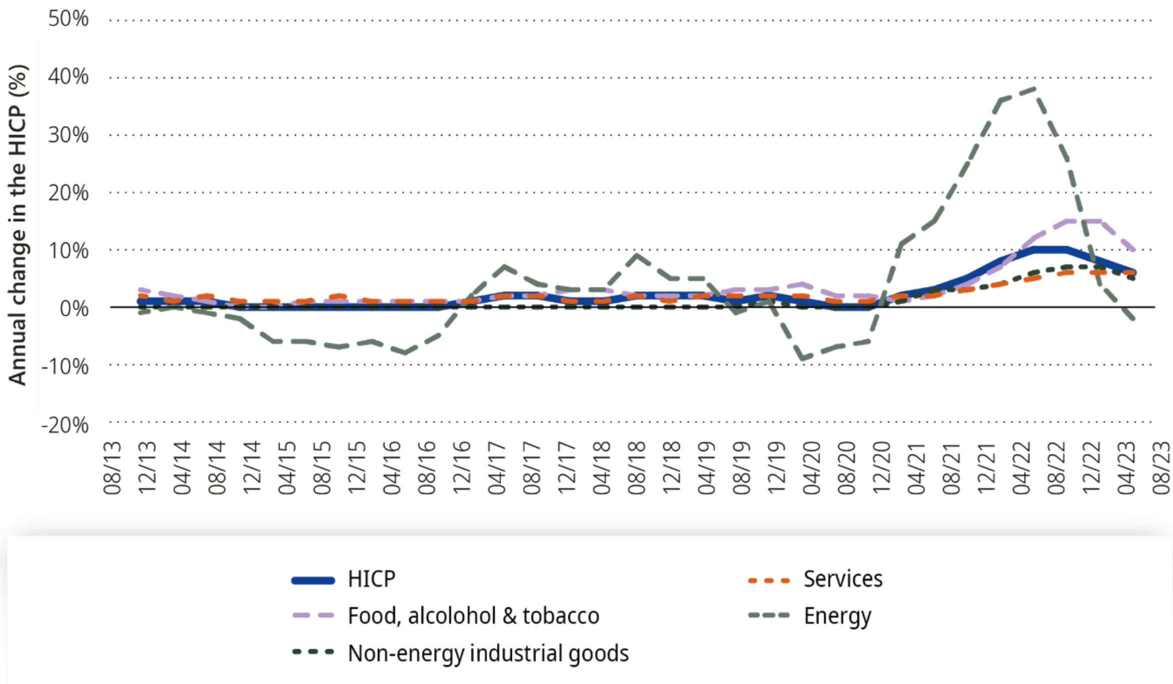
11.1 Fair and just transition in a challenging context

The EU is moving towards net zero while dealing with the cost-of-living crisis, income disparities and constrained fiscal space.

Since the European Green Deal communication in 2019 (EC, 2019c), the socioeconomic and geopolitical context in which the EU is pursuing its climate objectives has become increasingly challenging. The COVID-19 pandemic in 2020–2022 and subsequent recovery have resulted in global supply shortages and inflation (Lebastard et al., 2023). These worsened in the wake of Russia's war of aggression against Ukraine, which resulted in historically high energy prices in the EU and increased food prices globally.

High levels of inflation (see Figure 75) led to a cost-of-living crisis in the EU and undermined the international competitiveness of EU businesses, notably in energy-intensive sectors (ESABCC, 2023a). A recent Eurofound survey sheds light on the resulting hurdles for the European workforce, such as struggles to make ends meet and poor job security, as well as declining trust in public institutions (Eurofund, 2023).

Figure 75 Euro area inflation and its main components, October 2013 to October 2023 (%)



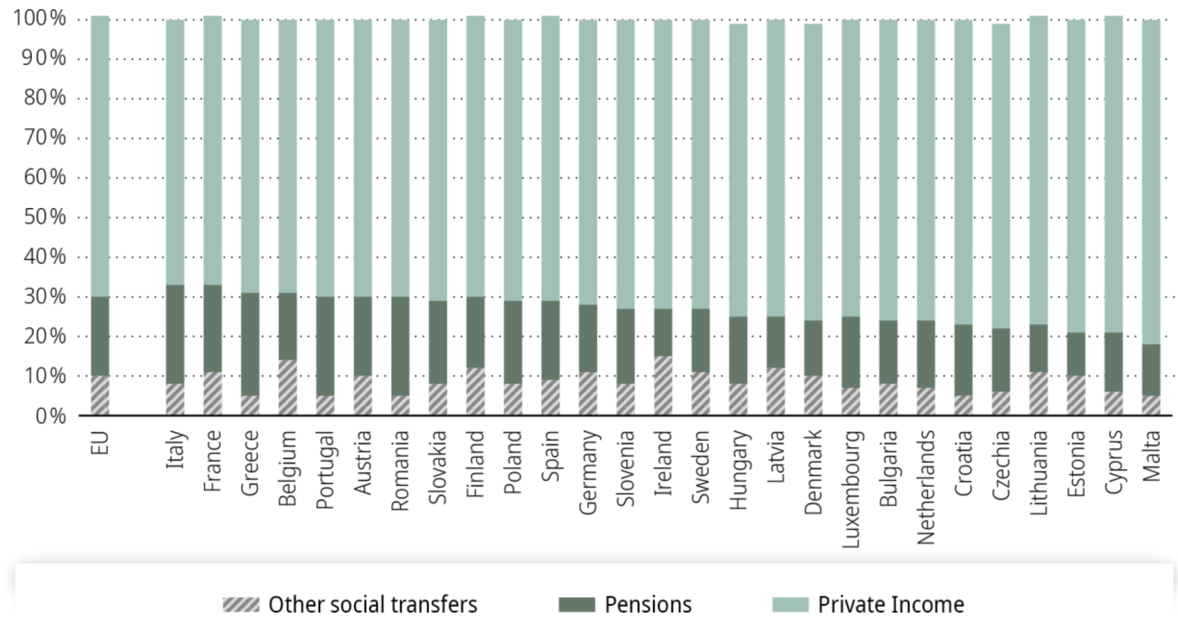
Source: Eurostat (2023n)

As a response to the increasing inflation, the ECB has increased interest rates to a record high level since the euro was established in 1999. The ECB's benchmark deposit rate went up to 4 % in September 2023, from 0.5 % in September 2019 (ECB, 2023b). Central banks' interest rates have increased investment financing costs, that is, cost of capital. Increases in the cost of capital are exacerbated by financial risks linked to, for example, geopolitical and policy uncertainties (IEA, 2023b). High financing costs can discourage investment spending, while the opposite is needed on the EU's pathway to climate neutrality (see Chapter 12 'Finance and investments').

Furthermore, the economic slowdown and various support measures in the context of COVID-19 and the energy crisis led to a surge of government debt across the EU in 2020, and, although the EU's government debt to GDP ratio is decreasing, the available fiscal space of the EU Member States is more constrained today than it was in 2019 (Eurostat, 2023k). High interest rates set by the ECB increase costs in public debt management (Claeys and et al., 2023), further constraining the fiscal space of EU Member States. This in turn affects social transfers that reduce the high disparities in income in the EU Member States ([85]). The contribution of social transfers to the total median annual disposable income per inhabitant across the EU in 2022 is presented in Figure 76.

([85]) In 2022, the Gini coefficient for the EU was 29.6. The Gini coefficient is based on the comparison of cumulative proportions of the population against cumulative proportions of income they receive, and it ranges between 0 in the case of perfect equality and 100 in the case of perfect inequality .

Figure 76 Mean equivalised disposable income and share of social transfers



Notes: Categories estimated based on mean income including/excluding pensions and social transfers

Source: Adapted from Eurostat (2023p) (codes ilc_di03, ilc_di13, ilc_di14)

The pressure on social transfers to ensure redistributive equality is likely to grow together with the introduction and strengthening of some climate policy instruments, notably carbon pricing. It will be exacerbated by an ageing EU population (EC, 2021a) and competitiveness pressures.

The above considerations indicate that the EU's path towards climate neutrality is particularly exposed to the socioeconomic impacts of the climate policies.

11.2 Transition to high-well-being societies

To allow a transition to high-well-being societies in a net zero EU, EU climate policy cycles need to be informed by the distributional and wider socioeconomic impacts of their various measures in specific contexts. Co-benefits of climate policy measures need due consideration and better integration in the EU's policymaking.

According to the IPCC, 'ambitious mitigation pathways imply large and sometimes disruptive changes in economic structure, with significant distributional consequences, within and between countries, including shifting of income and employment during the transition from high to low emissions activities' . At the EU level, the better regulation toolbox (EC, 2021a) provides the European Commission with instructions regarding socioeconomic, including distributional, impact assessment of the proposed policies and measures. Moreover, in September 2022 the European Commission issued guidance to Member States on 'Better assessing the distributional impact of Member States' policies' (EC, 2022l).

However, recent EU analyses demonstrate that there is no systematic measurement of distributional and wider socioeconomic impacts of EU climate policies, and that there is a need to improve policymakers' understanding of such impacts (EEA and Eurofund, 2021; EPRS, 2023). Limited recognition and narrow understanding of the negative socioeconomic impacts that could arise from implementing climate policy measures are particularly acute in relation to the various dimensions of inequality (EPRS, 2023).

In addition, co-benefits of climate policy measures are often not sufficiently considered (Buchholz et al., 2020; Karlsson et al., 2020; Weitzel et al., 2023). This may be because of the difficulties in quantifying, illustrating or monetising such benefits. Without due consideration of the co-benefits, the EU may forgo some of the opportunities linked to the positive framing and science-based support to policymaking offering a 'comprehensive picture of what is at stake' (Karlsson et al., 2020). A tendency to focus policy assessments on direct market cost values may lead to neglecting more systemic solutions for which market prices are difficult to evaluate, but that advance societies towards a new idea of prosperity and the achievement of the sustainable development goals (Buchholz et al., 2020; Creutzig et al., 2022).

Better data and understanding of distributional and wider socioeconomic impacts of climate policy design and implementation, based on experience and forward-looking assessment tools, can help advance the EU's fair and just transition. Information generated through systematic measurement of socioeconomic impacts can inform policy design and help to improve it. In this way, it will allow for adaptive feedback loops across policy instruments linking ex ante assessments and ex post evaluations (see also Section 14.3). Thanks to that, EU policies will be more fit to reduce social inequalities in a net zero economy, making the most of multiple benefits of climate action, such as health and well-being (see for example EEA and Eurofund, 2021).

11.3 Better narratives for societal and behavioural changes

Climate policies driving societal and behavioural changes can be supported by narratives that are tailored to local contexts and built on evidence regarding the expected costs and benefits.

Apart from the equity considerations, the whole-of-society approach links strongly to demand-side mitigation (IPCC, 2022b, 2022f) and its untapped potential highlighted in terms of GHG emission reduction in the sectoral analyses of this report. Demand-side mitigation options are considered to increase well-being (Creutzig et al., 2022), and can be activated by, among others, non-technological measures in climate action including professional advice and awareness raising, community approaches and demonstrative interventions at a local scale (IPCC, 2022f; Niamir et al., 2020). Many of them build on people's willingness to adopt innovative or otherwise disruptive solutions, usually triggered by their understanding of the related benefits at the household, community or wider society level (see for example Maestre-Andrés et al., 2019; Van Der Linden et al., 2021). In this respect, non-technological measures such as considering societal readiness levels in the preparation of net zero transition plans and measures (Bernstein et al., 2022; Büscher et al., 2023) can be supported by technology, such as smart devices.

In the context of energy and buildings, behavioural interventions such as social comparison, goal setting, and labelling have the potential to significantly reduce the energy consumption of private households (Andor and Fels, 2018). Half of the 12 % drop in fossil gas consumption in EU buildings between 2019 and 2022 is attributed to behaviour changes. Voluntary energy consumption reduction can be further leveraged through EU policies, for example by encouraging better use of existing buildings (Bertoldi, 2022; Gaspard et al., 2023). Moreover, considering behavioural factors represents a promising way to mitigate excessive rebound effects after renovation (EEA, 2023a).

In agriculture, informing and educating consumers helps them to reduce food waste and choose sustainable and healthy diets. While some cultural and social values might hinder the adoption of more sustainable diets, policies can appeal to supportive values; for example, they can invoke health by highlighting the multiple benefits of sustainable diets.

So far, however, as described in sectoral chapters 4-9, EU climate policies have not sufficiently leveraged behavioural and societal changes in consumption patterns. This can be attributed to, among other influences, narratives surrounding climate policy instruments, which tend to be focused on GHG emission reduction and cost-effectiveness, without paying due attention to their multiple benefits or to local values and core beliefs (Rietig, 2019). For example, building retrofits triggered by the EPBD have not been sufficiently embedded in appealing narratives so far, often for lack of reliable data regarding the multiple benefits of deep energy retrofits of the building stock, such as job creation, energy poverty alleviation, public health, energy security and environmental sustainability (EC, 2021j).

Increased policy integration of multiple benefits at the EU level has been announced in the renovation wave strategy and the ensuing initiatives such as the New European Bauhaus (EC, 2022f). The New European Bauhaus aims at facilitating and steering the transformation of our societies alongside the values of sustainability, aesthetics and inclusion. It devises a delivery mechanism to spur such new lifestyles and future-proof the built environment (EC, 2023ay). The EPBD recast (EC, 2021ac) refers to wider benefits of energy efficiency and reinforces their contribution of those benefits to society through several provisions, for example as part of the proposed building renovation passport. The proposed revision fosters digitalisation of buildings through, for example, a smart readiness indicator, which can support behavioural changes, for instance by improving building users' access to data.

In energy supply, in locations where RES and energy demand reduction are perceived predominantly as remedies for air pollution, low-quality employment or energy dependence on imported fuels, prospects linked to these multiple benefits, rather than climate action, engage citizens in transformative changes (IPCC, 2022g; Mata Pérez et al., 2019). Following Russia's invasion of Ukraine in February 2022, European Commission communications emphasised the benefit of energy security linked to measures increasing the roll-out of renewable energy and encouraging energy savings (EC, 2022a). That made the EU policies in these areas relatable and understood by the wider public who were enduring the energy crisis and geopolitical instability.

In this context, EU climate policies across sectors could benefit from better narratives informed by data and tailored to local needs.

11.4 Attenuated regressive impacts

Regressive impacts of climate policies can be attenuated by well-designed and well-resourced social policy measures.

The perceived fairness of EU climate policies will determine whether they are implemented successfully (IMF, 2023; ECA, 2022; EPRS, 2023b). The climate transition exposes fairness issues. Many climate policy instruments, whether regulatory (e.g. standards) or economic (e.g. carbon taxes), carry a risk of disadvantaging lower-income households and vulnerable groups, for instance through green gentrification, restricting access to energy services and – as in the case of fossil fuel workers – loss of jobs (see e.g. Zakeri et al., 2022). Climate policies bring also substantial long-term benefits to societies, such as lower energy bills, higher thermal comfort and improved air quality, with positive outcomes in terms of health and well-being. They also avoid the immense economic and social costs of climate inaction (see for example IPCC, 2022h). Lower-income households and vulnerable groups tend to be exposed more to these costs and benefits (EEA and Eurofund, 2021; IPCC, 2022l).

The around 10 % of EU citizens who cannot afford to heat or cool their homes properly often occupy low-performing buildings that lead to high energy costs (Eurostat, 2023o; Thomson et al., 2019). Moreover, the inability to maintain thermal comfort at home is also likely to coincide with health issues for residents. The problem of energy poverty in conjunction with unhealthy living conditions is common across the EU (IEA, 2020) and is reflected in the definitions of 'energy poverty' and 'vulnerable households' ([86]) in the Social Climate Fund regulation (EU, 2023m). The proposal for a revised ETD (EC, 2021y) includes a simplified definition linking vulnerability only to disposable income ([87]). Vulnerability in the context of high energy bills goes beyond the disposable income consideration, however. Social inequalities in the context of climate change mitigation are also linked to, among other factors, spatial location (e.g. rural/urban) gender, ethnicity, age and disability (IPCC, 2022f).

The sizeable socioeconomic impacts of climate policy measures call for a strong link between climate policies and social policies. This link has been found insufficient in recent analyses conducted by the EEA, Eurofound and the European Parliament's think tank (EEA and Eurofund, 2021; EPRS, 2023)

Stronger links between social and climate policies would be in line with the existing EU climate policy aspiration to leave no-one behind, repeatedly affirmed by EU leaders, in the context of just transition policy (EU, 2021b). EU efforts in this context include energy products and electricity used by vulnerable households being exempted from taxes under the proposed ETD, the European Commission's recommendation on energy poverty (EC, 2023i), and the setting-up of the Energy Poverty Advisory Hub (EC, 2023y) and the European Commission on Energy Poverty and Vulnerable Consumers Coordination Group (EC, 2022a). Together with the Social Climate Fund (EU, 2023m), these initiatives have the potential to mitigate some socioeconomic risks linked to energy prices and the cost of compliance with high energy performance standards and carbon pricing under the EU ETS and the EU ETS 2.

The Social Climate Fund (see also Box 6) is an example of using revenue from carbon emissions trading to address the equity and distributional impacts of carbon-pricing instruments. As such, it will be of utmost importance that it is targeted and resourced appropriately, so that it can fulfil its objectives. While it is positive that the Social Climate Fund budget can be increased through transfers from other funds, there are concerns that its reliance on EU ETS revenues may lead to insufficient finance for the fund (EESC, 2021). Moreover, experience from the Just Transition Fund suggests that the implementation of the public consultation requirement when developing national/local plans guiding the fund's disbursement can be challenging and is not to be taken for granted (EC, 2023bg).

In addition to the above initiatives, including the Social Climate Fund and the Just Transition Fund, the EU has put in place several social policy measures that can help attenuate regressive impacts of EU climate policies. Their adequate resourcing and targeting can be supported by closer interaction between social and climate policies, including better recognition of climate policies' socioeconomic impacts (see Section 11.3 above).

Box 6 Social Climate Fund

Adopted in May 2023, the EU regulation establishing a Social Climate Fund (EU, 2023m) aims to contribute to a socially fair transition towards climate neutrality by addressing the social impacts of including GHG emissions from buildings and road transport within the scope of the EU ETS. Its specific objective is to 'support vulnerable households, vulnerable micro-enterprises and vulnerable transport

([86]) Energy poverty for the purposes of the Social Climate Fund is defined as 'household's lack of access to essential energy services that underpin a decent standard of living and health, including adequate warmth, cooling, lighting, and energy to power appliances, in the relevant national context, existing social policy and other relevant policies'; 'vulnerable households' means 'households in energy poverty or households, including low income and lower middle-income ones, that are significantly affected by the price impacts of the inclusion of greenhouse gas emissions from buildings within the scope of the EU ETS Directive 2003/87/EC and lack the means to renovate the building they occupy' (Article 1 of the Social Climate Fund regulation).

([87]) Vulnerable households under the proposed ETD are households below the 'risk of poverty' threshold, defined as 60 % of the national median equivalised disposable income.

users, through temporary direct income support and through measures and investments intended to increase the energy efficiency of buildings, decarbonisation of heating and cooling of buildings, including through the integration in buildings of renewable energy generation and storage, and to grant improved access to zero- and low-emission mobility and transport' (Article 3). The Social Climate Fund resources will come from EU ETS 2 revenues covering buildings and transport and should reach up to EUR 65 billion between January 2026 and December 2032. This amount can be topped up with resources from EU funds under shared management, and it can also partly be transferred to such funds, at the request of a Member State. The Social Climate Fund will be disbursed based on the social climate plans prepared by the Member States through a participatory process in which local and regional authorities, economic and social partners, civil society organisations, youth organisations and other stakeholders are involved (Article 5). The first plans should be submitted to the European Commission in mid-2025 and the Social Climate Fund will put into operation in 2026.

11.5 Summary table

Table 17 Policy consistency summary – whole-of-society approach

Policy gaps	– EU climate and social policies are not sufficiently complementary so far. Few EU climate policies recognise their negative socioeconomic impacts, and even fewer identify ways to address them.
Ambition gaps	– The narratives surrounding climate policy instruments tend to be focused on GHG emission reduction and cost-effectiveness, without due attention paid to their co-benefits or to local needs and values.
Implementation gaps	– Despite the Better Regulation toolbox being equipped with instructions regarding the assessment of distributional and wider socioeconomic impacts, EU climate policies have not always been accompanied by systematic measurement of such impacts.

12 Finance and investments

Key messages

As an estimate, investments in clean energy and transport need to at least quadruple to achieve the EU's climate goals. This can be achieved by increasing the absolute level of investments in these sectors towards an annual average of EUR 1 241 billion (an increase of about EUR 500 billion) and reorienting all existing investments in these sectors towards mitigation technologies.

Needs. The European Commission's modelled scenarios estimate that investments related to mitigation in energy and transport sectors need to reach an average annual level of about EUR 1 241 billion over 2021–2030, to achieve the EU's climate objectives. According to recent research (IPCC, EIB, Bloomberg New Energy Finance (BNEF)), only a small share of current investments in energy and transport is climate related (about EUR 200–300 billion per year). Given this evidence, the Advisory Board estimates that investments in mitigation technologies in energy and transport need to increase by at least a factor of four (as illustrated in Figure 77 below), through a combination of increasing total investments in energy and transport (by at least EUR 500 billion annually) and redirecting existing finance flows towards mitigation technologies. Given the size and scope of the investment gap, a concerted effort by both public and private sectors is required.

Gaps. The above estimates are based on a variety of sources with different scopes and levels of granularity. Currently, there is insufficient information available on the investments required to fund the transition towards climate neutrality. There is also a lack of available indicators to track progress at the sectoral level. This knowledge gap is mainly due to the lack of a harmonised methodology for identifying and estimating climate-related investment needs **(policy gap)**.

Recommendation F1. The EU should strive for a more granular and accurate overview of required and actual investments in climate mitigation to monitor and assess progress. Specific recommendations on how to effectively increase both public and private climate investments are included in the key messages below.

Fossil fuel subsidies need to be phased out completely and urgently. The share of subsidies that is aimed at supporting vulnerable households should be well targeted, without undermining the incentives for energy efficiency and savings or the shift towards RES.

Needs. Fossil fuel subsidies hinder the reorientation of private financial flows towards climate mitigation and increase the risk of locking in GHG emissions. They also reduce the public budget available to support climate investments. Therefore, they need to be phased out rapidly, as also called for in the COP26 Glasgow Climate Pact, the European Green Deal and the 8th EAP.

Gaps. Despite repeated political commitments, EU State aid guidelines continue to allow fossil fuel subsidies **(policy inconsistency)**. Fossil fuel subsidies remained relatively stable in the last decade (around EUR 50 billion per year), and even increased sharply in 2022 (to EUR 120 billion) in the context of the energy crisis. The 8th EAP requires the European Commission and Member States to set a deadline for the phasing out of fossil fuel subsidies consistent with the 1.5 °C objectives, but so far only a few Member States have enacted laws or set out clear plans that specify how and by when this will be achieved **(implementation gap)**.

Recommendation F2. Member States should clearly specify in their updated NECPs how and by when they will phase out fossil fuel subsidies, including a clear trajectory towards a full phase-out by a specific year in the immediate future. The European Commission should assess during their review of these NECPs whether this requirement is met.

Support measures for vulnerable households that constitute a fossil fuel subsidy should be transformed into well-targeted interventions that do not undermine the incentive for energy savings or the shift towards RES (see also Section 11.4).

The EU budget aims to make a significant contribution towards reaching the required investments needed to reach climate neutrality. However, this is hindered by flaws in the methodology for tracking climate-related spending and by the lack of information about what happens after the RRF ends, which increases uncertainty.

Needs. The EU budget needs to contribute towards the EU's climate objectives, by supporting investments in climate action and avoiding investments in GHG-intensive activities (in other words, by climate mainstreaming). Furthermore, the EU has committed to spending at least 30 % of its long-term budget under the MFF and at least 37 % of the RRF on climate-related objectives. Combined, this corresponds to an estimated average of EUR 83 billion a year of EU public budget to be spent on climate action in 2021–2027.

Gaps. There are substantial flaws in the methodology applied to track the spending of the EU budget on climate action, which result in overestimating the EU budget's contribution towards the EU's climate objectives **(ambition gap)**. These include the reliance on high-level coefficients in combination with overly optimistic assumptions about the climate impact of spendings (with the CAP a primary example), the lack of an *ex post* assessment of whether budgets planned for or committed to climate action were actually spent on that, and a lack of reporting about spending on activities that increase GHG emissions; such reporting would be in line with the 'do no significant harm' principle. The methodology applied under the RRF is more robust, as it is partially aligned with the EU Taxonomy to prevent harmful investments, but it still relies on coefficients in tracking climate contribution **(ambition gap)**. Furthermore, the RRF itself is expected to cease after 2026 and it is not clear whether it will be succeeded by a similar instrument, reflecting a lack of long-termism **(policy gap)**.

Recommendation F3. The reporting methodology to track climate spending under the EU budget should be improved to more accurately track expenditures that effectively contribute towards the EU's climate objectives. The reporting methodology should also track spending on activities that breach the 'do no significant harm' principle; for example, it could do this by aligning with the principles of the EU Taxonomy framework.

Recommendation F4. The EU should consider continuing the approach of the current RRF beyond 2026. The framework is financed by common debt and supports the EU budget, to boost EU public investment, strengthen the EU's sovereignty and accelerate the climate transition.

State aid rules have been relaxed to allow increased spending by Member States in response to the pandemic and the energy crisis. However, their fiscal space is constrained by increased demands on public expenditures, decreasing revenues and the fiscal rules set out in the Stability and Growth Pact. Member States' divergent fiscal headroom increases the risks of fragmentation in the single market. The EU's response to this risk (the Strategic Technologies for Europe Platform) has so far been inadequate.

Needs. In addition to the EU budget, Member States also need to increase their climate spending to close the investment gap. State aid rules need to strengthen the single market and support the further development of mitigation technologies, addressing the investment gap in the energy and transport sectors.

Gaps. The potential for increasing Member State borrowing to support investment needs related to the transition to climate neutrality is limited by the requirements of the Stability and Growth Pact. Despite calls from policymakers and experts to provide specific rules for climate-related public investments, the European Commission's recent proposal to reform the Stability and Growth Pact does not differentiate investments related to the climate transition **(ambition gap)**.

In the meantime, the relaxation of State aid rules increases the risk of fragmenting the EU single market. Proposals from European Commission to address this (the proposed Strategic Technologies for Europe Platform, as a first step towards an EU Sovereignty Fund) include too limited a budget (EUR 10 billion compared with more than EUR 300 billion per year in State aid in 2021) to be sufficiently effective **(ambition gap)**.

Recommendation F5. A rapid phase-out of fossil fuel subsidies (see recommendation F2) would increase Member States' revenues or reduce their expenditures, which could then be reoriented to finance climate investments. A structural common fiscal capacity based on a common debt (see recommendation F4) would help to mitigate the risk of fragmenting the single market.

The private sector will need to deliver most of the required climate-related investments. This needs to be driven by ambitious EU policies, to build a pipeline of bankable projects across the EU.

Needs. Given the magnitude of the investment gap and the difficulty of increasing (both EU and national) public spending on climate, the private sector will need to make a substantial contribution to achieve the required level of climate-related investments. This needs to be driven by sufficiently ambitious EU policies to improve the bankability of climate-related investments, and by tailored financing solutions. There is also a need for an effective policy mix that addresses standards and regulations, support infrastructure, faster issuing of permits, technical assistance and capacity building. Stable investment conditions and better use of public funds will play a key role in this respect (see also Chapters 4–10). Various policy options are discussed in other chapters of this report, and in particular in Chapters 0–8 on the different sectors and Chapter 10 'Pricing emissions and rewarding removals'.

Claims on sustainable investments need to be based on harmonised and science-backed frameworks.

Needs. Sustainable investments (taking into account environmental, social and governance (ESG) criteria) and green bonds have become increasingly popular in recent years. The increasing appetite of the market for these financial products can contribute to the financing of required climate-related investments, provided that they are based on credible and transparent sustainability criteria to avoid greenwashing.

Gaps. In the past, the environmental integrity and credibility of sustainable investments and green bonds could not be ensured, for lack of a harmonised, robust classification system. The EU aims to address this with the development of the EU Taxonomy framework in 2020, and the EU Green Bond Standard in 2023. While these are overall steps in the right direction, the EU Taxonomy labels certain fossil gas activities as sustainable. Despite the specific criteria, that increases the risk of fossil fuel lock-ins **(policy inconsistency)**. Furthermore, whereas many private entities in the EU will have to report on the alignment of their investments and activities with the EU Taxonomy, there is no requirement to meet a minimum degree of alignment. Such alignment's contribution to shifting investments towards sustainable activities will thus primarily rely on investors' preferences. Similarly, the green bond standard is voluntary, and its effectiveness will therefore depend on whether bond issuers will choose to apply it in the future. So far, green bonds issued under NextGenerationEU are not necessarily aligned with the EU Taxonomy and the EU Green Bond Standard, which reduces transparency on the use of proceeds and can undermine credibility in the credit market, resulting in higher borrowing costs **(ambition gap)**.

Recommendation F6. The regular updates of the TSC of the EU Taxonomy should lead towards full alignment of the EU Taxonomy with the climate neutrality objective and treat investments in natural gas as non-sustainable, to avoid the risk of creating lock-ins.

Recommendation F7. As a minimum, the European Commission should start to apply the EU Green Bond Standard to green bonds issued to finance NextGenerationEU, to strengthen reporting transparency on the use of proceeds and foster market confidence, which can result in lower borrowing costs.

12.1 Context, scope and overview

The Paris Agreement, IPCC AR6 and the European Green Deal emphasise the role of finance as a critical enabling factor for the achievement of ambitious climate objectives (UNFCCC, 2015; EC, 2019c; IPCC, 2022n). Achieving the objectives of the European Green Deal would require a substantial increase in investments, the magnitude of which would require mobilising both the public and the private sector. The current economic context, characterised by slower economic growth, constrained public budgets, inflation and elevated interest rates, affects the EU's capacity to finance the climate transition (see also Section 1.1).

The aim of this chapter is to assess progress in financing the climate transition in the EU, and to what extent EU policies are driving the necessary mobilisation of public and private finance. It starts with an overview of current and required investments in the climate transition, based on available data. It then provides an assessment of the potential and required policies to mobilise the EU budget, national public budgets and private capital to reach the required investments. It then proceeds to assess progress and policies on the phase-out of fossil fuel subsidies, and the potential roles of the EU Taxonomy and green bond market to close the climate investment gap. A thorough assessment of the EU's progress towards achieving its commitments on climate finance is beyond the scope of this report, but it is briefly discussed in Box 7 ‘international climate finance’.

Box 7 international climate finance

The EU remains committed to supporting the developed economies’ goal of jointly mobilising USD 100 billion per year up to 2025 to support developing economies. Between 2014 and 2021, EU support to developing countries increased by 50 %, reaching EUR 23 billion a year, which includes contributions from the EU budget, Member States and the EIB. In 2021, over 54 % of EU funding to developing economies was related to climate adaption or a combination of climate mitigation and adaptation, and almost half of the funding was in the form of grants (EEA, 2023j). Currently there is limited public information available on the uses of funding reported under EU contributions to international climate finance. This hinders the assessment of policy effectiveness. More detailed reporting on a project-by-project basis would improve transparency and could attract more interest from private funding initiatives.

In its advice on an EU 2040 objective, the Advisory Board has identified the need for the EU to contribute to climate mitigation outside the EU, to close the gap between what it can feasibly do to reduce domestic net emissions and what it should do in line with its fair share towards the global 1.5 °C objective (ESABCC, 2023b). This could be achieved by, among other methods, providing finance for climate mitigation projects outside the EU.

12.2 Progress on climate-related investments

Assessing progress in climate-related investments faces methodological challenges.

This section aims to assess progress towards financing the climate transition in the EU by comparing actual with required climate-related investments (also referred to as investment needs). Investment needs are widely used as an indicator for measuring the required system change (when compared with current flows and asset bases). They usually focus on investments required to realise new infrastructure. One of the benefits of this indicator is that it is relatively easy to compare with private sector investment flows. However, it also has limitations, as it does not capture the need to build institutional capacity to strengthen knowledge and skills; nor does it measure needs for investment to address economic losses due to physical climate risks or investment needs related to adaptation (IPCC, 2022m).

There are two main challenges in assessing progress in climate-related investments. Firstly, there is no clear and verifiable definition of what constitutes climate finance flows or climate-related investments. This presents a difficulty in estimating progress and identifying investment gaps, as using different definitions can lead to different conclusions (Yeo, 2019). Boundaries between private and public finance can also be unclear, as private climate-related investments often benefit from public support in the form of co-financing, guarantees or fiscal measures (Weikmans and Roberts, 2019). In addition, the accuracy of modelled investment needs is also influenced by multiple, inherent sources of uncertainty. One source of uncertainty is change in technology costs, such as the levelised cost of energy of different renewable energy technologies. The relatively high share of investments since the early 2000s in the renewables sector has contributed to the rapidly declining technology costs of solar PV and wind in more recent years (“Energy Transition Investment Trends 2023,” ; IEA and IRENA, 2017). Cost reductions could free up investment and financing capacities for potential use in other climate-related activities. Another source of uncertainty about financing needs is the interplays between:

— the economic growth rate,
— the link between growth and energy demand, including rebound effects of energy efficiency gains,
— changes in variables such as fossil fuel prices, inflation and real interest rates (IPCC, 2018).

Since 2020 the European Commission has prepared multiple estimates on different investment needs for achieving specific strategies (e.g. the hydrogen strategy and REPowerEU). Estimated investment needs varied considerably, partly because of rapid changes in the macroeconomic context (COVID-19, energy crisis, inflation) and technology costs, but also because different definitions and methodologies were applied in different periods (EEA, 2023l). The lack of a unified methodology to estimate investment needs undermines comparability and makes it challenging to accurately track progress.

The progress assessment in this chapter is based on the best available data on historical and required climate-related investments within the EU, covering both public and private sources of funding. As the different sources use different definitions and scopes, and given the inherent uncertainties described above, the results should be interpreted as an indicative estimate to illustrate the order of magnitude.

Climate-related investments in the EU need to at least quadruple, both by reorienting existing investments and by increasing total energy investments.

IPCC AR6 estimated that total investments supporting climate mitigation in Europe ([88]) were on average about EUR 220 billion per year in 2017–2020 ([89]). This would need to increase to EUR 960 billion per year (which represents more than a quadrupling) until 2030 to be consistent with pathways that limit global warming to well below 2 °C (IPCC, 2022n) (see Figure TS.25).

The EIB's estimates of climate-related investments in the EU are in the same order of magnitude, increasing from about EUR 240 billion in 2019–2020 to about EUR 310 billion in 2021. It concludes that current spending on climate mitigation needs to increase significantly to achieve climate neutrality by 2050 (EIB, 2023b). BNEF also reports an increase in climate-related investments in the EU, from on average EUR 70 billion per year in 2011–2019 to almost EUR 200 billion in 2022 (BNEF, 2023). Both the EIB and BNEF have identified an increase in climate-related investments in recent years, which is mainly driven by the increased uptake of electric vehicles, the deployment of solar and wind energy, and energy efficiency improvements (FS-UNEP and BNEF, 2018).

Finally, the European Commission's scenarios that underpin the EU climate objectives also include data on historical and required investments. The MIX scenarios of the impact assessments accompanying the climate target plan and the Fit for 55 package estimate that overall investments in energy and transport need to increase by 62 %, from an average of EUR 764 billion per year in 2011–2022 to EUR 1 241 billion per year on average in 2021–2030. Under the REPowerEU plan, investments would need to increase even further to about EUR 1 276 billion per year up to 2030. The scenario data does not distinguish between climate- and non-climate-related energy investments (EC, 2023l, 2020a, 2022p). However, given the need to fully decarbonise the energy system, all future investments should be aligned with European climate targets. This is also consistent with the IPCC data described above, which estimated that climate-related investments in Europe would need to increase to almost EUR 1 trillion per year to be compatible with 'well below 2 °C' pathways (with even higher investment needs likely for compatibility with 1.5 °C pathways).

All the sources above cover different scopes in terms of geography, years and sectors/technologies, as summarised in Table 18.

([88]) This include some countries beyond the EU-27: Norway, Switzerland, Turkey and the United Kingdom.
([89]) All values are converted into 2022 euro.

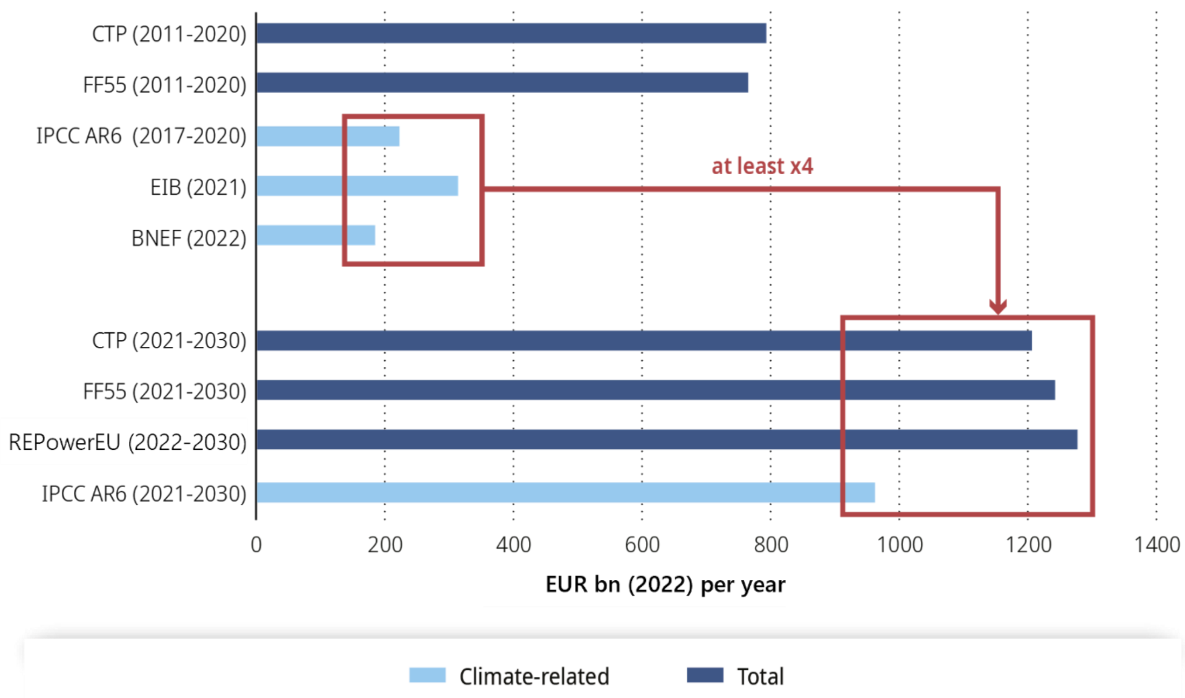
Table 18 Overview of the scopes of the different data sources used for assessing investment needs

Data source	Scope
IPCC AR6	– 2017–2020 average for Europe (including non-EU countries) – Energy supply: low-emission electricity generation and electricity grids – End use sectors: energy efficiency in buildings and industry, transport
EIB	– 2019–2021 data for EU-27 – Energy supply: renewable energy – End use sectors: energy efficiency, sustainable transport – Others: climate-related R&D, forestry (very low share in total investments)
BNEF	– 2022 data for EU-27 – Energy supply: renewables, nuclear, hydrogen (electrolysis, storage and pipelines), energy storage, CCS – End use sectors: ZEVs and recharging/refuelling infrastructure, heat pumps – Others: sustainable materials
European Commission climate target plan and Fit for 55	– Average 2011–2020 data for EU-27 – Energy supply: all electricity generation (RESs, fossil, nuclear), electricity grid, boilers, production and transport of new fuels – End use sectors: energy-related investments in residential, tertiary and industry sectors, all vehicles and recharging/refuelling infrastructure in transport

Based on the available data, the Advisory Board estimates that climate-related investments need to at least quadruple, from between about EUR 200 billion and EUR 300 billion per year in recent years to about EUR 1 000 billion per year up to 2030, as illustrated in Figure 77. This would require the redirection of existing investment flows into the energy system, as well as an overall increase in energy and transport investments (+ EUR 500 billion per year ([90])).

([90]) The EUR 500 billion a year of investments in energy and transport exclude the additional investments required for REPowerEU (EUR 35 billion a year) and the Net-Zero Industry Act (EUR 12 billion a year). Including these figures would increase the additional investments needed (for example, the ECB (2023c) has estimated the required additional invesmtents to achieve the objectives of the European Green Deal and Net-Zeron Industry Act at EUR 620 billion a year). The 2023 climate action progress report (EC, 2023ax) advises against adding these figures, given their different scopes, timeframes and estimation methods.

Figure 77 Historical versus required climate-related energy investments



Notes: CTP is based on the Climate Target Plan impact assessment, FF55 data is based on the Net-Zero Industry Act staff working document. REPowerEU data includes an additional €300 billion on top of FF55. All data is converted to 2022 euro values.

Sources: Climate Target Plan impact assessment (EC, 2020s) (Table 46), staff working document accompanying REPowerEU (EC, 2022s), Net-Zero Industry Act staff working document (EC, 2023l) (Table 9), IPCC (2022l) (Figure TS.25), EIB Investment Report 2022/2023 (2023b) (Figure 31), BNEF (2022).

Meeting the investment needs requires a combined effort of the public and private sector.

The magnitude of the total investment flows in the real economy can be approximated by the gross fixed capital formation, which includes investments in both tangible assets (notably infrastructure and equipment) and intangible assets (intellectual property) (Eurostat, 2022c). Current gross fixed capital formation is estimated at about EUR 2.8 trillion (approximately 23 % of the EU's GDP) (Eurostat, 2022c). This suggests that the EU has sufficient investment capacity to meet its climate objectives, but that it would require redirecting approximately 30–40 % of the current total investment flows towards climate mitigation projects, or less if gross fixed capital formation is increased through climate mitigation. It should be emphasised here that these investments lead to later savings of expenditure on fossil fuels and climate damage and hence should not be misread as costs of mitigation. The magnitude of the gap is beyond the sole capacity of either the public or the private sector and will require a combined effort by both.

The EU action plan on financing sustainable growth outlines the overarching strategy to meet the required investments.

The European Commission's overall approach to meet the required investments is outlined in the 2018 action plan on financing sustainable growth, which was updated in 2020 as a follow-up to the European Green Deal (EC, 2018c). It outlines 10 action points in three categories:

— actions to redirect capital flows towards a more sustainable economy (including actions such as the EU Taxonomy classification system, the development of an EU Green Bond Standard and the sustainable Europe investment plan (also referred to as the Green Deal investment plan),
— actions to mainstream sustainability into risk management,
— actions to foster transparency and long-termism (including the revision of the non-financial reporting directive, which is now referred to as the corporate sustainability reporting directive).

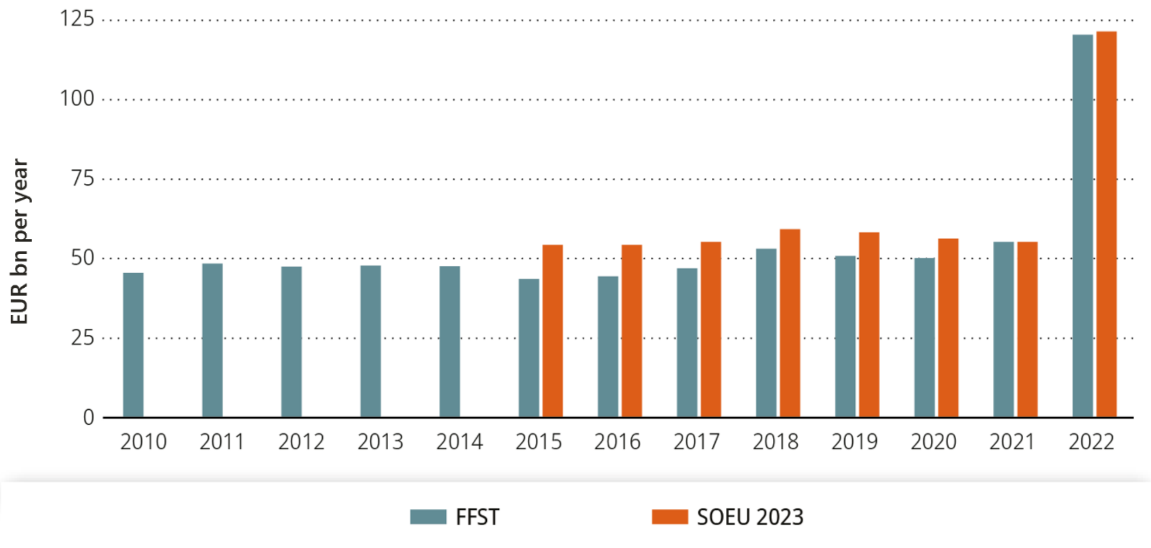
Whereas a full assessment of this action plan is beyond the scope of this report, some of its components (the EU Taxonomy framework, the green bond standard and the green deal investment plan) are assessed in more detail in subsequent sections.

12.3 Fossil fuel subsidies

Fossil fuel subsidies persist and have even increased in the context of the energy crisis.

Several sources report on fossil fuel subsidies in the EU, including the European Commission's annual state of the energy union report (EC, 2023aw), Member States' annual national energy and climate progress reports, and independent assessments by organisations such as the EEA and the OECD (OECD and IISD, 2023; EEA, 2023i). As shown in Figure 78, the EU has made little progress towards phasing out fossil fuel subsidies. Reported fossil fuel subsidies remained stable between 2010 and 2020 at around EUR 50 billion per year. In 2022, they more than doubled to ca. EUR 120 billion, as governments provided substantial amounts of support to both households and businesses to mitigate the impact of the energy crisis.

Figure 78 Changes in fossil fuel subsidies in the EU



Sources: Fossil Fuel Subsidy Tracker (OECD and IISD, 2023), EC (2023aw)

The share of fossil fuel subsidies in total energy subsidies reduced gradually from 31 % in 2015 to 26 % in 2021, as they remained stable while other types of energy subsidies increased. However, in 2022 the share of fossil fuel subsidies in total energy subsidies rebounded to 31 %, and in absolute amounts fossil fuel subsidies (EUR 123 billion in 2023) exceeded the amount of subsidies for RES (EUR 87 billion in 2022) (EC, 2023aw).

In addition to these fossil fuel subsidies, the EU and its Member States have provided other forms of energy subsidies to shield households and businesses from the impacts of the energy crisis. The IEA tracked more than EUR 325 billion in total support to reduce energy bills during 2022 in the EU (IEA, 2023d). Similarly, the European Commission reports that overall energy subsidies increased from about EUR 200 billion in 2018–2021 to between EUR 350 billion and EUR 390 billion in 2022 (including EUR 112 billion to 'all energies', which also includes fossil fuels) (EC, 2023aw). Although not all this spending is captured by the definition of 'fossil fuel subsidies' as applied by the European Commission and the OECD, the Advisory Board has assessed that in many cases it has distorted the price signal, which reduced the incentive for making energy efficiency investments, rationalising energy consumption or switching to RES (ESABCC, 2023a). Furthermore, these expenditures have not always been well targeted towards the most vulnerable consumers and have posed a substantial fiscal burden on Member States (EC, 2023n).

There is no clear phase-out plan or deadline for the majority of fossil fuel subsidies.

The eighth EAP requires the European Commission and Member States to 'set a deadline for the phasing out of fossil fuel subsidies consistent with the ambition of limiting global warming to 1.5 °C' (EC, 2022q). Member States are required to include in their biennial national energy and climate progress reports an assessment of progress towards phasing out energy subsidies, in particular for fossil fuels (EU, 2018e). According to these reports, although many Member States confirm their intention to phase out fossil fuel subsidies, only five Member States have enacted laws or clear plans that specify how and by when (EEA, 2023i). For more than half of all fossil fuel subsidies, there is either no end-date or an end-date after 2030 (EC, 2023aw).

Fossil fuel subsidies can hinder the climate transition by undermining the reorientation of private investments, reducing the available budget for public investments and locking in fossil fuels.

Fossil fuel subsidies ([91]) are a major obstacle to the transition towards climate neutrality. By lowering the cost of fossil fuel use, they hinder the required reorientation of financial flows towards non-fossil, climate-friendly alternatives. Furthermore, they also decrease the amount of public funding that is available to finance the climate transition. By supporting the use and financing of fossil fuel-related assets, they lock in future GHG emissions, which is inconsistent with emission pathways necessary to reach the Paris Agreement goals. This inconsistency exposes investors and asset owners to the risk of stranded assets (Semieniuk et al., 2022). A rapid phase-out of fossil fuel subsidies is therefore considered to be a top priority to close the climate investment gap. In line with international commitments such as the COP26 Glasgow Climate Pact, both the European Green Deal and the 8th EAP call for the phase-out of subsidies for fossil fuels.

12.4 Mobilising the EU budget

Approximately EUR 580 billion of EU funds are earmarked for climate action for 2021–2027.

The EU's long-term budget (referred to as the MFF) totals EUR 1.2 trillion for 2021–2027. It has the aim of supporting the long-term objectives of the EU, including the climate transition. For 2021–2027, the EU committed to spending 30 % of the MFF (EUR 360 billion) on climate action, compared with at least 20 % in 2014–2020 (EC, 2016b). NextGenerationEU is the EU's recovery instrument to support its economic recovery after the COVID-19 pandemic. It provides an additional budget of EUR 800 billion for 2021–2026. The vast majority of this (EUR 723 billion) will be spent through the RRF, in the form of

([91]) Fossil fuel subsidies exist in different forms, including price/income support (e.g. price caps), tax reductions (e.g. lower rates, exemptions and rebates) and direct transfers (e.g. energy vouchers and direct subsidies).

grants and loans to support investments. Member States are required to spend at least 37 % of the funds they receive via the RRF on climate-related investments and reforms (EU, 2021a). The European Commission reported that all Member States have exceeded this threshold, and that in total 40 % (or EUR 203 billion) will be spent on climate-related activities. The European Commission has assessed that the EU plans to spend EUR 578 billion of its total budget (MFF and RRF) on climate action in 2021–2027 (on average about EUR 72 billion per year) (EC, 2023ax).

The discussions on the revision of the MFF for the period after 2027 will start in the next few years. Some experts have already flagged the need to increase the overall budget and reorient spendings, in particular to support the EU's climate and energy objectives (Franco-German working group on EU institutional reform, 2023). NextGenerationEU and the RRF, however, are currently intended to cease by the end of 2026, with no follow-up instrument planned. This would lead to a substantial drop in EU public climate spending after 2026.

The effectiveness of the EU budget is undermined by flaws in the methodology to track climate spending.

The methodology for estimating climate spending in the MFF is based on coefficients (EC, 2016b) ([92]) that are applied to the planned expenditure on different intervention fields, as a proxy for their expected contributions towards climate change mitigation and climate change adaptation. The main advantage of this approach is the light administrative burden and ease of use. More specifically, the European Commission uses three coefficients (EC, 2016b):

— a 100 % coefficient is applied to programmes that are expected to have a significant climate impact;
— a 40 % coefficient is applied to planned spending that is expected to make a 'moderate' contribution to climate objectives;
— a 0 % coefficient is applied to projects with an insignificant contribution.

Overall, this methodology implies significant approximations in estimating expected contribution to climate objectives, as the Rio markers do not enable precise quantification of the monitored spending (Cremins and Kevany, 2018). A high-percentage coefficient is applied to budget items that are expected to contribute more positively to climate objectives, and a low-percentage coefficient is applied to budget items from which little benefit is expected in terms of climate.

A report by the ECA (2022c) identified several flaws in this methodology, which can be summarised as follows.

— It allowed for overly optimistic assumptions about the relevance of certain expenditures to climate action. The CAP is a prime example: it accounted for EUR 100 billion of EU climate spending in 2014–2020 (half of the EU's total climate spending in that period), even though it had little impact on actual agricultural GHG emissions (ECA, 2021). For 2021–2027, the CAP continues to account for a substantial share of total EU climate spending (EUR 146 billion, or 25 % of the total), even though it is unlikely to deliver substantial GHG emission reductions (see Chapter 8 'Agriculture').
— It does not track potentially negative climate impacts of EU budget expenditures. The ECA's recommendation to enhance reporting under the MFF by identifying spending with potential negative impacts on climate was not accepted by the European Commission (EC, 2022ac).
— Reporting on climate spending is primarily based on *ex ante* plans, without checking *ex post* if planned climate spending was realised.

([92]) These are based on the Rio markers for climate, developed by the OECD in 2018.

— It allowed for inconsistencies, with similar types of projects receiving different coefficients, illustrating the subjectivity involved and the unclear criteria. For example, rail transport projects in the trans-European network funded by the Connecting Europe Facility were assigned a 100 % coefficient in estimating climate contribution, whereas similar projects under the European Regional Development Fund or the Cohesion Fund were assigned only a 40 % coefficient.

Overall, the ECA report (ECA, 2022c) concludes that, for 2014–2020, these flaws resulted in an overestimation of climate spending by at least EUR 72 billion (33 % of the total EUR 216 billion climate spending reported by the European Commission). The majority (80 %) of this is linked to an overestimation of the climate contribution of the CAP. It furthermore concluded that, despite some limited improvements, these flaws continue to undermine accurate reporting on climate spending under the 2021–2027 MFF.

The methodology used for the EU's RRF, which is the core of NextGenerationEU, has been updated to reflect definitions from the EU's sustainable finance taxonomy including the 'do no significant harm' principle. However, the methodology used to track spending on climate objectives remains broadly unchanged and continues to rely on coefficients (Baccianti, 2023). The recent review of the RRF by the ECA (ECA, 2023c) finds that the current performance monitoring framework does not sufficiently capture performance on climate and other intended objectives.

The European Commission also does not differentiate between spending on climate change mitigation and climate change adaptation. Aggregating both climate objectives under a single reporting line means that it is not possible to reliably estimate progress towards meeting investment needs for each objective. The lack of relevant and reliable reporting on investments that support climate adaption objectives hinders the mainstreaming of climate resilience across the EU policies that are supported by intervention instruments funded through the EU budget.

The EU budget on its own is insufficient to close the investment gap, even when taking into account the crowding-in effect.

The EUR 578 billion of the EU budget that is earmarked for climate action is a substantial amount, but on its own insufficient to meet the total required investment identified in Section 12.2. One of the three key pillars of the Green Deal investment plan is therefore to use the EU budget as a lever to crowd in private and other (national) public investments. One mechanism is InvestEU, which provides the EIB and other multilateral banks with an EU budget guarantee to allow them to increase their risk taking and to crowd in additional investments. With this approach, it aims to double the impact of the EU budget for climate action, and to mobilise EUR 1 trillion for climate investments over 2021–2030 (EC, 2020s).

Although generally welcoming it as a step in the right direction, independent analysts have warned that it will not be sufficient to cover the required investment needs. The independent think tank Bruegel (2020) assessed that, even if the EUR 1 trillion objective is achieved, it will only cover up to one third of the required investments. When considering the investment needs identified in Section 12.2 (which showed that climate-related investments would need to increase by roughly EUR 1 trillion per year), the Green Deal investment plan will cover only 10 % of total investment needs. The gap becomes even larger when taking into account that not everything classed as climate spending in the EU budget will actually contribute to the climate mitigation objectives, given the flaws in the monitoring methodology explained above.

12.5 Mobilising national budgets

State aid guidelines have been loosened and allow more public climate funding at the national level, but they are not yet fully aligned with the EU's climate objectives and risk undermining the single market.

The national budgets of EU Member States can also play an important role, especially in supporting investments in mitigation enablers, stimulating demand for net zero technologies and implementing adaptation projects. Some types of support might, however, be subject to EU State aid rules ([93]).

In recent years, EU State aid rules have been adjusted several times, which has resulted in, among other things, more leeway for Member States to financially support the climate transition. After a first temporary adjustment in 2020–2022 (in the context of the COVID-19 pandemic), State aid rules were temporarily relaxed in 2022–2023 by means of the temporary crisis and transition framework, to support investments supporting the green transition and alleviate the impact of the energy crisis (EC, 2022j). A positive element of this temporary framework is that the European Commission has abandoned its usual technology-neutral approach in order to allow selective subsidies for net zero technologies such as batteries, solar panels, wind turbines, heat pumps, electrolysers and CCU/CCS, as well as related critical raw materials. This is a welcome development because, as explained by Anadón et al., 2022, 'in a context of innovation and structural change, policies will almost always advantage some technologies more than others. It is better to choose deliberately rather than accidentally, supporting innovation in low-carbon directions. Some policies intended to be neutral can have a bias towards incumbents, and incremental change'.

Meanwhile, the guidelines on state aid for climate, environmental protection and energy were also revised in 2022 to align them with the European Green Deal (EC, 2022i). As these guidelines are recent and have not yet been widely applied (owing to the temporary framework in force until 2025), the Advisory Board was not able to do a full assessment of these guidelines. Nevertheless, some inconsistencies with the EU's climate neutrality objective can already be highlighted. The guidelines do not ban support for fossil fuels. Instead, they allow further public funding in the form of tax incentives and capacity mechanisms for fossil gas operations under specific conditions, further relaxed under the temporary crisis framework (EC, 2023m) (see also Section 12.5)

A final concern is that, although State aid can address urgent investment needs, too much flexibility can also lead to market fragmentation, disadvantaging smaller Member States with less-developed capital markets and weaker economies. A long-term European strategy to finance the energy transition necessitates a stronger single market that gives businesses better access to finance across all Member States. To address this, the European Commission President, Ursula von der Leyen, launched the idea of an EU Sovereignty Fund. A first step to test this concept is the Strategic Technologies for Europe Platform, which was proposed in June 2023. The proposal includes the allocation of an additional EUR 10 billion to targeted programmes, including InvestEU, Horizon Europe and the Innovation Fund (EC, 2023d). However, the amount of available funding is dwarfed by comparison with the state support programmes approved by the European Commission, which have increased substantially in recent years to EUR 335 billion in 2021 (EC, 2023d).

([93]) State aid is defined as an advantage in any form conferred by national public authorities to undertakings on a selective basis, and is generally prohibited by the EU law (Article 107 of the Treaty on the Functioning of the EU). There are some exceptional circumstances in which State aid is not only allowed but also encouraged as a beneficial intervention from a socioeconomic perspective. Over the years, the European Commission's powers to set rules and make decisions about State aid have expanded, notably in terms of the exceptional circumstances in which State aid by the EU Member States is justified.

Member States' investment capacities are constrained by the recent crises and the EU's fiscal policy framework.

As previously described (see Sections 1.1 and 11.1), Member States' budgetary space has been substantially constrained in recent years by higher expenditures, lower economic growth and increasing interest rates.

One way to address this would be for Member States to increase borrowing to finance climate-related investments. However, the current EU fiscal policy framework, as recorded in the Maastricht Treaty (1992) and the Stability and Growth Pact (1997), aims to preserve fiscal discipline within the EU, by requiring Member States to limit their annual deficit to maximum 3 % of their GDP, and the aggregate debt to 60 % of their GDP (Karagounis et al., 2015). Whereas these rules might be recommendable from a fiscal perspective – as potential negative externalities from a spiralling debt crisis would have a direct systemic effect across the EU – they also limit the ability of Member States to borrow additional money to finance climate investments, even if such investments are recommendable from a long-term perspective. There have therefore been several calls to adjust the fiscal policy framework, for instance by allowing Member States to exclude investments related to the climate transition from the calculated deficit- and debt-to-GDP ratios (Darvas and Wolff, 2023). The rules of the Stability and Growth Pact were suspended for 2020–2023 to allow Member States to address the impacts of the COVID-19 pandemic and, subsequently, the energy crisis. In 2023, the European Commission published a proposal to revise the EU's fiscal rules, building on the Maastricht Treaty (EC, 2023d). However, although it allows for a more gradual (up to 7 years) fiscal adjustment path, it does not provide any specific treatment for public expenditures on climate action (Bruegel, 2023).

Another possible way for Member States to increase their climate spending without increasing their overall debt would be to increase revenues or decrease other public spending. However, this option also faces challenges. Increasing revenues, for instance by raising taxes, is politically difficult, and also risks undermining a Member State's competitiveness given the absence of a fiscal union. Decreasing expenditures might also be challenging, given that multiple other societal challenges also warrant increased public spending (e.g. digitalisation, social infrastructure or increased military spending in the context of the current geopolitical tensions) (EEA, 2023l).

The assessment above highlights the challenge of substantially increasing national public spending on the climate transition. One possible way forward that can contribute to solving this conundrum is a rapid phase-out of fossil fuel subsidies, as further described in Section 12.3.

12.6 Mobilising private finance

Private finance will need to make a substantial contribution to close the investment gap.

The magnitude of the investment gap as described in Section 12.2, and the challenges of increasing public climate spending (see Sections 12.4 and 12.5), highlight the importance of private finance to close the investment gap. Different sources have estimated the required ratio of private to public climate investments ranging from 2:1 to 5:1, which implies that the private sector would need to deliver 66–83 % of the total required climate-related investments. However, wide variations could be possible between EU Member States. For example, the EIB projected that in central and eastern Europe about 60 % of additional investments will be funded from public sources and the share will be only 37 % in western and northern Europe (EEA, 2023l).

The mobilisation of private finance requires ambitious policies to improve the bankability of climate-related investments.

Private actors generally seek positive returns on investments, and the required increase in private finance flows will not materialise unless policies provide favourable conditions for climate-related investments that can generate a sufficient supply of bankable projects. This can be facilitated by streamlining permit-issuing processes, carbon-pricing mechanisms, financial incentives (e.g. tax credits, public guarantees), technical assistance, institutional capacity building, standards and regulations, as well as enabling conditions such as infrastructures and regulatory stability. Such policies are covered in other chapters throughout this report, in particular Chapters 0–8 on the different sectors and Chapter 10 'Pricing emissions and rewarding removals'. The overarching conclusion of these chapters is that the EU's overall climate policy has been strengthened in recent years, although further improvements remain necessary (see Section 7.5, under 'Enabling condition: private investment').

In the domain of financial policies, private finance can be further mobilised towards climate investments by phasing out fossil fuel subsidies (see Section 12.3) and labelling (see Section 12.7).

The popularity of sustainable investments is growing, but their impact depends on a robust classification mechanism.

While scaling up climate finance remains a challenge, investments that take into account ESG sustainability criteria (measured following self-regulated standards) are increasingly popular (Maiti, 2021). A recent market analysis (Bloomberg, 2022) suggests that global ESG assets may surpass USD 50 trillion by 2025, compared with USD 35 trillion in 2020, with Europe remaining one of the most important markets. The primary ESG approaches focus on exclusion criteria, with shareholder activism and corporate engagement also gaining traction (GSIA, 2020). However, research indicates that ESG investing by itself is not enough to yield meaningful climate outcomes (Kölbel et al., 2020). ESG strategies and reporting tools are not sufficient to understand the tangible impact of the financial sector claiming to advance environmental and social outcomes climate change.

The EU Taxonomy provides a harmonised framework to label activities as 'environmentally sustainable', including certain types of fossil gas activities.

The European Commission has identified the need for more robust assessment and standardisation of ESG methodologies to understand climate and other environmental impacts (EC, 2018a). Responding to the challenge of a fragmented market for ESG ratings, which to a large extent remains self-regulated (Jonsdottir et al., 2022; Charlin et al., 2022), the European Commission launched the EU Taxonomy, which is a classification system with harmonised criteria for labelling economic activities as environmentally sustainable. For an economic activity to be classified as environmentally sustainable, it must (i) contribute to at least one of six sustainability objectives (which include climate change mitigation and adaptation), (ii) without significantly harming any of the other six objectives (referred to as the 'do no significant harm' principle), (iii) while complying with minimum social safeguards. To expand the utility of the EU Taxonomy, the regulation introduced two additional categories of activities qualifying as environmentally sustainable: enabling activities ([94]) and transitional activities ([95]).

([94]) Enabling activities are economic activities that enable other activities to make a substantial contribution to at least one of the six environmental objectives, if it does not lead to a lock-in of assets that undermine long-term environmental goals, and has a substantial positive environmental impact based on life cycle considerations.

([95]) Transitional activities are activities that can be considered to contribute substantially to climate objectives if their GHG emissions are substantially lower than the sector or industry average, they do not hamper the deployment of low-carbon alternatives and they do not lead to a lock-in of carbon intensive assets, considering the economic lifetimes of those assets.

Whereas the EU Taxonomy regulation sets out the overall framework, the specific criteria (referred to as TSC) are set out by the European Commission through delegated acts. To remain relevant to the latest research and market developments, these TSC are subject to regular review by the European Commission to reflect technological progress, ensuring that sectors and activities can be added or deleted through amendments to the regulation. The first act to be adopted under the EU Taxonomy regulation was the Climate Delegated Act (EC, 2021b), which established the TSC for the first two objectives of the EU Taxonomy: climate change mitigation and climate change adaptation. This initial delegated act covered about 40 % of EU-domiciled publicly listed companies, which are responsible for roughly 80 % of direct GHG emissions in Europe. One year later, the European Commission adopted a Complementary Climate Delegated Act (EC, 2022b), which established the TSC for fossil gas and nuclear activities. These allow the labelling of certain fossil gas activities as transitional activities contributing to climate change mitigation, provided they meet certain criteria (e.g. such activities would need to remain below certain emission intensity and energy efficiency thresholds). However, these thresholds are too high, and, even if the emissions can be lowered through CCU/CCS, such electricity plants should be marginal in the decarbonised energy systems (ESABCC, 2023b); see also Section 4.3, under 'Lever: coal and fossil gas phase-out' and 'Lever: targeted carbon capture and utilisation/storage'. Another example of the TSC under the EU Taxonomy potentially jeopardising the net zero transition pertains to the depth of building renovation, where reducing primary energy demand by 30 % can be considered sustainable without necessarily linking it to staged deep retrofits (see Section 7.5, under 'Enabling condition: private investment').

While an in-depth analysis of the TSC is beyond the scope of this report, the Advisory Board notes that not all EU Taxonomy thresholds for economic activities are currently in line with climate neutrality (see for example (Schütze and Stede, 2021). In this respect, it is important that the European Commission initiate regular updates of the criteria in line with Article 19 of the EU Taxonomy regulation (EU, 2020).

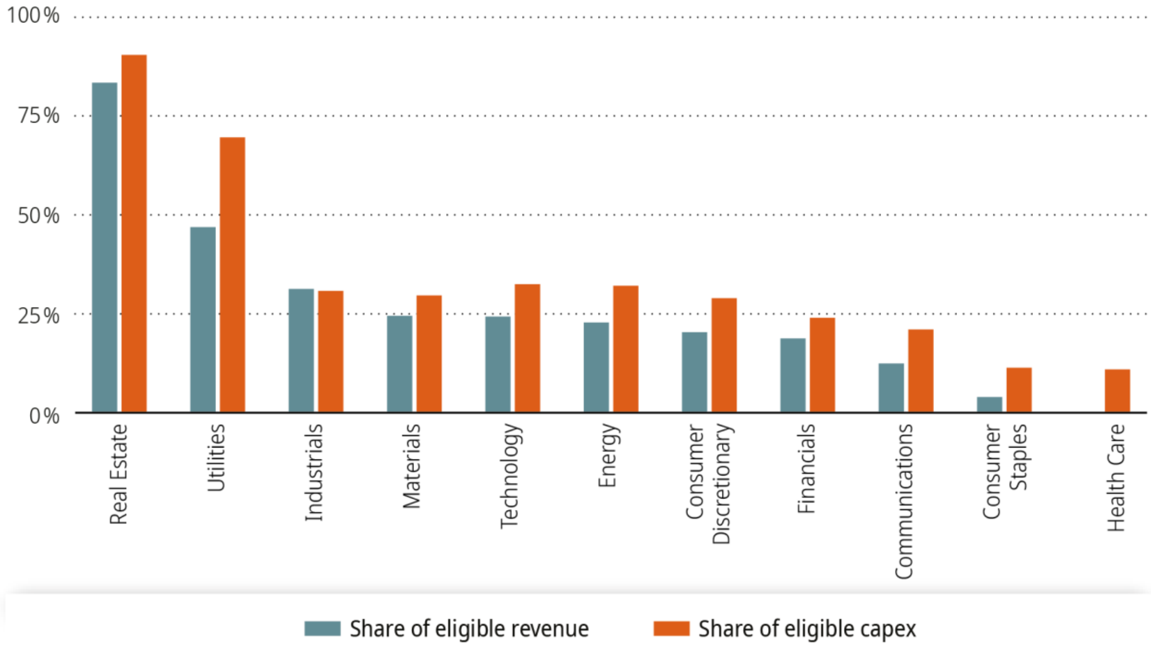
Initial data shows large differences between sectors' alignment with the current TSC in the EU Taxonomy.

The Corporate Sustainability Reporting Directive ([96]) (EC, 2021l) and Sustainable Finance Disclosure Regulation (EC, 2018b) require certain entities to disclose information on the degree of alignment of their activities with the EU Taxonomy. However, they do not include a legal obligation for those entities to reach a minimum degree of alignment. Whereas the EU Taxonomy, the directive and the regulation are thus important steps forward to increase transparency and credibility, their effectiveness in shifting investments towards sustainable activities will purely rely on investors' preferences, which will also be determined by the bankability and marketability of sustainable investments.

Based on the data reported so far, there are large differences in different economic sectors' alignment with the EU Taxonomy (see Figure 79). On a positive note, in the real estate and utilities sectors (the latter of which includes the electricity sector) a large share of capital expenditure is already eligible under the EU Taxonomy, reflecting the plethora of available options for investments in projects that can potentially meet the TSC. However, for other key relevant sectors such as industry, materials, energy ([97]) and finance, only 30 % of capital expenditure can be eligible under the EU Taxonomy. For these sectors, there is still much room for improvement to shift existing investment flows towards sustainable activities.

([96]) This will replace the 2014 Non-Financial Reporting Directive.
([97]) This includes non-regulated energy companies, primarily in the oil and gas industry.

Figure 79 Eligibility of different sectors' revenues and capital expenditure under EU taxonomy



Source: Bloomberg terminal, based on company reported data (BNEF, 2022)

12.7 EU green bond market

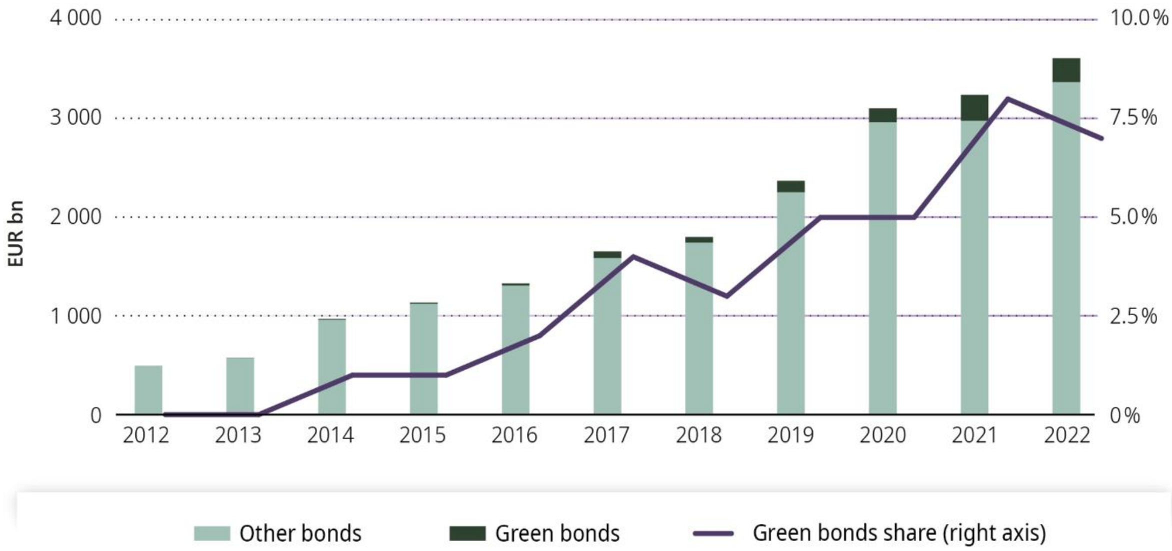
Green bonds could provide an opportunity to scale up climate finance, provided their additionality and environmental integrity are ensured.

Green bonds are fixed-income investment securities that provide financing to sustainable projects run by either companies or governments. Since the EIB inaugurated the green bond market in 2007 with the first climate awareness bond, the market has seen significant growth. In 2022 European companies and governments raised EUR 241 billion issuing green bonds, which represented 47 % of the global proceeds in that year. However, their share in the total EU bond market remains relatively low at 7 % (see Figure 80). Most assets financed with green bonds have been in renewables (21 % of the issuance activity), clean transport (16 %), and clean technologies and buildings (11 %) (Bloomberg, 2023).

The rapid rise of climate-related bond issuances could present an opportunity for scaling up climate finance (IPCC, 2022m). This is particular the case in the EU, as the European capital market relies more on debt instruments than on shareholder equity to finance new projects (Gaud et al., 2007). However, their actual impact depends greatly on their environmental integrity and additionality (Shishlov and Censkowsky, 2022). So far, this is not ensured: there is no common definition of or assessment framework for what constitutes a green bond. They are currently labelled as such based on criteria defined by the rating agent used by the bond issuer (Ehlers et al., 2022). This increases the risk of greenwashing.

Another limitation of green bonds is that they provide limited incentives for corporations to phase out harmful activities. This can be attributed to the design of the green bonds: it addresses only green projects, which on many occasions form only a small part of the overall activities in a diversified corporate structure.

Figure 80 Development of the EU green bond market



Source: Bloomberg terminal (Bloomberg, 2023)

The EU green bond standard could improve the transparency and credibility of green bonds, but is only voluntary. Its effectiveness will depend on the degree to which it is applied.

To address the fragmentation in the green bond market, the European Commission proposed in 2021 a European green bond standard, which was finally adopted in October 2023 (EC, 2021ae). Overall, the standard is aligned with the EU Taxonomy framework described in Section 12.6. The application of this harmonised standard is, however, strictly voluntary, and its effectiveness will therefore depend on the degree to which it is applied by bond issuers.

NextGenerationEU is largely (up to EUR 250 billion, representing almost 30 % of the total) funded by the issuance of green bonds, which will make the European Commission the largest green bond issuer in the world. However, these bonds currently do not follow the requirements of the EU Taxonomy, which also means they are not aligned with the European Green Bond Standard. This reduces transparency on the use of proceeds and can undermine credibility in the credit market, resulting in higher borrowing costs (Larcker and Watts, 2020; Löffler et al., 2021; Partridge and Medda, 2020).

12.8 Summary table

Table 19 Policy consistency summary – finance and investments

Policy inconsistencies	– EU State aid rules still allow fossil fuel subsidies. – The Stability and Growth Pact does not treat investment related to the climate transition differently from other types of investment.
Policy gaps	– There is no reporting on EU budget expenditure on activities that breach the 'do no significant harm' principle of the EU Taxonomy. – There is no structural, long-term common fiscal capacity based on a common EU debt (beyond the RRF).
Ambition gaps	– EU policies do not sufficiently encourage the creation of bankable projects that would attract private investment. – The Strategic Technologies for Europe Platform has so far been inadequate because of its limited budget (EUR 10 billion, compared with more than EUR 300 billion per year of State aid in 2021). – Only soft EU policy measures encourage EU Member States to phase out fossil fuel subsidies. – There are substantial flaws in the methodology for tracking EU spending on climate action, which undermine the EU budget's contribution to the EU climate objectives.
Implementation gaps	– Only a few Member States have enacted laws or clear plans that specify how and by when the phase-out of fossil fuel subsidies will be achieved.

13 Innovation

Key messages

A more ambitious policy on research, development and deployment (RD & D) is needed to accelerate innovation and support competitiveness.

Needs. The EU aspires to be a global leader in climate ambition, action and innovation. This requires increasing investments in climate-related RD & D, and both private and public sectors have a role to play in supporting this objective. The EU needs to make RD & D investments and enact additional demand policies that stimulate innovation and crowd in private investment. Spending on innovation needs to increase, to ensure that Europe remains competitive in the global landscape of clean technologies. Planned expenditure on R & D across all research areas (not just climate related), including through the European Green Deal, continues to fall short of the 3 % GDP target that was set back in 2010 and reiterated in 2021. Despite the increasing needs for cleaner technologies across all sectors, public funding on innovation stagnated over the last decade, at 0.8 % of the EU-27's GDP in 2021 compared with 0.8 % of the EU-27's GDP back in 2011.

Gaps. The main EU policy instruments aiming to catalyse private investment are Horizon Europe and the Innovation Fund. One of their main focuses is climate-related technologies; however, their administrative complexity hinders the crowding-in of private investments **(implementation gap)**. Public funding instruments can sometimes be slow in reacting to the changing needs of the fast-paced global clean technology arena. This should be monitored at the EU level, particularly beyond early-stage research **(policy gap)**. For example, public funding in the United States took many years to begin providing more substantial support for RD & D in energy storage.

Recommendation In1. There is a role for increasing various forms of public climate-related RD & D investments, including supporting private sector activity. They need to be distributed strategically, encouraging the participation of start-ups and small and medium-sized enterprises. Increased RD & D investments are needed to ensure that the EU can remain in a position to invent, patent and commercialise the mitigation technologies of tomorrow. The administrative complexity of the EU's funding instruments can be streamlined in order to encourage the participation of small and medium-sized enterprises and start-ups, given that they often lack the resources to participate in time-intensive and complex processes. Spending on climate- and energy-related technologies currently represents only about 9 % of total spending on innovation. An effective policy mix that combines instruments such as carbon pricing, fiscal incentives and grants can direct a larger amount of public and private RD & D towards technologies that directly contribute to the climate neutrality objective (please see Chapter 10 'Pricing emissions and rewarding removals').

Currently there is a significant funding gap for projects that are towards the end of the RD & D process, the demonstration stage, and for commercial deployment. Policies that support innovation need to ensure that there is sufficient investment to give them a chance to cross the 'valley of death'.

Needs. While the EU originates more than 30 % of all top scientific publications, there is a significant lag in innovative solutions for clean energy. Part of the disconnect between scientific excellence and commercialisation can be attributed to the scarcity of funding at the demonstration and early commercialisation stages. Climate technology projects that evolve from the early stages of R & D and prototyping towards piloting have fewer sources of funding available than those in other subject areas and in other countries.

Gaps. Current policy intervention instruments focus their support at the two ends of the RD & D process, the early R & D stage and the late maturity and diffusion stage (the former through the European Research Council and Horizon Europe, and the latter through pricing and other demand-pull incentives). This policy mix leaves a funding gap for climate technology manufacturing or deployment projects aiming to complete the piloting and demonstration stage and move towards the early deployment of clean technologies **(policy gap)**. This funding gap is further widened by the relative lack of support from venture capital, as this concept remains less developed in Europe than in the United States, for instance **(policy gap)**.

Recommendation In2. Access to finance needs to address all the stages of the RD & D process and across to deployment, as innovation is only as close to market as the weakest link in the development process. The current system of support for RD & D could give additional attention to the demonstration and early commercialisation phases in the forms of additional grants, loans, loan guarantees and government procurement. The combination of increased investments in R & D (recommendation In1) and in demonstration and commercialisation through additional tools and market-pull policies, such as carbon prices and other, more targeted, incentives, can help attract additional venture capital and other types of investments.

Across the EU, funding support for innovation and early deployment needs to further diversify and support a wide range of early stage technologies with high mitigation potential in industry, some transport applications, agriculture and food, and CDR.

Needs. The EU's leadership position in mitigation technologies is underpinned by a strong position in a small number of mature technologies such as wind power and rail transport. Strengthening Europe's strategic autonomy in key sectors, which could reduce its exposure to various geopolitical risks, requires developing a portfolio of early-stage clean technologies to support the transition. Some of that may involve developing capabilities in parts of the supply chain for climate technologies that are more mature, but also in sectors where there are currently fewer mature technologies, including agriculture, some key industries and CDR. Europe lags behind international peers in the development of emerging technologies, such as lithium-ion batteries and electrolytes used in hydrogen production, in terms of its relative position over time in the number of patents for those technologies.

Gaps. The Net-Zero Industry Act aims to partially address the need to strengthen the knowledge and industrial manufacturing capacity in key technologies, but an explicit link to the earlier stages of the innovation process could help strengthen the EU's position **(policy gap)**. Policy instruments such as the strategic energy technology plan, which aims to strengthen collaborations between industry and research, also need to address behavioural barriers to innovation such as the fear of failure, emphasising the value of the knowledge generated when trying to innovate, and the value of sharing that knowledge **(ambition gap)**.

Recommendation In3. Policy intervention instruments such as the revamped strategic energy technology plan should strengthen collaborations and networks in novel technologies with high mitigation potential, encouraging knowledge sharing and the wider dissemination of lessons learned.

Innovation policies need to crowd in private investments, fostering closer collaborations between private and public knowledge organisations.

Needs. The innovation cycle needs to accelerate. This requires stronger collaborations between private and public knowledge organisations. Longer-term frameworks, including incentives and regulations, are needed in order to successfully crowd in more private investments in early-stage technologies with high mitigation potential. When potential future support is unpredictable, there is a risk that a project may be ended prematurely owing to lack of resources, and the knowledge generated may be lost. Policies supporting innovation need to prioritise learning, iteratively upscale, engage the private sector, disseminate knowledge and create robust demand.

Gaps. Policy instruments on innovation need to foster collaborations between private and public knowledge organisations, creating opportunities for building stronger collaborations **(policy gap)**. The existing EU funding architecture offers limited predictability beyond 2030, which increases uncertainty for long-term projects **(ambition gap)**. The Net-Zero Industry Act aims to increase the EU's manufacturing capacity in strategic technologies to reach at least 40 % of domestic needs; however, the existing reporting mechanisms offer limited means to track progress towards achieving this target **(policy gap)**. It is also unclear if the same level of coverage is needed to advance the EU's transition in a way that is just and that increases the resiliency of supply chains.

Recommendation In4. The revamped strategic energy technology plan needs to foster a closer collaboration between private and public actors and broader dissemination of the knowledge generated, so that more private investments can crowd in. In order to monitor progress towards the policy objectives of the Net-Zero Industry Act, relevant and reliable information is needed on investments across the supply chains of key climate technologies and on asset deployment.

Innovation should not be seen as an argument for postponing climate action.

Innovation cycles typically take decades from first proposal to full commercialisation. While an important enabler, R & D alone cannot be considered a panacea. Innovation can bring important benefits in, for example, reducing costs and improving efficiency. However, expected developments of new technologies should not be relied upon to delay action or social innovation that can curb emissions.

13.1 Scope

According to IPCC AR6 (contribution of Working Group III, Chapter 16) innovation in climate mitigation technologies, encompassing the process from R & D to technology deployment, has seen 'enormous activity and significant progress in recent years' in supporting system transitions to limit warming. This is evidenced by the recent rapid cost reductions and diffusion of climate-friendly products such as the electric car, the solar panel and the heat pump. Technological challenges remain in a range of economic activities including freight, agriculture, shipping and aviation, metallurgy (steel and aluminium) and cement production. These sectors rely on burning fossil fuels or using them as feedstock, as mitigation alternatives either do not exist or are not available at the necessary scale.

The development of new decarbonisation technologies and the improvement of existing ones are essential to move towards a carbon-neutral economy in a cost-efficient way, while simultaneously pursuing economic growth opportunities that strengthen productivity (IPCC, 2022, (Grassano et al., 2020) and driving the economy's overall competitiveness (Anadón et al., 2017). The last few decades of experience with low-carbon technologies show that a combination of technology-push investments and policies with demand-pull interventions to create or grow early markets is needed in order to accelerate technology unit cost reductions and scale up more rapidly. A recent synthesis of experience with policies shaping innovation in clean energy technologies around the world also shows that policies need to be adaptive, make choices, address questions about inclusion and justice, and harness tipping points in cost reductions (EEIST, 2022). To some extent, these insights are already reflected in some European policy efforts: investments in mitigation technologies have taken centre stage in the recent RRF, REPowerEU, Net-Zero Industry Act and Green Deal industrial plan. However, a number of policy areas need to be further addressed in order to accelerate innovation in clean technologies to continue supporting the competitiveness of European industry.

13.2 Progress on innovation

Methodology to track progress

Tracking progress on innovation remains challenging because innovation is a complex process that cannot be understood using one or even multiple metrics, each of which has limitations. In addition, the relationship between policy inputs (e.g. finance, education) and intermediate outputs (i.e. patents, pilot projects) is sometimes unclear (Moaniba et al., 2018). Policy objectives such as more affordable energy, industrial transformation and economic growth are hard to attribute to specific inputs (Grubb et al., 2021), although evidence is growing (Peñasco et al., 2021) that a range of indicators can be used as proxies for innovation, including RD & D investments, publications, funding and follow-on investments.

Total research and development spending

The EU is falling short on its objective of spending 3 % of its GDP on R & D.

The EU has a long-standing objective to increase spending towards R & D to at least 3 % of the GDP (Lisbon 2000 strategy and Europe 2020 strategy). This objective does not include any specific target for increasing R & D spending on energy and climate.

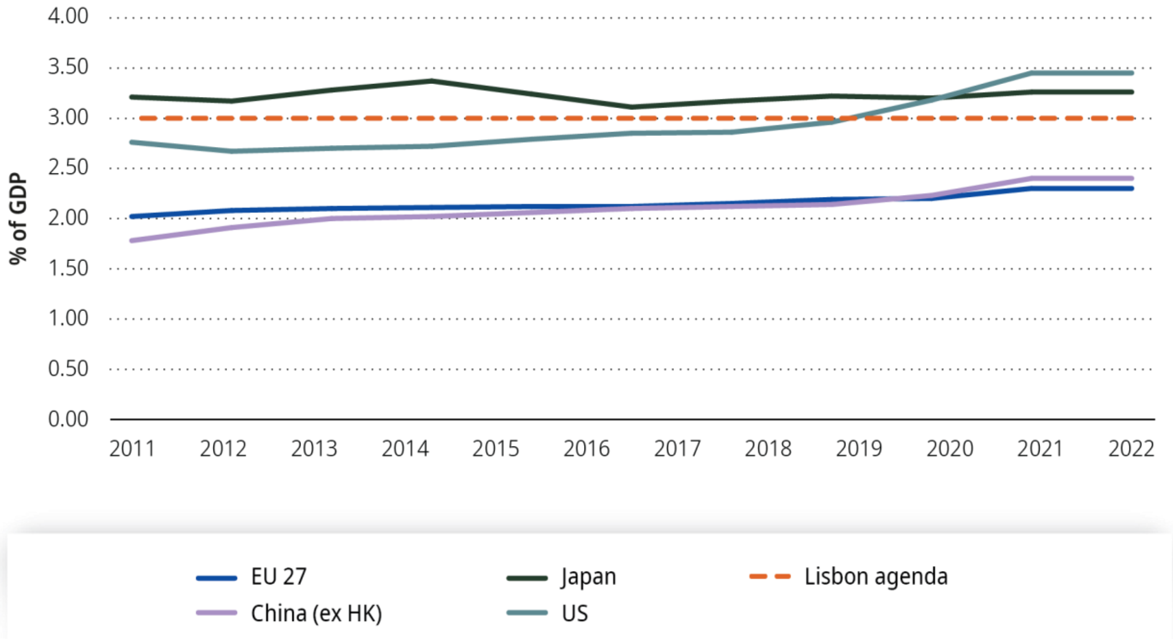
The ratio of R & D to GDP is also known as R & D intensity (Eurostat, 2021), and data about the EU and other major economies are shown in Figure 81. This ratio increased marginally in the EU during 2011–2021, rising from 2.02 % in 2011 to 2.31 % in 2020 but decreasing in 2021 to 2.27 %. The slight decrease in R & D intensity between 2020 and 2021 could be explained by the GDP rebound in 2021 after the significant drop in 2020 as a result of the COVID-19 pandemic. To compare it to the situation before the COVID-19 crisis, the R & D intensity of the EU saw a marginal increase from 2.02 % to 2.19 % between 2011 and 2019. In other words, over 2011–2021, the EU as a whole made limited progress in increasing R & D expenditure towards the 3 % target pledged in the Europe 2020 strategy.

In contrast, over the same decade, R & D intensity trends were different (and in some cases more dynamic) in other parts of the world. Between 2011 and 2021, R & D intensity in the United States increased from 2.76 % in to 3.45 %, and in China from 1.78 % to 2.4 %. Japan's remained consistently above 3.10 %. As a result, the EU is progressively falling behind other regions on R & D spending. That gap can erode competitiveness in strategic sectors such as energy and international transport. It is estimated that the energy sector represents about a tenth of the EU's total R & D expenditure, or 0.02 % of its GDP (IEA, 2023i).

Higher spending on R & D both in energy and beyond requires higher contributions from both public and private participants, and public spending needs to become more effective at crowding in private investments (Becker, 2015). An analysis of R & D expenditure by source of funds shows that about two thirds of the total expenditure within the EU is funded by the private sector whereas almost one third is funded by EU and Member State resources. According to the data from Eurostat, as evidenced in

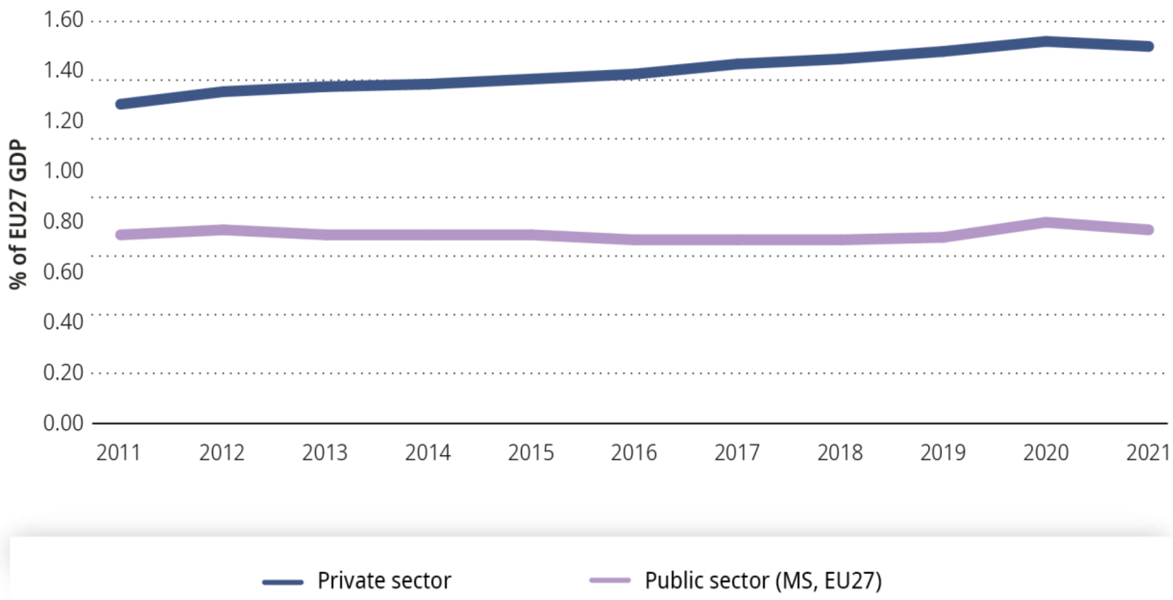
Figure 82, the main development over 2011–2021 was a fall in the share of funding by the public sector from 37 % to 34 %, with a corresponding increase for the private sector from 63 % to 66 %.

Figure 81 Gross domestic expenditure on research and development, 2010–2021



Sources: Eurostat (2023j), OECD (2023c) (US, Japan and China).

Figure 82 EU-27 R & D spending in the public and private sectors



Notes: Eurostat's statistics on R&D expenditure are compiled using guidelines laid out in the Frascati manual 2015, published in 2015 by the OECD. Public spending includes funding from both member states and the EU budget.

Source: Eurostat (2023j)

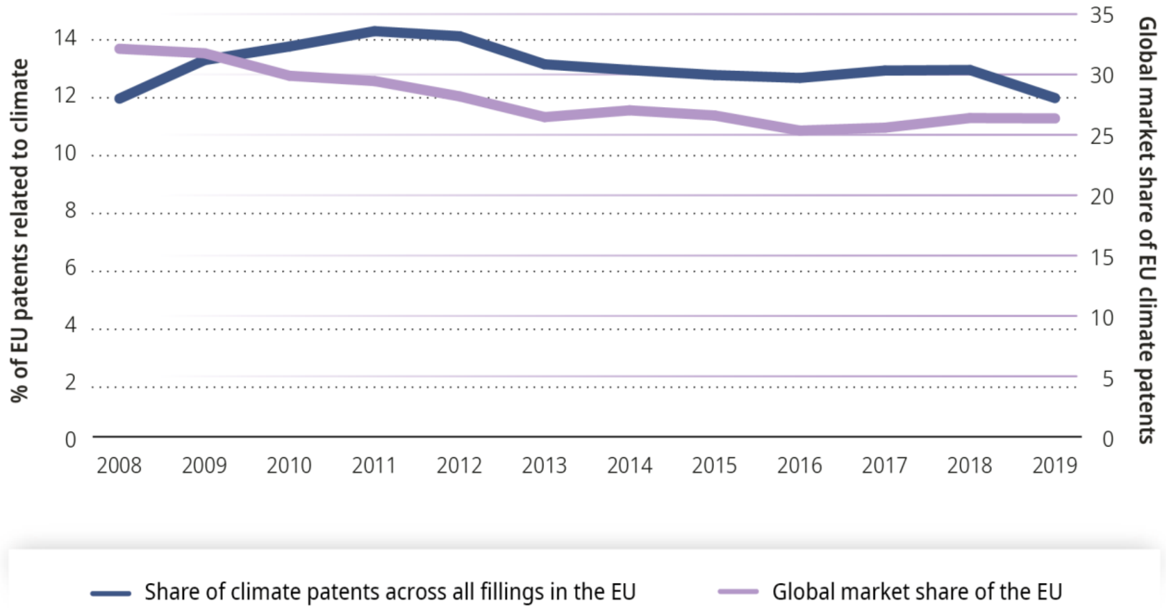
Research on energy R & D finds no evidence that increases in energy R & D draw out (or crowd out) R & D resources from other sectors (Goldstein et al., 2020; Popp and Newell, 2012). Moreover, other research, focused on public funding for defence R & D, shows evidence of public investments crowding in private investments (Noriega et al., 2018). Public institutions funding energy R & D and engaging with small companies have been associated, in some cases causally, with improved patenting outcomes or follow-on investments by firms.

Climate-related patenting

Climate-related patenting in the EU is slowing down.

Patents in climate-related technologies ([98]) have been increasing over the last 10 years, with European companies targeting high-value inventions with international protection, which suggests growing confidence in their competitiveness in the global energy technology market. However, the absolute number of EU patent filings related to climate change mitigation has stagnated more recently. The decline in patenting activity in 2019 may reflect the maturity of some technologies such as solar PV, bioethanol and wind (IEA, 2020), combined with low energy prices at the time (Probst et al., 2021).

Figure 83 Share of climate patents among all EU filings and the global market share of the EU in climate-related patents



Notes: Patents related to climate change mitigation include: Energy generation through RES: geothermal, hydro, oceanic, solar (PV and thermal), wind; Energy generation of nuclear origin fusion and fission; Technologies for efficient electrical power generation, transmission or distribution Reactive power compensation, efficient operation of power networks; Technologies for the production of fuel of non-fossil origin Biofuels, from waste. Technologies with potential or indirect contribution to GHG emissions mitigation; Energy storage (batteries, ultracapacitors, flywheels), hydrogen technology, fuel cells, etc.; and other energy conversion or management systems reducing GHG emissions.

Source: OECD (2023b)

([98]) The definition of climate-related technologies in the OECD database used for the analysis of patent trends includes the following sectors: solar, wind, hydro, geothermal, marine, sustainable biomass and waste to energy, biofuels and smart energy technologies (such as smart grids, energy efficiency and electric vehicles).

A closer examination of the share of climate-related patents in the overall number of patent filings in the EU suggests a loss of momentum, as this share initially increased from 11.9 % in 2008 to reach 14.3 % in 2011 and then reverted to near the starting point (Figure 83). This has a direct impact on the share of EU climate patents in the global market, as evidenced by the decline in the EU's market share from 32.2 % in 2008 to 26.4 % in 2019. Given that most new investments in clean energy technologies are expected to take place outside the EU, it is unlikely that this trend will reverse without a decisive change in the policy mix. Overall, the recent trends in climate-related patent filings and R & D expenditure suggest that the EU contributes less to the development of new green technologies than its ambition would suggest. As previously mentioned, patents have well-known limitations as an innovation metric, but can be helpful to identify and compare trends.

13.3 Policy consistency on innovation

Need for more public–private cooperation

At every stage of the RD & D process, both public and private sector actors play critical roles. The role of governments encompasses education, R & D funding, tax incentives, providing network infrastructure, protecting intellectual property, supporting exports, helping small and medium-sized enterprises, providing the regulatory framework, and shaping, and in some cases creating, early markets (Roberts and Geels, 2019).

In addition to increased funding, it is also important to take a more holistic and deliberate approach to shaping technology innovation to address the climate challenge in a way that advances societal goals (including climate mitigation) and is inclusive and just. Public investment in enabling infrastructure could support such an approach, increasing the probability that innovations will succeed (IPCC, 2022o). Research on public RD & D investments in the energy sector shows that these investments are generally associated with positive impacts on environmental, technological, innovation and competitiveness outcomes (Peñasco et al., 2017). There is also a growing literature indicating that, at least in the energy sector, public funding and tax incentives for RD & D are useful to small and medium-sized enterprises.

Given the magnitude and speed of the change needed, there are also indication that the institutions supporting and coordinating energy innovation need to better enable the fast commercialisation of technologies; in many cases, the time between the invention of a technology and its wide diffusion has spanned decades (Stephan et al., 2017). There is also evidence of a valley of death after R & D, when technology risks are high but investment costs increase. Finally, some analysis suggests that at some times the outcomes of start-ups in energy were not as positive as those in biotech and IT, reinforcing the need for additional types of finance to scale up and commercialise new energy technologies (Gaddy et al., 2016).

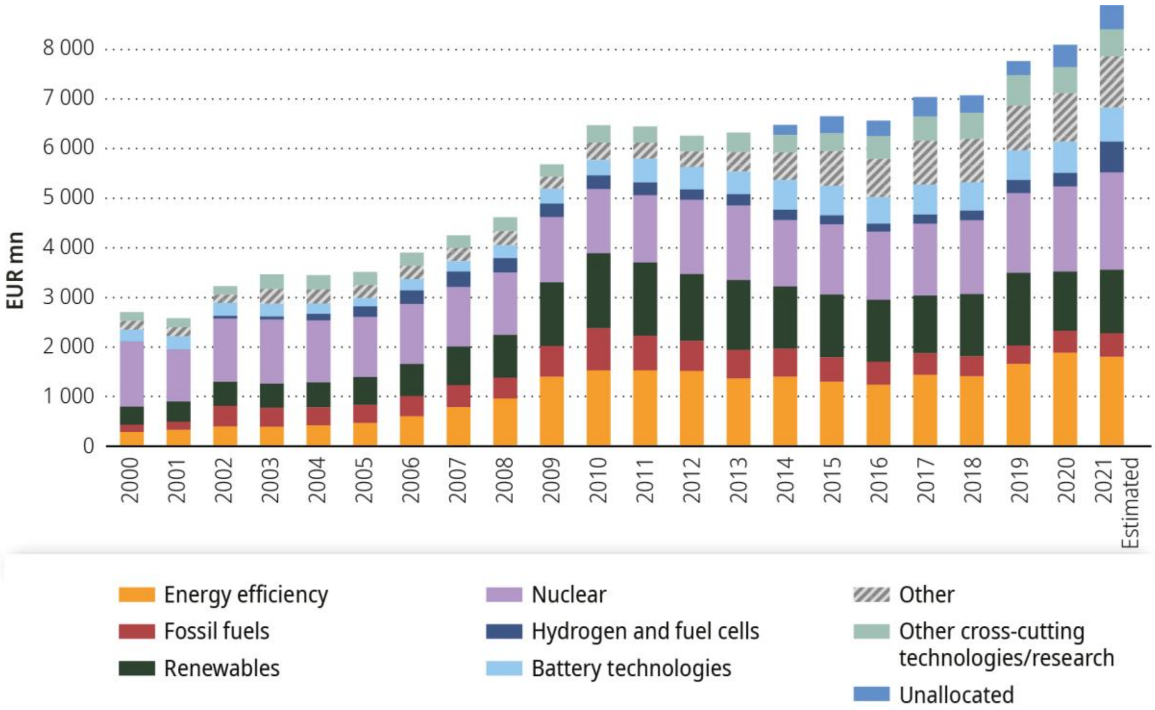
Public funding for key technologies lagging behind

Public funding of RD & D is lagging behind on key technologies that are necessary for the transition towards climate neutrality, such as batteries and hydrogen. Batteries are a key technology that enables the decarbonisation of the transport sector, but also serves for energy storage in the energy supply sector; this is also recognised in the 2018 strategic action plan on batteries. According to Figure 84, public funding for RD & D in batteries has accounted for a relatively constant share of 9 % of total public expenditure on RD & D. The battery industry in the EU lags behind the growing global competition (Lebedeva et al., 2021), suggesting that a bigger effort in some storage areas may be valuable. The early investment associated with large-scale production allowed Asia to scale up and retain technological leadership in battery technologies (IEA, 2021b).

Hydrogen is also a key enabler in reducing emissions in industry (see Section 5.4) and long-range transport (see Section 6.4 under 'Lever: fuel switches', and for increasing flexibility in the energy supply sector (see Section 4.3 under 'Lever: system integration'). To realise this potential, more intense innovation is needed along the entire hydrogen supply chain, including electrolysers, to improve performance and reduce costs. Despite the significant increase in the proportion of spending on hydrogen-related RD & D from almost zero in 2000 to 7.9 % of the total spending in 2021, current levels of spending on deployment (EUR 621 billion) are about half the amount required (EUR 1 370 billion) to reach the REPowerEU targets of producing 10 million tonnes and importing an additional 10 million tonnes by 2030 (EC, 2022ad). This could suggest that additional support for early deployment could be helpful in complementing the R & D increases.

At the same time, public funding for fossil fuel RD & D including CCS remained above 5 % of the total energy RD & D budget between 2000 and 2021 (estimated total) (Figure 84). This support is inconsistent with the EU's pledge to phase out fossil fuel subsidies (EEA, 2023i). Reorienting funding away from fossil fuels and towards mitigation technologies would reduce funding gaps in key enabling technologies and also send a strong signal that the EU prioritises energy security and climate mitigation.

Figure 84 Public spending on RD & D by sector



Notes: Data collected at member state and EU level, in 2021 euro values.

Source: IEA (2023c) (indicator: 'Public R&D spending').

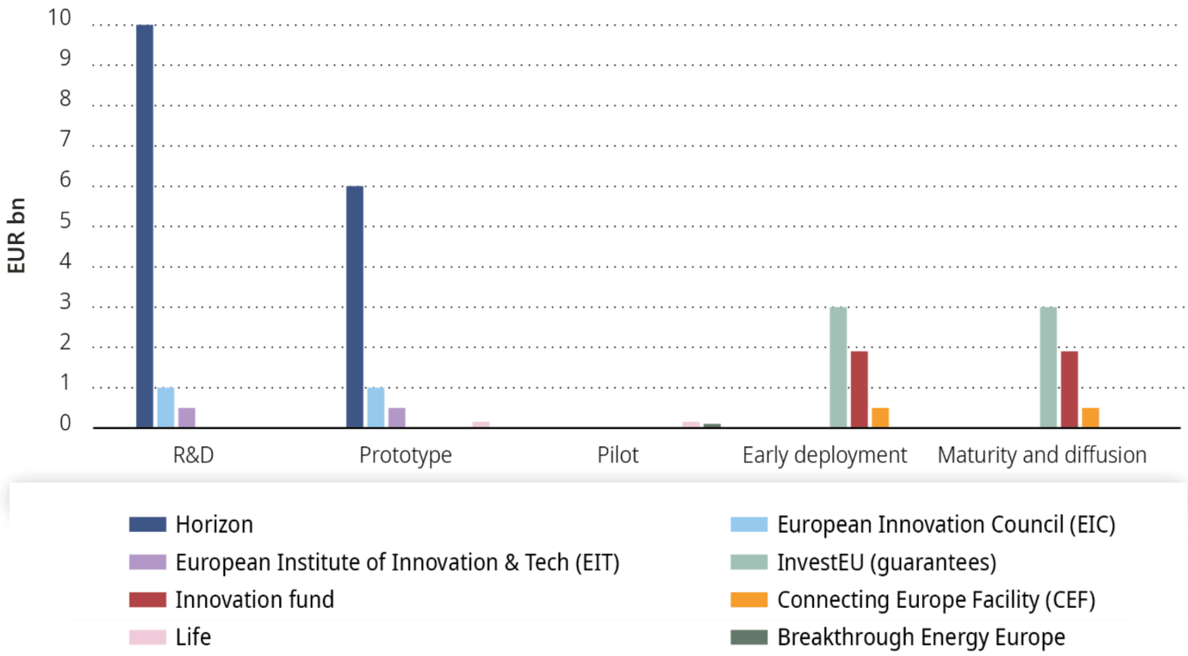
Persisting risk of funding gaps at the demonstration and early deployment stages

The RD & D process can be summarised in the following five key stages (IPCC, 2022o), which can vary in duration, as the pathway to maturity can be long and success is not guaranteed.

1. **R & D.** Creative work is undertaken on a systematic basis in order to increase the stock of knowledge, and this knowledge is applied to devise new applications and solutions.
2. **Prototype.** A research project is developed into a design and then into a prototype for a new device (e.g. a furnace that produces steel using hydrogen instead of fossil fuels).
3. **Pilot.** The first demonstration examples of a new technology are introduced at the size of a full-scale commercial unit (e.g. installing a carbon capture system at a cement plant).
4. **Early deployment.** At this stage, there is still a cost and performance gap between the new technology and established ones (e.g. electric versus combustion engine cars). Policy needs to address this to level the playing field.
5. **Maturity and diffusion.** As deployment progresses at scale, the product moves into the mainstream as a common consumer choice for new purchases (e.g. LED lamps).

The EU has a range of funding programmes to support climate-related innovation across all stages, including Horizon Europe, the Innovation Fund, the LIFE programme, the European Institute of Innovation and Technology, the European Innovation Council, InvestEU, the Connecting Europe Facility and Breakthrough Energy Europe. The availability of funding through these programmes across the main stages of the RD & D process (R & D, prototype, pilot, early deployment, and maturity and diffusion), is summarised in Figure 85. Despite the plethora of available mechanisms, there is a material funding gap at the middle stage of the RD & D process (pilot stage).

Figure 85 Available public funding by stage of the RD & D process

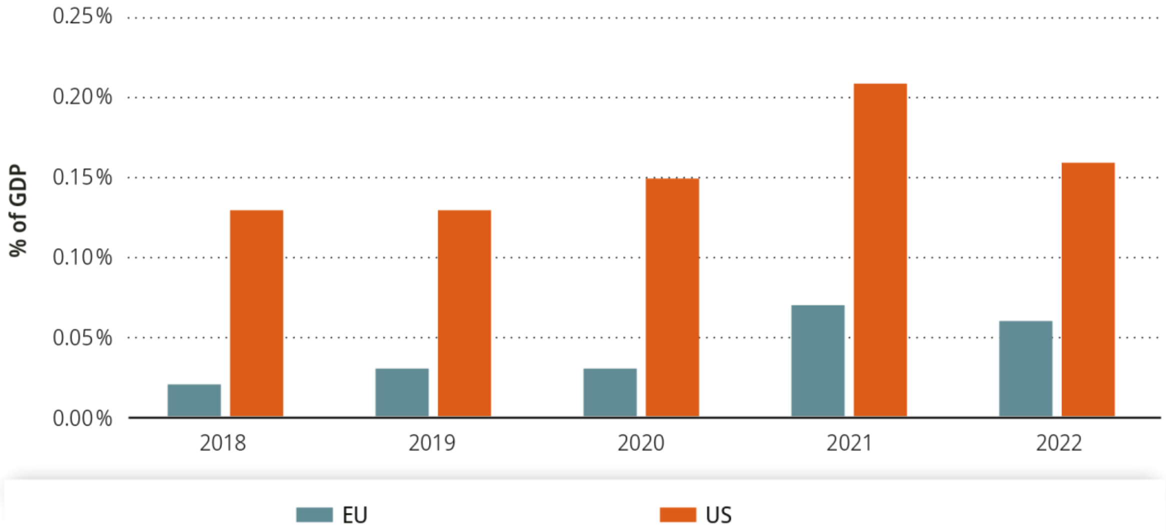


Notes: Annualised estimates for the period 2021 – 2027, except from the Innovation fund which is annualized for the period 2020-2030 and the Breakthrough Energy Europe which spans over the 2018-2023 period, in 2022 EUR values.

Sources: Policy documents for corresponding programmes (CINEA, 2021; EC, 2024, 2023ak, 2021p, 2019d, 2023bi; EIT, 2024; Wallace, 2019)

The venture capital financing model, used to overcome the valley of death in biotech and software technology, has not been as suitable for hardware start-ups in energy, because of their higher capital intensity and their dependence on network infrastructure. The current venture capital model and private finance do not sufficiently cover the need to pilot energy technologies at scale (Nemet and Greene, 2022). As Figure 86 demonstrates, investment in EU companies that specialise in clean technologies ([99]) lags behind that in the United States. This includes seed, series A, series B and growth investments. More specifically, in 2022 the EU invested only about 0.06 % of its GDP in clean tech start-ups whereas in the United States this investment amounted to 0.16 % of GDP.

Figure 86 Investments in cleantech across Europe and the United States (% of GDP)



Notes: All values are expressed in 2022 Euros. Includes funding in Seed, Series A, Series B and Growth investments. For a full definition of cleantech technologies please see footnote 97.

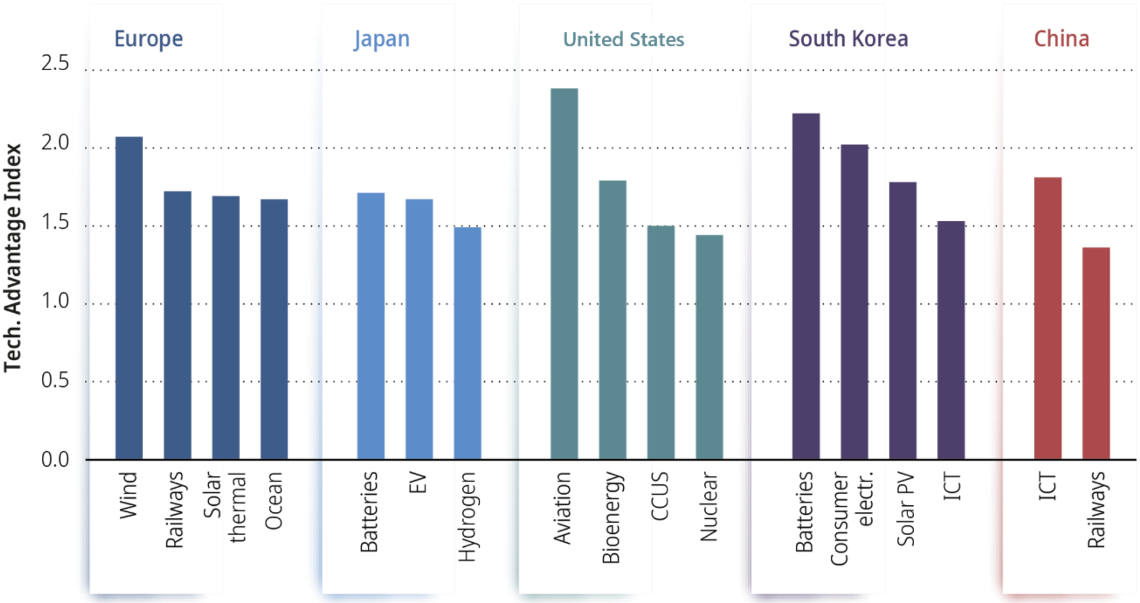
Source: Cleantech for Europe (forthcoming).

Need to diversify early-stage research and development to boost competitiveness

According to the recent joint publication by the IEA and the European Patent Office (IEA, 2021a), countries are specialising nationally in honing their competitive edge in specific technologies and collaborating internationally to foster regional technology advantages. In this respect, Europe ranks first in wind renewables and railways, two mature sectors, whereas sectors that are at an inflection point in their growth, such as batteries, hydrogen and carbon capture, are more developed in regions outside Europe. EU policies that support RD & D need to address a broader range of technologies that might currently stand at a low technology readiness level but have a high mitigation potential. This would enable Europe to remain competitive in ownership and control of the intellectual property necessary to enable the transition in sectors where mitigation alternatives to carbon abatement are limited.

([99]) The cleantech category in transport includes the following technologies: fuel cells, electric vehicle charging, ride sharing, micro-mobility, fleet management and route efficiency. Cleantech in energy includes wind power, solar power, geothermal, nuclear, energy storage, biofuels and hydrogen. Cleantech in agriculture includes precision agriculture, indoor farming, increasing crop yields, decreasing food waste, cultured meats and alternative proteins. Cleantech in industry includes biochemicals, process electrification, circular economy, recycling and innovative materials. Cleantech in buildings includes insulation, energy efficiency systems, heat pumps and waste heat reuse. Other cleantech activities also include satellite imagery, carbon offsetting, carbon accounting, weather forecasting and climate modelling.

Figure 87 Technology advantages of global innovation centres



Notes: The technology advantage index indicates a country's specialisation relative to its overall innovation capacity. It is defined as a country's share of international patent fillings in a particular filed of technology divided by the country's share in all fields. A value above one reflects a country's specialisation in a given technology.

Sources: Adapted from IEA (2021a, p. 18).

13.4 Summary table

Table 20 Policy consistency summary – Innovation

Policy gaps	– Public funding instruments can be slow in reacting to the changing needs of the fast-paced global clean technology arena. – There is a significant funding gap for projects aiming to complete the piloting stage and move towards the early deployment of clean technologies. – This funding gap is further widened by the lack of sufficient support from venture capital, as this concept remains less developed in Europe than in the United States – The Net-Zero Industry Act aims to partially address this, strengthening manufacturing capacity in key technologies, but it remains silent on innovation aspects. – Policy instruments on innovation treat private and public knowledge organisations separately, which hinders the opportunity to build stronger collaborations. – The Net-Zero Industry Act aims to increase the EU's manufacturing capacity in strategic technologies to reach at least 40 % of domestic needs; however, the existing reporting mechanisms offer limited means to track progress towards achieving this target.
Ambition gaps	– Policy instruments, such as the strategic energy technology plan, that aim to strengthen industry and research collaborations need to address behavioural barriers to innovation such as the fear of failure, emphasising the value of sharing the knowledge generated. – The existing EU funding architecture offers limited predictability beyond 2030, which increases uncertainty for long-term projects.
Implementation gaps	– While Horizon Europe and the Innovation fund aim to catalyse private investment in climate-related technologies, their administrative complexities hinder the crowding-in of private investments

14 Climate governance

Key messages

National energy and climate plans, LTSs and progress reports are pivotal to the delivery of the EU's climate policies. Their timeliness and quality can be further improved.

Needs. Achieving the EU's climate goals depends on the delivery mechanisms embedded in the Governance Regulation, notably the NECPs and LTSs. The NECPs are required to be in line with the LTSs. Long-term planning is fundamental to climate policies, as it helps to assess and manage the socioeconomic impacts of the transition. The NECPs are an important source of information regarding the ambition and progress of the EU Member States in achieving milestones on the path to net zero, such as reductions in fossil gas, phase-out of fossil fuel subsidies, sustainable sourcing of biomass and demand-side mitigation policies. Without timely and full implementation of the Governance Regulation, the EU risks underdelivering on its climate ambition, including its mitigation and reporting commitments under the Paris Agreement.

Gaps. Many of the NECPs are delayed and not all LTSs were submitted by January 2020, which indicates an **implementation gap** under the Governance Regulation. The 10-year frame of the NECPs seems too short to ensure policy consistency with 2050 objectives, and the connection between the NECPs and LTSs is based on weak consistency processes **(ambition gap)**. The quality of information on some of the key milestones on the EU's path to net zero included in the first NECPs submitted, and their updates so far, is insufficient to allow the European Commission to assess the consistency of national policies and measures with climate neutrality **(implementation gap)**.

Recommendation G1. The European Commission should rigorously enforce the Governance Regulation to ensure its full and timely implementation by all EU Member States. LTSs should become subject to EU-level reviews with country-specific recommendations, and lay the basis for the NECPs. The European Commission should encourage the Member States to include all relevant information in their updated NECPs and progress reports, notably the following: use of public funds to leverage private finance for climate-related projects (Chapter 12), fossil fuel phase-out plans (Chapter 4), demand mitigation measures (Chapter 7), projected biomass energy use and compliance with the LULUCF Regulation and sustainability and GHG criteria under the RED III (Chapter 4 and 9) and commitment to phase out fossil fuel subsidies (Chapter 12).

Rigorous enforcement of the Governance Regulation should go hand in hand with effective compliance mechanisms embedded in other parts of EU climate legislation. There is a concern that the compliance mechanisms in the ESR are currently too weak.

Needs. Beyond the Governance Regulation, the key role of Member States' compliance with the EU law in climate matters is an imperative highlighted in all chapters of this report. While some acts have more effective compliance mechanisms than others, there is a concern that such mechanisms under the ESR are particularly feeble. According to the European Commission's assessment, aggregated projections by Member States show that the planned measures would reduce EU-wide emissions covered by the ESR by 32 % in 2030 compared with 2005 levels, far short of the EU-wide target to reduce emissions in 2030 by 40 % compared with 2005 levels.

Gaps. The 5-year cycle of the ESR's formal compliance checks leads to a substantial time lag between detected non-compliance and automatic penalties and, if still needed, any enforcement action

(ambition gap). The first comprehensive review will take place in 2027, but academic contributions already warn against the looming compliance deficit and the resulting launch of a formal infringement procedure by the European Commission beyond 2032.

Recommendation G2. The EU should make the Member States' progress towards their respective binding targets set under the ESR more visible to the public and put in place stronger compliance mechanisms to ensure sufficient emission reductions in the non-ETS sectors.

Access to information and public participation at the EU level can be further improved for increased transparency, democratic legitimacy and public understanding of the net zero transition. The consistency and coherence of EU climate and competition policies should be improved.

Needs. Participation, transparency and good communication are essential to climate policy design and effective implementation with minimal public climate-related discontent. The Governance Regulation requires Member States to ensure that the public is given full access to information and effective opportunities to participate in the preparation of the NECPs and LTSs. The European Climate Law requires the European Commission to assess on any relevant draft policy or measure for consistency with climate neutrality, which reinforces the impact assessment requirement under the better regulation rulebook applicable to the European Commission. The EU and its Member States are Parties to the Aarhus Convention: the United Nations Economic European Commission for Europe Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters.

Gaps. Deficits in transparency and in public engagement are observed in NECP preparation at the national level **(implementation gap)**. Moreover, despite the impact assessment practice having improved significantly in 2022 thanks to the climate neutrality checks, far-reaching non-legislative acts establishing taxonomy criteria for sustainable investment and defining some renewable transport fuels have not been accompanied by appropriate impact assessments including public consultation and climate neutrality checks **(implementation gap)**. In addition, the EU is in breach of the Aarhus Convention in relation to access to justice in state aid matters and public engagement in the NECP process **(implementation gap)**.

Recommendation G3 The transparency and democratic legitimacy of climate policies should be strengthened by rigorous enforcement of the European Climate Law and the Governance Regulation. Relevant far-reaching acts should be systematically accompanied by impact assessments including public consultations and climate neutrality consistency assessments. This also applies to the upcoming non-legislative acts, namely delegated and implementing regulations supplementing the gas package legislation and the Methane Regulation (see also Chapter 4 'Energy supply'), as well as the legislative proposals under the CAP and the next MFF with their implementing acts. They should be transparent and follow the procedural steps embedded in the European Climate Law and the Better Regulation rulebook, without undue recourse to exceptional circumstances in which effective public consultations can be omitted. Access to information, and access to administrative and judicial procedures for members of the public to challenge decisions taken by the European Commission on State aid measures, should be improved to ensure the effective safeguarding of fundamental human rights, including the right to a high level of environmental protection.

Weak participatory governance at the local and national levels undermines coordination and societal trust in EU climate policies. This calls for better implementation of a permanent climate and energy dialogue in each EU Member State.

Needs. According to the IPCC, subnational actors are important for mitigation because municipalities and regional governments have jurisdiction over climate-relevant matters such as land use, waste and urban policy, and are able to experiment with climate solutions and forge partnerships to leverage enhanced climate action. Article 11 of the Governance Regulation mandates each Member State to establish a permanent multilevel climate and energy dialogue, in which local authorities, civil society organisations, the business community, investors, other relevant stakeholders and the public engage and discuss options for energy and climate policies in the context of the NECPs and LTSs. The needs for multilevel governance and coordinated action are increasingly apparent in the EU's sectoral policies, for example under the new obligations for the Member States to conduct heating and cooling assessments as part of the NECP process and for municipalities with over 45 000 inhabitants to prepare local heating and cooling plans. Article 3 of the European Climate Law invites EU Member States to establish national climate advisory bodies, responsible for providing expert scientific advice on climate policy to the relevant national authorities. Such advisory bodies at the national level can be tasked with (i) providing the relevant authorities with expert scientific advice on climate policy, (ii) monitoring policy and (iii) supporting the multilevel climate and energy dialogue.

Gaps. Recent analyses indicate that multilevel climate and energy dialogues in some Member States are of poor quality. The uncertainty over the quality of implementation of Article 11 of the governance regulation pertains to (i) the number of Member States with permanent multilevel dialogues, (ii) the involvement of all required stakeholder categories and (iii) the coverage of topics discussed. The Committee of the Regions points out that the dialogues are often not permanent and the NECPs are not always in tune with subnational climate policies **(implementation gap)**. The European Climate Law only encourages the Member States to establish national climate advisory bodies, without making such bodies mandatory and no link to such bodies is made in the procedural obligations of the NECPs, for example as part of the multilevel climate and energy dialogues **(ambition gap)**.

Recommendation G4. Building on the insight available through the EU multilevel cooperation initiatives, and taking into account the voices of the Committee of the Regions, civil society, local authorities, and scientists, the European Commission should strive to ensure stronger compliance with Article 11 of the Governance Regulation so that every Member State has a permanent multilevel climate and energy dialogue in place, allowing coordinated and informed climate action at the EU, regional, national and local levels. The Advisory Board recommends that all EU Member States that have not done so yet should establish independent climate advisory bodies. The upcoming revision of the Governance Regulation should enable a stronger connection to the European Climate Law in this respect.

14.1 Policy planning for target delivery

The EU climate governance can be improved and made fit for 2050 through the upcoming revisions of the European Climate Law and the Governance Regulation.

The **European Climate Law** sets the EU climate neutrality target by 2050 and provides an overall sense of the EU policy direction towards 2050 climate neutrality and the interim targets (ref). The corresponding policy delivery mechanisms are embedded in the **Governance Regulation**. While it is too early to assess EU climate governance effects in terms of delivering the 2030 and 2050 climate targets (Schoenefeld and Knodt, 2021), scientists and stakeholders are already warning that the EU's climate governance is not fit for the radical transformation ahead of the EU in view of its 2050 climate neutrality target (EC, 2023ai; Hancher, 2022; Kulovesi and Oberthür, 2020; Oberthür et al., 2023). The upcoming revisions of both acts can improve the EU's climate governance and make it fit for 2050.

The EU's net zero transition can be facilitated by the swift adoption of a science-led 2040 target.

Climate laws enable mitigation by, among other measures, setting targets and enhancing regulatory certainty (IPCC, 2022p). According to the European Climate Law (Article 4), the intermediate 2040 target is to be set based on a European Commission proposal made no later than June 2024. The Advisory Board issued its recommendations regarding the 2040 target (ESABCC, 2023c) in June 2023. The swift adoption of a science-led 2040 target is important to guide the EU's transition to climate neutrality through the post-2030 policy framework. The adoption of a 2040 target should open up the process of revising the existing legislation so that it is fit for after 2030, reflecting the linked revision clauses, for example under Article 15 of the ESR (EU, 2018c).

Target delivery relies on long-term planning and an EU-level overview of key milestones on the path to net zero.

The EU's climate governance is based on the mandatory planning, monitoring and reporting processes carried out by the EU Member States and the European Commission (Kulovesi and Oberthür, 2020). To deliver on the climate targets underpinned by the EU energy union strategy, which are binding on the EU, the Member States plan the climate policy measures and embed them into their NECPs and LTSs. Long-term climate strategies, including the impact assessments of their socioeconomic aspects (Annex IV of the Governance Regulation), can enable a whole-of-society approach (see Chapter 11) and contribute to the delivery of the climate ambition under the Paris Agreement (UNFCCC, 2023). These plans and strategies are submitted to the European Commission, which assesses if their respective contributions are, on aggregate, sufficient to deliver on the EU's ambition. Through progress reports, the EU Member States allow the European Commission to monitor and assess progress towards targets. In this sense, the European Commission is the guardian of the EU's collective ambition and progress, and is expected to take action should the achievement of the EU's climate targets be at risk (Oberthür, 2019). As part of this process, the European Commission reports the overall progress to the European Parliament and is responsible to it, in line with Article 18 of the Treaty on European Union, and Articles 233–234 of the Treaty on the Functioning of the European Union.

The first NECPs were submitted to the European Commission in 2020. By mid 2023, the EU Member States were to submit their updated versions and progress reports. Many of them are delayed, which is partly because of legal changes driven by the Fit for 55 package, and the resulting adjustments at the national level. Late submission of NECPs risk delaying their assessment and follow-up. The final NECPs are due in June 2024.

The EU cannot afford any further delay to climate action, and needs to provide **long-term policy signals** based on long-term plans for the net zero transition. In this respect, the 10-year time frame of the NECPs seems too short to ensure policy consistency with 2050 objectives. This gap can be bridged by stronger links between the NECPs and the LTSs, which have a 30-year span. Despite the requirement for NECPs to be in line with the LTSs under Article 15 of the Governance Regulation, such consistency may be meaningless in practice given the way the LTSs are developed in the first place. They are not subject to iterative dialogue between the Member States and the European Commission, as the NECPs are. The European Commission merely checks their collective ambition regarding achieving climate goals at the EU level. Moreover, the LTS update clause under Article 15 of the Governance Regulation relies on an arbitrary trigger (i.e. 'where necessary'), effectively weakening the relevance of the LTSs and their already feeble links to the NECPs. The LTSs therefore need a more prominent place in the EU's climate governance than they currently have. They need to be submitted by all EU Member States – which is already an obligation but is not fulfilled (EC, 2022af) – and become subject to EU-level reviews with country-specific recommendations so they can lay a robust foundation for the NECPs.

Finally, the NECP process is an important source of information regarding the progress and ambition of each EU Member State in achieving milestones on the path to net zero, such as targeted deployment of fossil gas, the phase-out of fossil fuel subsidies, sustainable deployment of bioenergy, and policies and measures in non-ETS sectors including demand-side mitigation policies. It is vital to learn from the first assessment of NECPs, when not all relevant information was included by all Member States; for example, only six Member States included a timeline to phase out some of the existing fossil fuel subsidies, and the NECPs lacked 'details on how to supply the required sustainable biomass, by feedstock and origin and trajectories for forest biomass, and how they are aligned with measures to maintain and increase the carbon sink' (EC, 2020q, p. 24). Moreover, in the assessment of NECP progress reports conducted in 2023, the European Commission observed that the reported information, notably pertaining to building stock decarbonisation and investment, was often incomplete and inconsistent and was thus not helpful for drawing EU-wide conclusions (EC, 2023j). As highlighted earlier in this report, the European Commission can encourage Member States to include the following information in their updated NECPs: fossil fuel phase-out plans, with a focus on the declining business case for fossil gas (Chapter 4); national ambitions regarding RES investments, to give investors a better overview, e.g. volumes of auctions measured against the required pace of progress (Chapter 4); building-related data and sufficiency measures (Chapter 7); compatibility aspects in terms of the projected use of forest biomass energy compared with the targets under the LULUCF Regulation and with sustainability and GHG criteria under the RED III (Chapters 4 and 9); finance and investment data and commitments to phase out fossil fuel subsidies (Chapter 12); and ways public participation and permanent multilevel engagement are facilitated (Section 14.3).

14.2 Compliance and enforcement

Enforcement of EU climate legislation is necessary in cases of non-compliance.

The European Commission examines the NECPs and progress reports, assessing both compliance with EU law and the effectiveness of national climate policies and measures (Higham et al., 2021). Should it identify a gap in ambition, policy or progress, the European Commission issues recommendations to the relevant Member State. It is for the Member State to decide on how to act on the recommended corrective course, and for the European Commission to take the necessary follow-up. If this iterative process does not lead to compliance, the European Commission may decide to initiate **infringement procedures** (Schlacke et al., 2022; Monti and Martinez Romera, 2020). It is therefore up to the European Commission to 'continue to ensure that all relevant legislation is rigorously enforced' in the context of the EU's climate governance (EC, 2019c). In this role the European Commission is supported by other EU institutions (such as the European Parliament) and bodies and by other stakeholders, enabled by transparent and participatory policy and governance. EU-level enforcement is a poor alternative to well-designed policy adoption and implementation, however. As pointed out by legal scholars and practitioners, the EU's infringement procedures are often cumbersome and too lengthy to offer timely remedies in climate-relevant non-compliance cases (Hancher, 2022; Monti and Martinez Romera, 2020; Oberthür et al., 2023). For instance, in September 2022 the European Commission took the first step of the official infringement procedure by sending letters of formal notice to the four Member States that had not submitted their LTSs by January 2020 in line with Article 15 of the Governance Regulation (EC, 2022af). Enforcement of EU law at the national level is outside the scope of this report.

Stronger public visibility of the Member States' progress towards their respective binding targets set under the ESR, combined with stronger compliance mechanisms, is needed to ensure sufficient emission reductions in the non-ETS sectors.

Beyond the Governance Regulation, Member States' compliance with the EU law in climate matters plays a key role. That is an imperative highlighted in all chapters of this report. While some acts have more effective compliance mechanisms than others, there is a concern that such mechanisms under the **ESR** ([100]) are particularly feeble. Meeting the binding emission reduction targets for the non-ETS sectors under the ESR relies on the implementation of sectoral policies (see e.g. Runge-Metzger and Van Ierland, 2019). EU policies in this area need to be complemented by ambitious climate action at the national and subnational levels. The ESR emission reduction targets are therefore the EU's main compliance tool to ensure sufficient reductions in the non-ETS sectors on the path to net zero.

The progress towards targets is checked through an annual assessment (Article 8 of the ESR). Should the reported progress, after taking account of the multiple flexibilities at the Member State's disposal, be deemed insufficient, the European Commission opens an iterative dialogue with the Member State that may lead to a corrective action. The annual cycles have limited public visibility, however, compared with similar processes such as the European Semester.

In addition to the annual progress reporting and the dialogue, every 5 years (in 2027 for 2021–2025, and in 2032 for 2026–2030, as set out in Article 9 of the ESR) the European Commission conducts compliance checks, with automatic penalties in the form of emission budget adjustments and transfer prohibitions applicable in the event of excess GHG emissions (ref). Since no direct monetary sanctions are laid down and there is no price estimate in terms of EUR/tonne of CO_2eq in bilateral transfers, Member States have limited visibility of the costs of not achieving their national reduction objectives. This lack of direct financial incentive is exacerbated by a substantial time lag between a detected case of non-compliance and any potential enforcement actions. As a result, the final determination of non-compliance leading to a formal infringement procedure may only start in 2032, and, considering the long lead times of administrative and judicial procedures, any resulting remedy would not be effective in terms of timely emission reductions.

Although the first compliance check will only start in 2027, academic contributions already warn against the looming compliance deficit and the resulting necessity of enforcement action (see e.g. Peeters and Athanasiadou, 2020). This concern grows when the problem is considered together with the EU Climate Action Progress Report (EC, 2023j), in which the European Commission indicates that Member States' aggregated projections show that EU-wide ESR emissions would reduce by 32 % in 2030 compared with 2005 levels, including planned measures, which is 8 pp below the EU-wide target set for 2030 in the ESR.

([100]) The ESR aims to reduce GHG emissions in sectors outside the EU ETS (about 60 % of total GHG emissions) by 40 % by 2030 compared with 2005. This overall objective is translated into legally binding national targets, which are differentiated based on Member States' GDPs per capita, ranging from – 10 % to – 50 %. Each Member State is assigned annual emission allocations based on a linear trajectory towards its target. Member States have to ensure that their annual emissions in relevant sectors do not exceed these annual allocations. They can use a range of flexibility mechanisms to achieve compliance in a cost-effective way, including banking, borrowing and trading of allocations and limited flexibilities with the EU ETS and the LULUCF sector.

14.3 Assessments, public participation, and multilevel dialogue

Democratic legitimacy enabled by public participation, transparency and access to justice are essential to effective climate policies. Climate neutrality consistency checks required under the European Climate Law are key in this respect and should be further mainstreamed.

Participation, transparency and good communication are essential to climate policy design and effective implementation with minimal climate-related public discontent (IPCC., 2022p). Public engagement improves the democratic legitimacy and wider understanding of EU climate policies (see for example ESABCC, 2023; IMF, 2023). Article 10 of the Governance Regulation requires the EU Member States to engage the public in the preparation of the NECPs and LTSs. Article 9 of the European Climate Law requires the European Commission to 'facilitate an inclusive and accessible process at all levels … for the exchange of best practice and to identify actions to contribute to the achievement of the objectives of' the European Climate Law. In line with Article 6 of the European Climate Law, the European Commission 'shall assess the consistency of any draft measure or legislative proposal, including budgetary proposals, with the climate-neutrality objective … and the [EU] 2030 and 2040 climate targets before adoption' (EU, 2021c). Climate neutrality consistency checks and public consultation feed into impact assessment and are 'required for [European] Commission initiatives that are likely to have significant economic, environmental or social impacts or which entail significant spending, and where the [European] Commission has a choice of policy options' (EC, 2021e).

Impact assessments including public and stakeholder consultations are required under the EU policymaking rules known as 'better regulation', developed on the basis of the interinstitutional agreement between the European Parliament, the Council and the European Commission on better lawmaking adopted in 2016 (EP et al., 2016). It is very positive that the European Commission has updated its better regulation instruments to ensure that new EU policies are consistent with climate targets, and applies these climate neutrality checks on new proposals since 2022. This practice has not been applied to proposals submitted before 2022 (e.g. as part of the impact assessment to the EU Taxonomy Climate Delegated Act) and should be further mainstreamed. Many EU delegated acts of binding and general application (Hancher, 2022) are highly relevant to EU's net zero transition. Supposed to supplement or amend certain *non-essential* elements of the legislated acts, they are not systematically accompanied by impact assessments, however. The omission to conduct an impact assessment may be justified in exceptional circumstances set out in the better regulation toolbox (EC, 2021a). It is not always clear, however, whether the omission to conduct a fully-fledged impact assessment and climate neutrality checks was indeed justified as in the cases of e.g. in the delegated act defining what constitutes renewable hydrogen in transport fuels (EC, 2023h). Moreover, the lack of the dedicated, formal impact assessments goes beyond the delegated acts; e.g. the European Commission evoked previous impact assessments and public consultations under the 2030 climate target plan, the revision of the EU ETS Directive, and other relevant initiatives under the European Green Deal to justify that the social climate plan regulation proposal was not accompanied by a dedicated impact assessment (EC, 2021ad). The need to include systematic assessment of distributional and socioeconomic impacts of draft climate policies and measures has been highlighted in chapter 11 Section 11.2.

In parallel, transparency and public engagement deficits have been observed in the NECP preparation at the national level (European Commission, 2023a). These deficits impact also the EU-level part of the NECP process, in particular the draft NECP assessment by the European Commission, which has been found in breach of the Aarhus Convention (ECE, 2021). As a follow-up, the European Commission has provided a guidance to the EU Member States (EC, 2022c) for the update of NECPs, and sent a remedial action plan to the Aarhus Convention Compliance Committee in 2022 (ref). While it is not certain yet how the guidance has led to reducing the transparency and public engagement deficits in the ongoing

NECP cycle, the civil society have raised concerns regarding this matter in April 2023 (Civil society organisations, 2023).

In this context, the transparency and democratic legitimacy of the EU and national climate policies could be strengthened by a rigorous and timely enforcement of climate neutrality consistency assessments and public consultation clauses in the European Climate Law and the Governance Regulation. Relevant far-reaching acts should be systematically accompanied by formal, dedicated impact assessments. In particular, the upcoming non-legislative acts i.e. delegated and implementing regulations supplementing the gas package legislation and the Methane Regulation (see Chapter 4 'Energy supply'), as well as the legislative proposals under the CAP and the next MFF with their implementing acts, need to be transparent and follow the procedural steps embedded in the European Climate Law and the Better Regulation rulebook, without undue recourse to exceptional circumstances in which full impact assessments can be omitted.

While impact assessments are an important *ex ante* insight into the proposed measures, they need to go hand in hand with *ex post* evaluations and fitness checks in line with better regulation guidelines and toolbox (EC, 2021a), as highlighted also in Section 11.2.

Finally, democratic legitimacy of climate policy depends also on effective **access to justice** in climate matters. Not only can climate litigation affect the outcome and ambition of the overall climate governance (IPCC, 2022p), but also courts in democratic jurisdictions 'possess strong claims to democratic legitimacy in the climate litigation cases as a result of their institutional capacity to weigh intergenerational harms and responsibly assess scientific claims.' (Kuh, 2020). While an analysis of the role of climate litigation in the EU climate policies is out of scope of this report, the Advisory Board flags its concern regarding access to justice in EU State aid control matters. The exclusive competence of the European Commission in State aid control has considerably expanded over time (Schneider, 2023). The European Commission's regulations, communications, and decisions in this area are not subject to the same level of legal guarantees as applicable to other areas of EU law (Council of the EU, 2015). This weakness is particularly acute in the context of the streamlined State aid rules under the crises-induced temporary framework approval which led to significant spending in energy and industry sectors. The scale of State aid indicates its potentially far-reaching consequences for EU's net zero transition (see also Section 12.5). Nevertheless, challenging the European Commission's decisions to approve state financial assistance before the Court of Justice of the EU is difficult for citizens and non-governmental organisations due to, among other impediments, such as timely access to information and high admissibility threshold of the claims, notably restricted to parties 'individually and directly concerned by the decision' (ClientEarth, 2023; Delarue and Bechtel, 2021; Hancher and Maria Salerno, 2021b; Winter, 2020). Due to the legal and procedural obstacles linked to state-aid, the EU was found in breach of the Aarhus Convention in 2021 (ACCC, 2021). The European Commission is in search of the solution to ensure full compliance of its State aid regime with the Aarhus Convention (EC, 2023t). Future policy development in this area is an opportunity to increase transparency and public engagement in EU policies with a view of achieving the climate neutrality objective by increasing consistency and coherence of EU climate and competition policies.

Permanent multilevel dialogue can help to coordinate climate policies development and implementation. Coordinated development of the local heating and cooling plans required under the EED is urgently needed to avoid further carbon lock-ins and attenuate impact of price increases triggered by the EU emission trading policies. The national climate advisory bodies can act as convenors supporting the multilevel dialogue on national climate policy.

According to the IPCC, 'sub-national actors are important for mitigation because municipalities and regional governments have jurisdiction over climate-relevant sectors such as land use, waste and urban policy; are able to experiment with climate solutions; and can forge partnerships with the private sector and internationally to leverage enhanced climate action'. (...) Sub-national institutions play a complementary role to national institutions by developing locally-relevant visions and plans, addressing policy gaps or limits in national institutions, building local administrative structures and convening actors for place-based decarbonisation' (IPCC, 2022p). Multilevel stakeholder involvement and decentralisation of decision-making ('the closest to the citizens the better') are all part of adaptive and fair climate transition frameworks (Willis et al., 2022; Anadón et al., 2022). Moreover, community approaches and other types of 'bottom-up approach driven by citizen engagement' (IPCC, 2022b) have significant benefits in terms of delivering climate justice and driving behavioural and societal transformation (IPCC, 2022f).

While many climate policies are decided at the EU level and implemented by the Member States, the Governance Regulation highlights the need for coordinated action, combining both legislative and non-legislative acts at the EU, regional, national and local levels. Under its article 11 it mandates each Member State to establish a permanent ([101]) 'multilevel climate and energy dialogue pursuant to national rules, in which local authorities, civil society organisations, business community, investors and other relevant stakeholders and the general public are able actively to engage and discuss the different scenarios envisaged for energy and climate policies, including for the long term, and review progress, (...)' discussing the NECPS and the LTS. The needs for multilevel governance are increasingly apparent in the EU sectoral policies, notably under the EED obligation for the Member States to conduct heating and cooling assessment as part of the NECP process and for municipalities with over 45 000 inhabitants prepare local heating and cooling plans (EU, 2023e). EU cities networks call for national- and EU-level adjustments to ensure adequate technical and financial resourcing of local authorities to develop such plans transparently and independently so that they deliver for net zero in coordination with other parts of the energy systems (EnergyCities, 2022), in line with art. 25 of the EED (EU, 2023e).

There is a concern however regarding poor quality of the multilevel climate and energy dialogues in some Member States (CoR, 2023b) and significant uncertainty over the quality of art. 11 of the Governance Regulation implementation based on the reporting under the NECP process (NECPlatform, 2023). The European Commission's assessment of the first round of the NECPs focused on a regional cooperation in the context of multilevel dialogues, although specified that, in an unprecedented process, 'several' Member States organised local, regional, sectoral workshops to discuss the content of their final NECP with stakeholders (EC, 2020i). The uncertainty surrounding the updates to the NECPs pertains to the number of Member States enabling such exchanges on a permanent basis, the involvement of all required stakeholder categories, and the coverage of topics discussed (NECPlatform, 2023). The weakness pointed out by the Committee of the Regions also links to the permanent nature of the dialogues and the limited integration of NECPs with subnational climate policies (CoR, 2023a).

([101]) The permanence of multilevel climate and energy dialogues is mentioned in the preamble, but not in the art. 11 of the governance regulation.

The EU supports permanent multilevel climate and energy dialogues through funding under the LIFE programme (EC, 2021x). Moreover, the EU policies foster broader multilevel governance and bottom-up action for net zero transition through initiatives such as the Covenant of Mayors for climate and energy (EC, 2023w) and the urban agenda for the EU (EC, 2021ak). The European Commission launched also the European Climate Pact and supports the Energy Communities Repository (EC, 2023x) and the Rural Energy Community Advisory Hub (EC, 2023bc).

Moreover, multilevel climate and energy dialogues can be supported by national **climate advisory bodies.** As set out in the European Climate law, such bodies can play an important role in convening stakeholders and providing expert scientific advice on climate policy to the relevant authorities (Evans and Duwe, 2021). They can also monitor relevant policy developments (EEA, 2021b). Despite being encouraged to do so, not all the Member States have established an independent climate advisory body so far.

14.4 Summary table

Table 21 Policy consistency summary – climate governance

Ambition gaps	– The 10-year frame of the NECPs seems too short to ensure policy consistency with 2050 objectives, and the connection between the NECPs and LTS is based on weak consistency processes. – The five-year cycle of the ESR formal compliance checks leads to a substantial time lag between a detected non-compliance and automatic penalties, and if still need be, any potential enforcement action. The first comprehensive review will take place in 2027; but academic contributions warn already against the looming compliance deficit and the resulting launch of a formal infringement procedure by the European Commission beyond 2032. – The European Climate Law only encourages the Member States to establish national climate advisory bodies, without making them mandatory and no link to such bodies is made in the NECP procedural obligations e.g., as part of the multilevel climate and energy dialogues.
Implementation gaps	– Many of the NECPs are delayed and not all LTS were submitted. – The quality of information on some of the key milestones on the EU's path to net zero included in first submitted NECPs, their updates and progress reports, is insufficient to allow the European Commission to assess consistency of national policies and measures with climate neutrality. – Transparency and public engagement deficits are observed in the NECP preparation at a national level. – The EU is in the breach of Aarhus Convention in relation to access to justice in state aid matters and public engagement in NECP process. – Moreover, despite the impact assessment practice having improved significantly in 2022 thanks the climate neutrality checks, far-reaching non-legislative acts establishing taxonomy criteria for sustainable investment and defining some renewable transport fuels have not been accompanied by appropriate impact assessments including public consultation and climate neutrality checks. – Recent analyses indicate poor quality of multilevel climate and energy dialogues in some Member States. The uncertainty over the quality of art. 11 of the Governance Regulation implementation pertains to: (i) the number of Member States with permanent multilevel dialogue, (ii) the involvement of all required stakeholder categories and (iii) the coverage of topics discussed. The Committee of the Regions points out to the weakness in terms of the permanent nature of the dialogues and the limited integration of NECPs with subnational climate policies.

15 Labour, skills and capacity building

Key messages

The transition to net zero will require a profound shift in the structure of the labour force. Ambitious sectoral targets will create new employment opportunities in many sectors, although skills shortages are already acute in the European economy and will deepen if not addressed by tailored policy measures to train and upskill the workforce.

Needs. The transition to net zero will require a profound shift in the European labour market: new jobs will be created in some sectors, while existing jobs will require new types of skills and competencies. Labour shortages are already acute across Europe and may worsen without additional supply, particularly in the energy systems and construction sectors; while upskilling, certification, and cross-cutting digital and interpersonal skills will be required across the workforce. Policy development and climate investments will create additional demands on the skills and capacity of public administration, while a transition to sustainable farming practices also requires the provision of appropriate support, advice and training to farm managers.

Gaps. The EU has put in place programmes and funding to address skills shortages in priority sectors, and to improve skills and capacity in public administration; while the Farm Advisory System exists to provide training and advice to farm managers. Although design and implementation of education and training schemes is largely the responsibility of member states, there are some remaining policy gaps at a European level, particularly regarding workforce mobility and mutual recognition of qualifications in the construction sector **(policy gap)**. Low participation in training in some key sectors (e.g. buildings, agriculture) also limits the opportunities to upskill and enhance knowledge exchange relevant to the transition **(implementation gap)**.

Recommendation S1. Investments in education, training and skills should be targeted to upskilling and improved mobility in the construction, renewable energy systems sectors; as well as cross-cutting skills like digitalisation and interpersonal skills. The EU should also support – for example, through the Technical Support Instrument and other funding schemes – skills and capacity-building projects aimed at enhancing the ability of public administrations to implement climate policies and investments. Further efforts are needed to ensure that the national Farm Advisory Systems provide appropriate support, advice and training to farm managers regarding sustainable farming practices and mitigation measures; as well as to increase awareness and uptake of training opportunities among farmers.

Training and reskilling are important to support and provide opportunities to those who may be negatively affected by the transition, such as coal and fossil gas workers. While the EU provides support under the Just Transition Fund, doubts remain over whether the design and ambition of this mechanism fully reflect the scale of transition in some regions and sectors.

Needs. In parallel, well-funded and -tailored employment and reskilling programmes are needed for workers in fossil fuel sectors that may be negatively impacted by the transition; to minimise distributional and regional impacts, and to ensure that the employment opportunities presented by the transition remain open to all.

Gaps. The EU has put in place a Just Transition Fund to support regions and occupations whose workforce will be negatively impacted by the transition; however, experience of previous reskilling initiatives suggests that issues around the eligibility criteria, funding and limited systemic measurement of outcomes has limited their impact **(ambition & implementation gap).** Transition schemes for workers in the fossil gas sector are also largely still absent at the EU level **(policy gap)**.

Recommendation S2. Further efforts are required to address weaknesses identified in the design and implementation of just transition programmes: particularly in ensuring that eligibility criteria and funding are targeted towards those workers and regions at greatest risk; to improve measurement of impacts and outcomes; and to increase participation in training by affected groups.

15.1 Workforce and skill needs in the net zero economy

The EU's transition to net zero will require a workforce with both the capacity and skills to deliver on targets across a range of sectors, including in construction/buildings, energy systems and agriculture. European climate policies to date have already created growth in sectors associated with the transition like renewable energy systems, and although research generally suggests that aggregate employment levels in the European economy are not likely to increase significantly under the Fit for 55 targets, there will be a profound shift in the structure of the labour force between sectors, occupations, required skillsets and regions (EC, 2022ai; Borgonovi et al., 2023).

For sectors linked to the net zero transition, workers will be required in a range of operational, manufacturing, installation, engineering and research roles (Eurostat, 2023f). Employment in wind energy is expected to grow from 300 000 in 2022 to 450 000 in 2030 (WindEurope, 2022). Direct employment in solar is also expected to increase from 200 000 in 2021, to almost 460 000 by 2030 under REPowerEU's target of 750GW (SolarPower Europe, 2022b), while the battery sector requires approximately 800 000 workers to be retrained or upskilled by 2025 (EC, 2023ah). More technicians and craftspeople will be needed to renovate millions of buildings to zero-emission standard (D'Agostino et al., 2021b; EASAC, 2021b), with an estimated 4 million construction workers needing to develop energy efficiency-related skills according to European Construction Sector Observatory (2020) ([102]).

The European Commission lists skills shortages among the key barriers to the EU's net zero transition, notably the locally-available labour force and its skills, including digital literacy (EC, 2022m, 2022ah). The EU already faces a shortage of skilled workers in the construction sector, which is expected to worsen 'as a consequence of green transition'. In addition, demand and supply for renewable energy technicians (including those with software skills) is imbalanced across the EU (ELA, 2023). For instance, up to 30 % of companies in offshore renewables reported experiencing skills shortages in 2020, primarily in research, engineering and technician roles (EC, 2020c). The uniqueness of net zero transition jobs may make them difficult to fill at first due to the small size of the dedicated occupational labour market (ELA, 2023; IPCC, 2022g). It will also be important that EU employment policy measures remain adaptive and anticipate market needs, e.g. in terms of innovation and circular use of materials given that recycling, remanufacturing and reuse offer greater employment opportunities than landfilling or incineration (IRENA, 2022a).

([102]) As much as 60 % of expenditure on home energy efficiency retrofits could go towards labour creating 12–18 jobs per million euro of investment, more than in other areas of energy policy (IEA, 2020). For instance, according to JRC, if 'renovation rate increased to 3 % within 10 years and maintained thereafter (...) the associated impact on employment would be approximately 55 millions of full-time equivalent job places' (JRC, 2020a). Moreover as highlighted in the Renovation Wave strategy decarbonisation of buildings requires also public administration to develop the necessary skills in the area (EC, 2020h)

Beyond specific occupations, there is also a need for cross-cutting skills to drive and manage the adoption of new technologies, with a particular emphasis on improved digital and interpersonal skills. For instance, public engagement is increasingly important for energy and engineering workers during the planning and permitting processes for RES developments, while construction workers play a more active role in advising consumers and encouraging them to make more sustainable choices (e.g. the choice of a heat pump vs. a fossil heating system). Improving the advisory, communication, and digital skills of the existing workforce can therefore be an important enabler for wider societal change (Borgonovi et al., 2023; EGFSN, 2021).

15.2 Construction and energy systems workers

The EU has put in place several programmes to address the skills shortages in the construction and energy systems sectors, and the ambition of the Green Deal industrial plan in addressing the skills gap is promising in this respect. Further investments in upskilling, improved workforce mobility and mutual recognition of qualifications between Member States can help to address skills shortages in these sectors.

In July 2023 there have been 13 EU funding instruments for upskilling and reskilling (EC, 2023aa), notably the European skills agenda (EC, 2020o), the Just Transition programme, the REPowerEU plan (EC, 2022m) with its sectoral strategies (e.g. EU Solar PV Industry Alliance under the EU (EC, 2022o)), the RRF, the Just Transition Fund, the InvestEU programme, BUILD UP skills initiative, the European Social Fund Plus (EC, 2023ad) and Erasmus+. The European Year of Skills 2023 also aimed to address skills shortages with an ambition to 'give a fresh impetus to lifelong learning, empowering people and companies to contribute to the green and digital transitions, supporting innovation and competitiveness' (EC, 2023ae).

The European skills agenda supports large-scale skills partnerships in strategic sectors under the Pact for Skills. Launched in 2020, the Pact for Skills is a shared engagement model for companies, workers, national, public authorities, social partners, cross-industry and sectoral organisations, education and training providers, chambers of commerce and employment services. The European skills agenda is complemented by the European Education Area (Council of the European Union, 2021) including the digital education action plan (EC, 2020m). 'Enhancing skills' is also one of the four pillars in the European Commission's Green Deal industrial plan, which contains several proposals to address skills shortages and improve workforce mobility in strategic industries (EC, 2023u).

The revised EPBD (EC, 2021ac), in line with the renovation wave strategy (EC, 2020h), also addresses workforce skills in the context of decarbonising the buildings sector. It requires Member States to put in place measures and financing to promote education and training to ensure 'a sufficient workforce with the appropriate level of skills corresponding to the needs in the building sector' (EC, 2021ac). Moreover, reskilling and up-skilling of workers, education, job-seeking initiatives are explicitly mentioned among funding areas for the Member States to use the revenues from emission trading under the revised EU ETS Directive (EU, 2023c). The 2023 Net-Zero Industry Act proposal sets out workforce-related measures for net zero technologies (EC, 2023ao).

While it is still too early to assess the impact of these initiatives, there are barriers to increasing participation in upskilling and training among construction workers, including the time and mode of training, the predominance of small and medium-sized enterprises with low training budgets in the sector, and low consumer demand (ECSO, 2020). In the construction sector roundtable organised as part of the Pact for Skills in 2020, participating stakeholders indicated that 'high mobility of the construction workforce can help address local skills shortages' (EC, 2020q); yet they pointed out that mobility is hindered by the lack of mutual recognition of qualifications amongst EU Member States, due to differences in training systems and legislation. As a way forward the stakeholders suggested 'a uniform assessment of workers and an automatic recognition of qualifications on a voluntary basis' (EC, 2020q). Currently the EU directive on the recognition of professional qualifications (EU, 2005) does not explicitly target construction workers, as they depend on national policy. Further EU support to Member States for reinforcing qualification recognition and facilitating the mobility of professionals in the construction and related sectors could help to address the skilled workforce gap (European Construction Sector Observatory, 2018).

As part of the REPowerEU chapters in recovery and resilience plans, EU Member States can include 'an accelerated requalification of the workforce towards green and related digital skills' (EU, 2023i). Moreover, building capacity of local authorities to streamline permitting for renewable energy projects is one of the RRF flagships providing technical support to the EU Member States (EC, 2022ak). The RED III aims at facilitating mutual recognition of installer skills, identifying skilled workforce shortages, and creating a database of trained certified installers of renewable technologies and demand response and storage systems (EU, 2023f). The database is expected to help increase public trust in such interventions. The REPowerEU plan (EC, 2022m) dedicates special attention to skills for the hydrogen economy, announcing a launch of a large project in this area supported by EU funding streams. There are positive signals under the EU action plan on digitalising the energy system (EC, 2022k), that incites the Member States to use the funds through available EU programmes to support upskilling and reskilling of the workforce for the digitalisation of the energy value chain, including through university-level upskilling programmes and partnerships.

15.3 Fossil fuel workers and just transition

Training and reskilling is also important to support and provide opportunities to those who may be negatively affected by the transition, such as coal and other fossil gas workers. While the EU provides support under the Just Transition Fund, doubts remain over whether the design and ambition of this mechanism fully reflect the scale of transition in some regions and sectors.

Employment increases and skills shortages in these sectors contrasts with declining employment in sectors negatively impacted by the transition, particularly the coal sector. Based on industry data between 2010 and 2018, coal jobs in the EU decreased by 32 % from 239 400 to 161 930 (JRC, 2021d), and employment in the 'mining of coal and lignite' sector is projected to fall by a further 89 % under the Fit for 55 targets. Such jobs, including coal mining, are estimated to cover around 5 % of employment in the EU (EC, 2022aj). While employment growth in other sectors could provide job opportunities for coal or other fossil fuel workers, there are substantial challenges that must be overcome to ensure that these workers can avail of these opportunities. These include a relative dissimilarity between existing job profiles and those required in other sectors, low participation in education/training schemes, and spatial mismatches between where jobs are gained and lost (Borgonovi et al., 2023). These challenges in the coal sector are compounded by more general trends, where the shift to renewable energy is associated with declining demand for manual workers and greater demand for technical and professional workers (Marin and Vona, 2019).

In line with the principles of a just transition, efforts to phase out fossil fuels must be accompanied by investments in workers and communities that are likely to experience a contraction in labour demand or significant structural change. However, the geographic concentration of the coal sector often requires a broader focus: since renewable jobs are often outside of coal regions, a straightforward reskilling and reemployment of coal workers in renewable energy sector may not be possible, and a just transition may also require support for broader economic and regional development (IPCC, 2022g). Therefore, the effectiveness of these investments depends on strong social dialogue processes and coordination between government, economic actors and civil society; necessary not only from an equity perspective and to ensure that appropriate support is provided to communities, but also to maintain wider public support for the transition (Anadón et al., 2022; ILO, 2015; IPCC, 2022g).

At the EU level, the Just Transition Fund (EU, 2021b) provides retraining opportunities to workers who bear the costs of the structural transformation (Marin and Vona, 2019), particularly coal, shale and peat workers. However, the ECA has found that EU support to coal regions to date has had a limited focus and impact on job creation, and observed lower levels of participation in training initiatives among affected workers than initially targeted. They also highlighted weaknesses in data collection and impact measurement, which made it difficult to assess the impact of investments (ECA, 2022a). These challenges also reflect some of the issues discussed in Chapter 11 (Whole of Society Approach) and Chapter 14 (Climate Governance), particularly the lack of systematic assessments of the socioeconomic impacts of EU climate policies and weaknesses in participatory decision-making. For example, an evaluation of the Just Transition Fund, taking into account lessons learned from its predecessor Initiative for Coal Regions in Transition, found remaining weaknesses in its current design and targeting. In particular, the study highlighted the eligibility criteria for potential Just Transition Fund projects and stakeholders, the restrictive nature of which was found to be 'inadequate for determining the worst-off' in the transition; insufficient and volatile funding; and differences in administrative capacity between regions as limiting factors of the current Just Transition Fund (Moesker and Pesch, 2022). As a result, there are doubts about whether the design and ambition of these initiatives match the scale of the transition required.

Transition schemes for workers in the fossil gas sector are also largely still absent at the EU level. The gas industry, along with public service and trade unions, have recently called to create 'momentum that ensures a Just Transition for gas workers across Europe' (Eurogas et al., 2023). The EU should address the declining fossil gas activities and any resulting employment impacts (Cedefop, 2023) in an open and proactive fashion (in line with the findings and recommendations regarding gas in chapter 4), and aim to create upskilling and reskilling opportunities for high-quality jobs in non-fossil fuel (and preferably even energy transition) activities.

15.4 Public administration

Effective and efficient public administration is crucial for the implementation of climate policies. This rapid policy development can place additional demands on member states' public administrations, while skills and capacity shortages also constrain public climate investments.

Effective and efficient public administration is an enabler of the transition to a climate-neutral society, and the policies discussed throughout this report will place significant demands on public administration at the local, national and European levels: from energy and infrastructure permitting (Chapter 4 'Energy supply') and spatial planning policies (Section 7.5 under 'Enabling condition: urban and spatial planning'); to public investment, procurement (Chapter 12) and climate governance (Chapter 14). Increased funding for climate-related investments will also create additional demands on the public sector to plan and deliver projects, meaning that capacity or skills shortages can constrain the effectiveness of these investments. These challenges have already been highlighted in relation to local government: for example, 69 % of municipalities in the EIB's 2022 Municipalities Survey reported skills shortages to be a barrier to their investments in climate mitigation and adaptation infrastructure, with particular shortages highlighted in relation to environmental and climate assessment, engineering, legal and digital skills (EIB, 2023c). The European Commission has identified a need for 'a multidisciplinary approach to policymaking, strong coordination and planning capacities across all levels of public administration' (EC, 2023o), while other studies have highlighted skills shortages in the planning systems and legal systems as barriers to implementing climate investments and policies (EGFSN, 2021).

The EU provides direct support to some Member States for capacity building and skills in public administration under the cohesion policy, and more widely via the Technical Support Instrument (TSI), which responds to requests from member states with tailored advice and technical support for climate and other reform policies. Member states can also request funding for public sector skills and digitalisation projects under various funding streams, including the RRF, Horizon Europe and the Digital Europe Programme (EC, 2021aj). The European Commission's recent communication on 'Enhancing the European Administrative Space' (ComPAct) also aims to support member states in enhancing capacity in public administration, and contains a pillar dedicated to supporting public administration in delivering on climate policies (e.g. provision of technical support and guidance, disseminating best practices, exchange and peer-learning opportunities for administrators) (EC, 2023o), although the impact of these proposals has yet to be assessed.

15.5 Agriculture

Although the CAP 2023–2027 contains more ambitious targets for training and knowledge exchange among farm managers than its predecessor, available insight so far shows that more effort is needed to increase interest in and uptake of these initiatives. With greater emphasis on sustainability, the Farm Advisory System can support farm managers in the transition to net zero.

The transition to more sustainable farming systems and the implementation of mitigation practices (see Chapter 8 'Agriculture') will require investment in skills, training and innovation for farmers and agricultural workers. Agriculture remains a large employer within the EU, with 8.7 million people working directly in agricultural production in 2020 (Eurostat, 2022b), although employment in agriculture has been falling since 2005. The agricultural workforce's unique demographic and socioeconomic characteristics presents additional challenges in the sector's resilience and ability to adapt to the transition. The agricultural workforce is older than sectors, with just 11 % of farm managers under the age of 40 in 2020. There is also a significant gender imbalance, and only 32 % of farm managers in 2020 were women (27 % of farmers under the age of 30) (EC, 2023bj). Finally, just 32 % of farm managers in 2016 have received agricultural training (9 % with full agricultural training), although this percentage represents an increase over the previous decade (EC, 2020n).

As one of its objectives, the 2023–2027 CAP recognises that *'s*upport for knowledge exchange, training, advice and innovation is key for securing smart and sustainable agriculture, forestry and rural areas', and the current CAP builds on the instruments established in the 2014–2020 period, particularly the requirement for Member States to put in place Farm Advisory Systems to provide hands-on advice and training on a range of financial, technical and environmental topics. The CAP continues to promote the agricultural European Innovation Partnerships (EIP-AGRI), supplemented by funding from Horizon Europe. This supports collaborations between farmers, foresters, scientists and rural businesses aimed at developing and testing innovative solutions to socioeconomic and environmental challenges, including the development/adoption of sustainable farming practices and agri-environment schemes. The European CAP Network has been established alongside these as a forum to disseminate research, examples of best practice and lessons learned from EIP-AGRI projects across Europe. The European Commission's review of Member States' CAP strategic plans for 2023–2027 highlighted and welcomed member states' ambition for fostering the agricultural knowledge and innovation systems: 6 million targeted participants in different knowledge and training initiatives over the period (up from the previous target of 2.9 million), as well as a threefold increase in agricultural European Innovation Partnerships to 6 600 (EC, 2023b). Within the wider sector, the Pact for Skills partnership for the agri-food industry was launched in 2022 to address skills challenges in the wider agri-food sector. These challenges include global value chain disruptions, increasing competition, climate change, urbanisation, changing consumer demands, and generational renewal (EC, 2022ah).

However, the European Commission's evaluation of the previous CAP programme highlights several challenges that may continue into the current implementation period. Due to slow implementation of the previous programme, just 23 % of the amount planned for knowledge exchange and training measures in the previous plan was spent by 2020, while only 1.22 million farmers (42 % of the 2020 target) ultimately availed of these initiatives. Interest in training was reportedly low among farmers, with the time and opportunity cost of participation identified as a major barrier to uptake, along with poor awareness or promotion of available initiatives. In particular, the evaluation highlighted very limited engagement by "hard-to-reach" farmers with these initiatives, a category which often includes the types of smaller and less-profitable farms that are least resilient in the transition to net zero (EC, 2022e). Other authors have similarly identified long working hours among European farmers as a barrier to their participation in training, as well as to their willingness to adopt new farming practices or additional mitigation measures (Murphy, 2022).

While the European Commission's review of CAP strategic plans for 2023–2027 (EC, 2023b) welcomes the emphasis from member states on practical and interactive knowledge exchange mechanisms (e.g. on-farm demonstrations, peer-to-peer learning, EIP-AGRI projects etc.), it expressed 'doubts on whether the overall level of support planned by Member States is in line with the increased ambition on knowledge sharing and innovation'. Upskilling in the sector, particularly in relation to climate resilience and adaptation, will require a more concerted effort to reach and engage farmers, particularly those "hard-to-reach" farmers who have not traditionally engaged with education and training systems before. As identified by the European Commission's evaluation of the previous programme, there also needs to be increased training of farm advisors themselves, particularly with regard to climate adaption and mitigation practices required in the transition to net zero.

15.6 Summary table

Table 22 Policy consistency summary – labour, skills and capacity building

Policy gaps	– Implementation of education and training schemes is mainly a national competence, although some policy gaps remain at a European level, particularly with regard to workforce mobility and mutual recognition of qualifications in the construction sector – Transition schemes for workers in the fossil gas sector are largely still absent at the EU level.
Ambition gaps	– The EU has put in place a Just Transition Fund to support regions and occupations whose workforce will be negatively impacted by the transition; however, experience of previous reskilling initiatives suggests that issues with eligibility criteria, funding and limited systemic measurement of outcomes can limit their impact.
Implementation gaps	– Low participation in education/training schemes in some sectors (e.g. buildings, fossil fuel regions, agriculture) also limits the opportunities to develop skills and enhance knowledge exchange relevant to the transition

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Abbreviations

8th EAP	8th Environment Action Programme
ACER	European Union Agency for Cooperation of Energy Regulators
Advisory Board	the European Scientific Advisory Board as established under the European Climate Law
AR6	6th Assessment Report of the IPCC
BECCS	bioenergy with carbon capture and storage
BEV	battery electric vehicle
BNEF	Bloomberg New Energy Finance
CAP	common agricultural policy
CBAM	Carbon Border Adjustment Mechanism
CCfD	carbon contract for difference
CCS	carbon capture and storage
CCU	carbon capture and utilisation
CCU/CCS	carbon capture and utilisation/storage
CDR	carbon dioxide removals
CEAP 1	The circular economy action plan of 2015
CEAP 2	The circular economy action plan of 2020
CH_4	methane
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
COP26	26th Conference of the Parties under the UNFCCC
CRF	common reporting format used for the GHG inventories reported to the UNFCCC
CSP	CAP Strategic Plan
DACCS	direct air carbon capture and storage
DSO	distribution system operator
EASAC	European Academies Science Advisory Council
ECA	European Court of Auditors
ECB	European Central Bank
EEA	European Environment Agency
EED	Energy Efficiency Directive
EIB	European Investment Bank
EIP-AGRI	agricultural European Innovation Partnerships
EPBD	Energy Performance of Buildings Directive
EPC	energy performance certificate
ESG	environmental, social and governance
ESR	Effort Sharing Regulation
ETD	Energy Taxation Directive
EU	European Union
EU ETS	EU Emissions Trading System
EU ETS 1	The EU ETS for stationary installations (chapter III of Directive 2003/87/EC)
EU ETS 2	The EU ETS for buildings, road transport and additional sectors (chapter IVa of Directive 2003/87/EC)
FAOSTAT	Corporate Statistical Database of the UN FAO
F-gas	fluorinated gas

GAEC	good agricultural environmental condition
GDP	gross domestic product
GHG	greenhouse gas
Gpkm	billion passenger-kilometres
Gtkm	billion tonne-kilometres
GW	Gigawatt
HDV	heavy-duty vehicle
ICEV	internal combustion engine vehicle
IEA	International Energy Agency
ILUC	Indirect Land Use Change
IPCC	Intergovernmental Panel on Climate Change
IWW	inland waterways
JRC	Joint Research Centre
kWh	kilowatt-hour
LIFE	L'instrument Financier pour l'Environnement
LTS	long-term strategy
LULUCF	land use, land use change and forestry
MFF	Multiannual Financial Framework
MSR	Market Stability Reserve
Mtoe	million tonnes of oil equivalent
N_2O	nitrous oxide
NAI	net annual increment, which represents the gross forest growth minus natural mortality
NECP	national energy and climate plan (see Governance Regulation (EU) 2018/1999)
OECD	Organisation for Economic Co-operation and Development
PCI	project of common interest
PHEV	plug-in hybrid electric vehicle
pp	percentage points
PV	photovoltaics
R & D	research and development
RD & D	research, development and deployment
RED II	the revised Renewable Energy Directive of 2018 (Directive 2018/2001/EU)
RED III	the revised Renewable Energy Directive of 2023 (Directive EU/2023/2413)
RES	renewable energy sources
RRF	Recovery and Resilience Facility
SAPEA	Science Advice for Policy by European Academies
TEN-E	Trans-European Networks for Energy
TEN-T	Trans-European networks for transport
TSC	technical screening criteria (under the EU Taxonomy)
TWh	terawatt hours
TYNDP	10-year network development plan
UN FAO	United Nations Food and Agriculture Organisation
UNFCCC	United Nations Framework Convention on Climate Change
VAT	value added tax
yr	year
ZEV	zero-emission vehicle

Bibliography

Abrell, J., et al., 2022, Optimale Zuteilung des CO2-Budgets der EU: Eine Multi-Modell-Bewertung, Kopernikus Projekt Ariadne (https://ariadneprojekt.de/media/2022/06/Ariadne-Analyse_CO2-Budget-Multi-Modell-Bewertung_Juni2022.pdf).

ACCC, 2021, Case ACCC/C/2015/128 European Union, (https://unece.org/env/pp/cc/accc.c.2015.128_european-union).

Accenture, 2022, From Disruption to Reinvention – The future of supply chains in Europe (https://www.accenture.com/us-en/insights/strategy/ukraine-future-supply-chains-europe).

ACEA, 2023, 'New car registrations: +17.2% in April, battery electric 11.8% market share' (https://www.acea.auto/pc-registrations/new-car-registrations-17-2-in-april-battery-electric-11-8-market-share/#:~:text=Despite%20a%204.3%25%20growth%20in,year%20to%207.4%25%20in%202023.) accessed 19 June 2023.

ACER, 2022a, Future Regulatory Decisions on Natural Gas Networks: Repurposing, Decommissioning and Reinvestments, No ACER/OP/DO/13/2017/LOT 2/RFS 05, Agency for the Cooperation of Energy Regulators (https://www.acer.europa.eu/Media/News/Documents/Future%20Regulation%20of%20Natural%20Gas%20Networks%20-%20Final%20Report%20DNV.pdf).

ACER, 2022b, Security of EU electricity supply in 2021: Report on Member States approaches to assess and ensure adequacy, European Union Agency for the Cooperation of Energy Regulators (https://acer.europa.eu/Publications/ACER_Security_of_EU_Electricity_Supply_2021.pdf).

ACER, 2023a, DECISION No 04/2023 OF THE EUROPEAN UNION AGENCY FOR THE COOPERATION OF ENERGY REGULATORS of 27 February 2023 on the European Resource Adequacy Assessment for 2022, (https://www.acer.europa.eu/Individual%20Decisions/ACER_Decision_04-2023_ERAA_2022.pdf).

ACER, 2023b, Report on Investment Evaluation, Risk Assessment and Regulatory Incentives for Energy Network Projects, European Union Agency for the Cooperation of Energy Regulators (https://acer.europa.eu/Publications/ACER_Report_Risks_Incentives.pdf).

ACER and CEER, 2022, Annual Report on the Results of Monitoring the Internal Electricity and Natural Gas Markets in 2021 Energy Retail and Consumer Protection Volume, European Union Agency for the Cooperation of Energy Regulators and the Council of European Energy Regulators (https://www.acer.europa.eu/Publications/MMR_2021_Energy_Retail_Consumer_Protection_Volume.pdf).

ADEME, et al., 2023, 'Odyssee-Mure' (https://www.odyssee-mure.eu/).

Agora Energiewende, 2023, 'Der CO2-Preis für Gebäude und Verkehr. Ein Konzept für den Übergang vom nationalen zum EU-Emissionshandel' (https://www.agora-energiewende.de/fileadmin/Projekte/2023/2023-26_DE_BEH_ETS_II/A-EW_311_BEH_ETS_II_WEB.pdf).

Akbari, H., et al., 2016, 'Local climate change and urban heat island mitigation techniques – The state of the art', Journal of Civil Engineering and Management 22(1), pp. 1-16 (DOI: 10.3846/13923730.2015.1111934).

Ali, U., et al., 2020, 'A data-driven approach to optimize urban scale energy retrofit decisions for residential buildings', Applied Energy 267, p. 114861 (DOI: 10.1016/j.apenergy.2020.114861).

Anadón, L. D., et al., 2017, 'Integrating uncertainty into public energy research and development decisions', Nature Energy 2(5), p. 17071 (DOI: 10.1038/nenergy.2017.71).

Anadón, L. D., et al., 2022, Ten Principles for Policy Making in the Energy Transition, Cambridge, UK (https://eeist.co.uk/eeist-reports/ten-principles-for-policy-making-in-the-energy-transition/).

Andersson, J. J., 2019, 'Carbon Taxes and CO2 Emissions: Sweden as a Case Study', American Economic Journal: Economic Policy 11(4), pp. 1-30 (DOI: 10.1257/pol.20170144).

Andor, M. A. and Fels, K. M., 2018, 'Behavioral Economics and Energy Conservation – A Systematic Review of Non-price Interventions and Their Causal Effects', Ecological Economics 148, pp. 178-210 (DOI: 10.1016/j.ecolecon.2018.01.018).

Association négaWatt, 2022, 'The material impacts of an energy transition based on sufficiency, efficiency, and renewables', (https://www.negawatt.org/IMG/pdf/220608_ecee_the-material-impacts-of-an-energy-transition-based-on-sufficiency-efficiency-and-renewables.pdf).

Augusto, L. and Boča, A., 2022, 'Tree functional traits, forest biomass, and tree species diversity interact with site properties to drive forest soil carbon', Nature Communications 13(1), p. 1097 (DOI: 10.1038/s41467-022-28748-0).

Axelsson, K., et al., 2023, Green Public Procurement: a lever for mitigating European greenhouse gas emissions, Stockholm Environment Institute https://doi.org/10.51414/sei2023.013

Baccianti, C., 2023, 'EU Climate Funding Tracker', Agora, (https://www.agora-energiewende.org/data-tools/eu-climate-funding-tracker) accessed 25 June 2023.

Bakkaloglu, S., et al., 2022, 'Methane emissions along biomethane and biogas supply chains are underestimated', One Earth 5(6), pp. 724-736 (DOI: 10.1016/j.oneear.2022.05.012).

Baldino, C. and Searle, S., 2021, Changes to the Renewable Energy Directive revision and ReFuel EU proposals: Greenhouse gas savings and costs in 2030, ICCT Briefing, International Council on Clean Transportation (Changes to the Renewable Energy Directive revision and ReFuel EU proposals: Greenhouse gas savings and costs in 2030).

Barbosa, R. and Skipka, S., 2019, 'Tax housing or land? : distributional effects of property taxation in Germany', Tax housing or land? : distributional effects of property taxation in Germany. Working Paper, CESifo Working Paper, 2019/8039.

Barkhausen, R., et al., 2022, 'Review and Analysis of Ecodesign Directive Implementing Measures: Product Regulations Shifting from Energy Efficiency towards a Circular Economy', Sustainability 14(16), p. 10318 (DOI: 10.3390/su141610318).

Barnes, J., et al., 2022, 'Energy communities as demand-side innovators? Assessing the potential of European cases to reduce demand and foster flexibility', Energy Research & Social Science 93, p. 102848 (DOI: 10.1016/j.erss.2022.102848).

Basma, H. and Rodriguez, F., 2021, 'Alternative fuels infrastructure in Europe: electric trucks and buses can't wait another decade' (https://theicct.org/alternative-fuels-infrastructure-in-europe-electric-trucks-and-buses-cant-wait-another-decade/) accessed 4 July 2023.

Becker, B., 2015, 'Public R&D Policies and Private R&D Investment: A Survey of the Empirical Evidence', Journal of Economic Surveys 29(5), pp. 917-942 (DOI: 10.1111/joes.12074).

Berndes, G., et al., 2016, Forest biomass, carbon neutrality and climate change mitigation, From Science to Policy, European Forest Institute https://doi.org/10.36333/fs03

Berndes, G., et al., 2022, The use of forest biomass for climate change mitigation: dispelling some misconceptions, IEA Bioenergy (https://www.ieabioenergy.com/wp-content/uploads/2020/08/The-use-of-biomass-for-climate-change-mitigation-dispelling-some-misconceptions-August-2020-Rev1.pdf).

Bernstein, M. J., et al., 2022, 'The Societal Readiness Thinking Tool: A Practical Resource for Maturing the Societal Readiness of Research Projects', Science and Engineering Ethics 28(1), p. 6 (DOI: 10.1007/s11948-021-00360-3).

Berrill, P., et al., 2021, 'Linking Housing Policy, Housing Typology, and Residential Energy Demand in the United States', Environmental Science & Technology 55(4), pp. 2224-2233 (DOI: 10.1021/acs.est.0c05696).

Bertoldi, P., et al., 2021, 'How to finance energy renovation of residential buildings: Review of current and emerging financing instruments in the EU', WIREs Energy and Environment 10(1) (DOI: 10.1002/wene.384).

Bertoldi, P., 2022, 'Policies for energy conservation and sufficiency: Review of existing policies and recommendations for new and effective policies in OECD countries', Energy and Buildings 264, p. 112075 (DOI: 10.1016/j.enbuild.2022.112075).

Bhardwaj, S. and Mostofi, H., 2022, 'Technical and Business Aspects of Battery Electric Trucks—A Systematic Review', Future Transportation 2(2), pp. 382-401 (DOI: 10.3390/futuretransp2020021).

Bibri, S. E., et al., 2020, 'Compact city planning and development: Emerging practices and strategies for achieving the goals of sustainability', Developments in the Built Environment 4, p. 100021 (DOI: 10.1016/j.dibe.2020.100021).

Birdlife Europe and EEB, 2022, Peatlands and wetlands in the new CAP: too little action to protect and restore, Policy briefing (https://www.birdlife.org/wp-content/uploads/2022/04/Analysis-Peatlands-Wetlands-CAP-strategic-plans-April2022.pdf).

Blattert, C., et al., 2023, 'Climate targets in European timber-producing countries conflict with goals on forest ecosystem services and biodiversity', Communications Earth & Environment 4(1), p. 119 (DOI: 10.1038/s43247-023-00771-z).

Bloomberg, 2023, 'Green bonds boom in first half of 2023 | Insights', Bloomberg Professional Services, 27 July 2023 (https://www.bloomberg.com/professional/blog/green-bonds-boom-in-first-half-of-2023/) accessed 24 November 2023.

BNEF, 2022, 'New Energy Outlook' (https://bnef.turtl.co/story/neo-2022/page/1?teaser=yes) accessed 12 June 2023.

BNEF, 2023, 'Energy Transition Investment Trends 2023', BNEF (https://about.bnef.com/energy-transition-investment/).

Boehm, S. et al., 2023, 'State of climate action 2023', Berlin and Cologne, Germany, San Franciso, CA and Washington, DC: Bezos Earth Fund, Climate Action Tracker, Climate Analytics, ClimateWorks Foundation, NewClimate Institute, the United Nations Climate Change High-Level Champios, and Worls Resources Institute (https://doi.org/10.46830/irpt.23.00010.)

Bolscher, H., et al., 2019, High Level Report: CCUS in Europe, CCUS Projects Network (https://ccuszen.eu/sites/default/files/HLR%20_CCUS-in-Europe.pdf).

Borgonovi, F., et al., 2023, The effects of the EU Fit for 55 package on labour markets and the demand for skills, OECD Social, Employment and Migration Working Papers No 297 https://dx.doi.org/10.1787/6c16baac-en.

BPIE, 2017, BUILDING RENOVATION PASSPORTS: CONSUMER'S JOURNEY TO A BETTER HOME, (https://bpie.eu/wp-content/uploads/2017/09/Factsheet_D-170918_Final-2.pdf), Buildings Performance Institute Europe.

BPIE, 2023, Conceptualising iBRoad2EPC: Can Energy Performance Certificates be upgraded to include Building Renovation Passport elements?, Building Performance Institute Europe (https://www.bpie.eu/publication/conceptualising-ibroad2epc-can-epcs-be-upgraded-to-include-building-renovation-passport-elements/).

Brack, D., 2017, Woody biomass for Power and Heat. Impact on the global climate, Research Paper, Chatham House (https://www.chathamhouse.org/2017/02/woody-biomass-power-and-heat).

Brandl, P., et al., 2021, 'Beyond 90% capture: Possible, but at what cost?', International Journal of Greenhouse Gas Control 105, p. 103239 (DOI: 10.1016/j.ijggc.2020.103239).

Bremmer, J., et al., 2021, Impact assessment of EC 2030 Green Deal targets for sustainable crop production, Wageningen Economic Research. Report 2021-150. https://doi.org/10.18174/558517 .

Bruegel, 2020, 'A trillion reasons to scrutinise the Green Deal Investment Plan', (https://www.bruegel.org/blog-post/trillion-reasons-scrutinise-green-deal-investment-plan) accessed 21 November 2023

Bruegel, 2023, 'Fiscal rule legislative proposal: what has changed, what has not, what is unclear?', Bruegel | The Brussels-based economic think tank (https://www.bruegel.org/analysis/fiscal-rule-legislative-proposal-what-has-changed-what-has-not-what-unclear) accessed 21 November 2023.

Bruninx, K. and Ovaere, M., 2022, 'COVID-19, Green Deal and recovery plan permanently change emissions and prices in EU ETS Phase IV', Nature Communications 13(1), p. 1165 (DOI: 10.1038/s41467-022-28398-2).

Buchholz, W., et al., eds., 2020, Ancillary benefits of climate policy: new theoretical developments and empirical findings, Springer, Cham, Switzerland.

Buck, H. J., et al., 2023, 'Countries' long-term climate strategies fail to define residual emissions', Nature Climate Change 13(4), pp. 317-319 (DOI: 10.1038/s41558-023-01614-7).

Buratti-Donham, J., et al., 2023, 'Transforming food systems towards agroecology – a critical analysis of agroforestry and mixed farming policy in 19 European countries', Agroecology and Sustainable Food Systems 47(7), pp. 1023-1051 (DOI: 10.1080/21683565.2023.2215175).

Büscher, M., et al., 2023, 'Making Response-Ability: Societal Readiness Assessment for Sustainability Governance', Sustainability 15(6), p. 5140 (DOI: 10.3390/su15065140).

Butt, A. A., et al., 2021, 'Investigating the energy saving potential of thermochromic coatings on building envelopes', Applied Energy 291, p. 116788 (DOI: 10.1016/j.apenergy.2021.116788).

Campos, I., et al., 2020, 'Regulatory challenges and opportunities for collective renewable energy prosumers in the EU', Energy Policy 138, p. 111212 (DOI: 10.1016/j.enpol.2019.111212).

Cedefop, 2023, Skills in transitions: the way to 2035., European Centre for the Development of Vocational Training., LU (https://data.europa.eu/doi/10.2801/438491).

CEFIC, 'Low-carbon technologies projects' (https://cefic.org/low-carbon-projects-map/) accessed 27 July 2023.

Cembureau, 2023, Activity report 2022 (https://www.cembureau.eu/media/m3jcyfre/cembureau-activity-report-2022-light.pdf).

Charlin, V., et al., 2022, 'ESG ratings: an industry in need of a major overhaul', Journal of Sustainable Finance & Investment 0(0), pp. 1-19 (DOI: 10.1080/20430795.2022.2113358).

Chiappinelli, O., et al., 2021, 'A green COVID-19 recovery of the EU basic materials sector: identifying potentials, barriers and policy solutions', Climate Policy 21(10), pp. 1328-1346 (DOI: 10.1080/14693062.2021.1922340).

Christensen, A., 2021, Transportation Carbon Intensity Targets for the European Union - Road and Aviation sectors., Report for the International Council on Clean Transport (https://theicct.org/wp-content/uploads/2021/12/GAMS-EU-fuels-modeling-consultant-report-Aug2021.pdf).

CINEA, 2021, 'Connecting Europe Facility 2021-2027 adopted', European Climate, Infrastructure and Environment Executive Agency, 20 July 2021, Brussels (https://cinea.ec.europa.eu/news-events/news/connecting-europe-facility-2021-2027-adopted-2021-07-20_en) accessed 10 January 2024.

CINEA, EC, 2023, Innovation Fund (INNOVFUND) Call for proposals Innovation Fund call for Large-Scale Projects (INNOVFUND-2022-LSC), (https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/innovfund/wp-call/2022/call-fiche_innovfund-2022-lsc_en.pdf).

Citizens' Observatory for Green Deal Financing, 2023, No recovery without citizens. Why public involvment is key to Europe's green transformation. (https://counter-balance.org/uploads/files/2023_06_20_No-recovery-without-citizens_why-public-involvement-is-key-to-Europes-green-transformation.pdf).

Civil society organisations, 2023, Public Participation in Climate Policies; NECP revision process, (https://caneurope.org/content/uploads/2023/04/CSO-Letter-Public-Participation-NECPs.pdf).

Claeys, G. and et al., 2023, The rising cost of European Union borrowing and what to do about it, No Policy Brief 12/2023, Bruegel (https://www.bruegel.org/sites/default/files/2023-06/PB%2012%202023.pdf).

Clausing, K. A., et al., 2023, How an international agreement on methane emissions can pave the way for enhanced global cooperation on climate change, (https://www.piie.com/sites/default/files/2023-06/pb23-7.pdf), Peterson Institute for International Economics.

Cleantech for Europe, 'EU Cleantech Annual Briefing 2022' (https://www.cleantechforeurope.com/publications/cleantech-annual-briefing-2022) accessed 16 November 2023.

ClientEarth, 2023, Access to justice in State aid matters in EU Member States Where do NGOs stand? (https://www.clientearth.org/media/x4javzkp/clientearth-study-access-to-justice-in-state-aid-matters-in-eu-member-states-where-do-ngos-stand.pdf).

Cludius, J., et al., 2020, 'Ex-post investigation of cost pass-through in the EU ETS - an analysis for six industry sectors', Energy Economics 91, p. 104883 (DOI: 10.1016/j.eneco.2020.104883).

Copernicus and ECMWF, 2023, 'Global carbon dioxide and methane monitoring' (https://atmosphere.copernicus.eu/ghg-services).

CoR, 2023a, Local and regional authorities in the governance of the energy union, European Committee of the Regions, Commission for the Environment, Climate Change and Energy, (https://cor.europa.eu/en/engage/studies/Documents/Local%20and%20regional%20authorities%20in%20the%20governance%20of%20the%20energy%20union/LRAs%20in%20energy%20governance_draft%20study%20with%20cover.pdf).

CoR, 2023b, Towards a multilevel Green Deal governance: the revision of the Governance of the Energy Union and Climate Action Regulation - draft opinion, Opinion Number CDR 903/2023, European Committee of the Regions.

Council and Parliament of the EU, 2023a, 'Farm Sustainability Data Network: Council and Parliament reach provisional political agreement' (https://www.consilium.europa.eu/en/press/press-releases/2023/06/29/farm-sustainability-data-network-council-and-parliament-reach-provisional-political-agreement/) accessed 30 November 2023.

Council and Parliament of the EU, 2023b, 'Industrial emissions: Council and Parliament agree on new rules to reduce harmful emissions from industry and improve public access to information' (https://www.consilium.europa.eu/en/press/press-releases/2023/11/29/industrial-emissions-council-and-parliament-agree-on-new-rules-to-reduce-harmful-emissions-from-industry-and-improve-public-access-to-information/) accessed 3 December 2023.

Council and Parliament of the EU, 2023c, Press release: Council and Parliament strike deal on energy efficiency directive (https://www.consilium.europa.eu/en/press/press-releases/2023/03/10/council-and-parliament-strike-deal-on-energy-efficiency-directive/) accessed 15 May 2023.

Council of the EU, 2015, Council Regulation (EU) 2015/1589 of 13 July 2015 laying down detailed rules for the application of Article 108 of the Treaty on the Functioning of the European Union (codification) (OJ L 248, 24.9.2015, pp. 9–29).

Council of the EU, 2023a, Climate action: Council and Parliament reach deal on new rules to cut methane emissions in the energy sector, (https://www.consilium.europa.eu/en/press/press-releases/2023/11/15/climate-action-council-and-parliament-reach-deal-on-new-rules-to-cut-methane-emissions-in-the-energy-sector/#:~:text=The%20regulation%20introduces%20new%20requirements,and%20limiting%20venting%20and%20flaring.).

Council of the EU, 2023b, Council formally adopts 15% gas demand reduction target, Council of the European Union (https://www.consilium.europa.eu/en/press/press-releases/2023/03/30/council-formally-adopts-15-gas-demand-reduction-target/).

Council of the European Union, 2021, Council Resolution on a strategic framework for European cooperation in education and training towards the European Education Area and beyond (2021-2030), (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021G0226(01)).

Cremins, A. and Kevany, L., 2018, 'An introduction to the implementation of Green Budgeting in Ireland', Staff Paper, Irish Government Economic & Evaluation Service.

Creutzig, F., et al., 2022, 'Demand-side solutions to climate change mitigation consistent with high levels of well-being', Nature Climate Change 12(1), pp. 36-46 (DOI: 10.1038/s41558-021-01219-y).

CRS, 2022, Inflation Reduction Act Methane Emissions Charge: In Brief, Congressional Research Service (https://crsreports.congress.gov/product/pdf/R/R47206#:~:text=The%20IRA%20methane%20charge%20applies,including%20methane%2C%20to%20EPA's%20GHGRP.).

D'Agostino, D., et al., 2021a, 'Assessing Nearly Zero Energy Buildings (NZEBs) development in Europe', Energy Strategy Reviews 36, p. 100680 (DOI: 10.1016/j.esr.2021.100680).

D'Agostino, D., et al., 2021b, 'Assessing Nearly Zero Energy Buildings (NZEBs) development in Europe', Energy Strategy Reviews 36, p. 100680 (DOI: 10.1016/j.esr.2021.100680).

Darvas, Z. and Wolff, G. B., 2023, 'A Green Fiscal Pact for the EU: increasing climate investments while consolidating budgets', Climate Policy 23(4), pp. 409-417 (DOI: 10.1080/14693062.2022.2147893).

De Beule, F., et al., 2022, 'The pollution haven effect and investment leakage: The case of the EU-ETS', Economics Letters 215, p. 110536 (DOI: 10.1016/j.econlet.2022.110536).

De Oliveira Garcia, W., et al., 2018, 'Increasing biomass demand enlarges negative forest nutrient budget areas in wood export regions', Scientific Reports 8(1), p. 5280 (DOI: 10.1038/s41598-018-22728-5).

De Vos, B., et al., 2015, 'Benchmark values for forest soil carbon stocks in Europe: Results from a large scale forest soil survey', Geoderma 251-252, pp. 33-46 (DOI: 10.1016/j.geoderma.2015.03.008).

Delarue, J. and Bechtel, S. D., 2021, 'Access to justice in State aid: how recent legal developments are opening ways to challenge Commission State aid decisions that may breach EU environmental law', ERA Forum 22(2), pp. 253-268 (DOI: 10.1007/s12027-021-00665-7).

Delbeke, J. and Vis, P., 2019, Towards a Climate-Neutral Europe: Curbing the Trend, Routledge, London.

Devine-Wright, P., ed., 2015, Renewable energy and the public: from NIMBY to participation, Routledge, London.

Di Paolo, L., et al., 2022, 'Carbon Footprint of Single-Use Plastic Items and Their Substitution', Sustainability 14(24), p. 16563 (DOI: 10.3390/su142416563).

DIW, 2021, Reform der Immobilienbesteuerung: Bodenwerte belasten und Privilegien streichen. DIW Wochenbericht 27 / 2021, S. 463-470, (https://www.diw.de/de/diw_01.c.821131.de/publikationen/wochenberichte/2021_27_3/reform_der_immobilienbesteuerung__bodenwerte_belasten_und_privilegien_streichen.html), DIW Wochenbericht.

Dolphin, G., et al., 2023, 'A net-zero target compels a backward induction approach to climate policy', Nature Climate Change 13(10), pp. 1033-1041 (DOI: 10.1038/s41558-023-01798-y).

Dunlop, T., 2019, 'Mind the gap: A social sciences review of energy efficiency', Energy Research & Social Science 56, p. 101216 (DOI: 10.1016/j.erss.2019.05.026).

Dunlop, T. and Völker, T., 2023, 'The politics of measurement and the case of energy efficiency policy in the European Union', Energy Research & Social Science 96, p. 102918 (DOI: 10.1016/j.erss.2022.102918).

Duranton, G. and Puga, D., 2020, 'The Economics of Urban Density', Journal of Economic Perspectives 34(3), pp. 3-26 (DOI: 10.1257/jep.34.3.3).

EASAC, 2017, Multi-functionality and sustainability in European Union's forests, EASAC Policy Report No 32, European Academies Science Advisory Council, Halle (Saale), Germany (https://easac.eu/fileadmin/PDF_s/reports_statements/Forests/EASAC_Forests_web_complete.pdf).

EASAC, ed., 2021a, Decarbonisation of buildings: for climate, health and jobs, EASAC Secretariat, Deutsche Akademie der Naturforscher Leopoldina - German National Academy of Sciences, Halle (Saale).

EASAC, ed., 2021b, Decarbonisation of buildings: for climate, health and jobs, EASAC Secretariat, Deutsche Akademie der Naturforscher Leopoldina - German National Academy of Sciences, Halle (Saale).

EASAC, 2023, The Future of Gas, No 46, European Academies' Science Advisory Council (https://easac.eu/fileadmin/user_upload/EASAC_Future_of_Gas_Web.pdf).

EC, 2011, White Paper - Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system (COM(2011) 144 final).

EC, 2014, Horizon 2020 - work programme 2014-2015. General Annexes. G. Technology readiness levels (TRL), Extract from Commission Decision C(2014)4995 (https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf)

EC, 2015a, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions — Closing the loop — an EU action plan for the circular economy (COM(2015) 614 final).

EC, 2015b, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank — a Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy COM/2015/080 final, (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2015:80:FIN).

EC, 2016a, Commission Recommendation (EU) 2016/1318 of 29 July 2016 on guidelines for the promotion of nearly zero-energy buildings and best practices to ensure that, by 2020, all new buildings are nearly zero-energy buildings C/2016/4392 (OJ L 208, 2.8.2016, p. 46–57).

EC, 2016b, 'Supporting climate action through the EU budget — European Commission', European Commission (https://ec.europa.eu/clima/policies/budget/mainstreaming_en) accessed 18 September 2023.

EC, 2017, 'European Battery Alliance' (https://single-market-economy.ec.europa.eu/industry/strategy/industrial-alliances/european-battery-alliance_en) accessed 26 June 2023.

EC, 2018a, Annex 2 to the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committe of the Regions. Europe on the move: Sustainable Mobility for Europe: safe, connected and clean (COM(2018) 293 final).

EC, 2018b, 'Commission legislative proposals on sustainable finance: Proposal for a regulation on disclosures relating to sustainable investments and sustainability risks and amending Directive (EU) 2016/2341', European Commission - European Commission (https://ec.europa.eu/info/publications/180524-proposal-sustainable-finance_en) accessed 11 March 2020.

EC, 2018c, Communication from the Commission to the European Parliament; the European Council, the Council, the European Central Bank, the European Economic and Social Committee and the Committee of the Regions. Action Plan: financing sustainable growth (COM(2018) 097 final).

EC, 2018d, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank 'A clean planet for all: a European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy' (COM(2018) 773 final).

EC, 2018e, In-depth analysis in support of the Commission Communication COM(2018) 773: a clean planet for all — a European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy (https://knowledge4policy.ec.europa.eu/publication/depth-analysis-support-com2018-773-clean-planet-all-european-strategic-long-term-vision_en).

EC, 2019a, Commission Delegated Decision (EU) 2019/1597 of 3 May 2019 supplementing Directive 2008/98/EC f the European Parliament and of the Council as regards a common methodology and minimum quality requirements for the uniform measurement of levels of food waste ((EU) 2019/1597).

EC, 2019b, Commission staff working document: evaluation of the Council directive 2003/96/EC of 27 October 2003 restructuring the Community framework for the taxation of energy products and electricity, No SWD(2019) 329 (https://taxation-customs.ec.europa.eu/news/commission-report-evaluation-energy-taxation-directive-2019-09-12_en).

EC, 2019c, Communication from the Commission. The European Green Deal (COM/2019/640 final).

EC, 2019d, 'The European Commission, European Investment Bank and Breakthrough Energy Ventures establish a new €100 million fund to support clean energy investments', 29 May 2019, Brussels (https://ec.europa.eu/commission/presscorner/detail/fr/IP_19_2770).

EC, 2019e 'Adoption of the Delegated Decision on the carbon leakage list for 2021-2030' (https://climate.ec.europa.eu/news-your-voice/news/adoption-delegated-decision-carbon-leakage-list-2021-2030-2019-02-15_en) accessed 22 November 2023a.

EC, 2020a, Commission Staff Working Document — impact assessment accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions — stepping up Europe's 2030 climate ambitions — investing in a climate neutral future for the benefit of our people (SWD(2020) 176 final — Part 1/2).

EC, 2020b, Commission Staff Working Document Impact Assessment accompanying the document Proposal for a Regulation of the European Parliament and of the Council on guidelines for trans-European energy infrastructure and repealing Regulation (EU) No 347/2013 SWD(2020) 346 final, (https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12382-Trans-European-energy-infrastructure-revision-of-guidelines_en).

EC, 2020c, Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions — A hydrogen strategy for a climate-neutral Europe (COM(2020) 301 final).

EC, 2020d, Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions — An EU strategy to harness the potential of offshore renewable energy for a climate neutral future (COM(2020) 741 final).

EC, 2020e, Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions 'EU Biodiversity Strategy for 2030. Bringing nature back into our lives' (COM(2020)380 final, Brussels, 20.5.2020).

EC, 2020f, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Region 'A farm to fork strategy for a fair, healthy and environmentally friendly food system' (COM(2020) 381 final).

EC, 2020g, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A new Circular Economy Action Plan. For a cleaner and more competitive Europe (COM(2020) 98 final).

EC, 2020h, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions — A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives (COM/2020/662 final), (https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1603122220757&uri=CELEX:52020DC0662), European Commission.

EC, 2020i, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions — an EU-wide assessment of National Energy and Climate Plans Driving forward the green transition and promoting economic recovery through integrated energy and climate planning, COM/2020/564 final, (https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1600339518571&uri=COM%3A2020%3A564%3AFIN).

EC, 2020j, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions — Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability COM/2020/474 final, (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0474).

EC, 2020k, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions 'Sustainable and smart mobility strategy — putting European transport on track for the future' (COM(2020) 789 final).

EC, 2020l, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions 'Powering a climate-neutral economy: An EU Strategy for Energy System Integration (COM(2020) 299 final).

EC, 2020m, 'Digital Education Action Plan (2021-2027)' (https://education.ec.europa.eu/focus-topics/digital-education/action-plan).

EC, 2020n, EU Agriculture in Numbers - Performance on the nine specific objectives of the CAP, Factsheet (https://agriculture.ec.europa.eu/system/files/2020-05/analytical-factsheet-eu-level_en_0.pdf) accessed 6 October 2023.

EC, 2020o, European Skills Agenda for sustainable competitiveness, social fairness and resilience, (https://ec.europa.eu/migrant-integration/sites/default/files/2020-07/SkillsAgenda.pdf).

EC, 2020p, Impact Assessment accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committe and the Committee of the Regions + Stepping up Europe's 2030 climate ambition Investing in a climate-neutral future for the benefit of our people, No SWD(2020)176 Final (https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=SWD:2020:176:FIN) .

EC, 2020q, Pact for Skills. Report from the roundtable for the construction ecosystem., European Commission (https://ec.europa.eu/social/BlobServlet?docId=23282&langId=en).

EC, 2020r, Recommendations to the Member States as regards their strategic plan for the Common Agricultural Policy, No COM(2020) 846 final (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0846).

EC, 2020s, Stepping up Europe's 2030 climate ambition Investing in a climate-neutral future for the benefit of our people (European Commission 2030 Target Plan and accompanying impact assessment), No COM(2020) 562 (https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=SWD:2020:176:FIN).

EC, 2021a, 'Better regulation' toolbox – November 2021 edition, European Commission, Brussels, Belgium (https://commission.europa.eu/system/files/2023-02/br_toolbox-nov_2021_en.pdf).

EC, 2021b, Commission Delegated Regulation (EU) 2021/2139 of 4 June 2021 supplementing Regulation (EU) 2020/852 of the European Parliament and of the Council by establishing the technical screening criteria for determining the conditions under which an economic activity qualifies as contributing substantially to climate change mitigation or climate change adaptation and for determining whether that economic activity causes no significant harm to any of the other environmental objectives (OJ L 442, 9.12.2021, p. 1–349).

EC, 2021c, Commission Staff Working Document: Impact Assessment Accompanying the document Directive of the European Parliament and of the Council amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union, Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading scheme and Regulation (EU) 2015/757, No SWD(2021) 601 (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021SC0601).

EC, 2021d, Commission Staff Working Document - Impact Assessment Report Accompanying the document 'Proposal for a Regulation of the European Parliament and the Council amending Regulations (EU) 2018/841 as regards the scope, simplifying the compliance rules, setting out the targets of the Member States for 2030 and committing to the collective achievement of climate neutrality by 2035 in the land use, forestry and agriculture sector, and (EU) 2018/1999 as regards improvement in monitoring, reporting, tracking of progress and review', No SWD(2021) 609 final, European Commission, Brussels (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=SWD:2021:0609:FIN).

EC, 2021e, Commission Staff Working Document Better Regulation Guidelines, SWD(2021) 305 final, (https://commission.europa.eu/system/files/2021-11/swd2021_305_en.pdf).

EC, 2021f, Commission Staff Working Document. Evaluation of Regulation (EU) No 913/2010 concerning a European rail network for competitive freight (SWD(2021) 134 final).

EC, 2021g, Commission Staff Working Document Impact Assessment Report accompanying the Proposal for a Directive of the European Parliament and of the Council on energy efficiency (recast), (https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12552-EU-energy-efficiency-directive-EED-evaluation-and-review_en).

EC, 2021h, Commission Staff Working Document Impact Assessment Report accompanying the Proposal for a Directive of the European Parliament and of the Council on energy efficiency (recast) SWD(2021)

623 final, (https://eur-lex.europa.eu/resource.html?uri=cellar:c20a8b93-e574-11eb-a1a5-01aa75ed71a1.0001.02/DOC_1&format=PDF).

EC, 2021i, Commission Staff Working Document: Impact Assessment Report accompanying the Proposal for a Directive of the European Parliament and of the Council on the energy performance of buildings (recast) SWD(2021) 453, (https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12910-Energy-efficiency-Revision-of-the-Energy-Performance-of-Buildings-Directive_en).

EC, 2021j, Commission Staff Working Document Impact Assessment Report accompanying the Proposal for a Directive of the European Parliament and of the Council on the energy performance of buildings (recast) SWD(2021) 453 final PART 1/4, (https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12910-Energy-efficiency-Revision-of-the-Energy-Performance-of-Buildings-Directive_en).

EC, 2021k, Communication from the Commission to the European Parliament and the Council. Action Plan to boost long distance and cross-border passenger rail. (COM(2021) 810 final).

EC, 2021l, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - EU taxonomy, corporate sustainability reporting, sustainability preferences and fiduciary duties: directing finance towards the European Green Deal (COM(2021) 188, Brussels, 21.4.2021).

EC, 2021m, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions 'Fit for 55: delivering the EU's 2030 climate target on the way to climate neutrality' (COM(2021) 550 final).

EC, 2021n, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions 'New EU Forest Strategy for 2030' (COM (2021)572 final).

EC, 2021o, EU code of conduct on responsible food business and marketing practices (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0846).

EC, 2021p, Horizon Europe: The EU Research & Innovation Programme 2021-2027, European Commission (https://research-and-innovation.ec.europa.eu/system/files/2022-06/ec_rtd_he-investing-to-shape-our-future_0.pdf).

EC, 2021q, Impact assessment report, accompanying the document. Proposal for a Council Directive restructuring the Union framework for the taxation of energy products and electricity (recast), No SWD(2021) 641 final (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021SC0641).

EC, 2021r, Impact Assessment Report accompanying the document Proposal for a Regulation of the European Parliament and the Council amending Regulations (EU) 2018/841 as regards the scope, simplifying the compliance rules, setting out the targets of the Member States for 2030 and committing to the collective achievement of climate neutrality by 2035 in the land use, forestry and agriculture sector, and (EU) 2018/1999 as regards improvement in monitoring, reporting, tracking of progress and review, No SWD(2021) 609 final (https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=SWD:2021:609:FIN).

EC, 2021s, Inception Impact Assessment. Revision of the Combined Transport Directive, (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=PI_COM:Ares(2020)3896535).

EC, 2021t, Inception impact assessment. Sustainable food system framework initiative, (https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13174-Sustainable-EU-food-system-new-initiative_en).

EC, 2021u, 'List of potential agricultural practices that eco-schemes could support' (https://agriculture.ec.europa.eu/system/files/2021-01/factsheet-agri-practices-under-ecoscheme_en_0.pdf).

EC, 2021v, 'Policy scenarios for delivering the European Green Deal' (https://energy.ec.europa.eu/data-and-analysis/energy-modelling/policy-scenarios-delivering-european-green-deal_en) accessed 10 August 2023.

EC, 2021w, 'Policy scenarios for delivering the European Green Deal' (https://energy.ec.europa.eu/data-and-analysis/energy-modelling/policy-scenarios-delivering-european-green-deal_en) accessed 23 November 2022.

EC, 2021x, Programme for the Environment and Climate Action (LIFE) Call for proposals, LIFE Clean Energy Transition (LIFE-2021-CET), (https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/life/wp-call/2021-2024/call-fiche_life-2021-cet_en.pdf).

EC, 2021y, Proposal for a Council Directive restructuring the Union framework for the taxation of energy products and electricity (recast) (COM(2021) 563 final).

EC, 2021z, Proposal for a Council Directive restructuring the Union framework for the taxation of energy products and electricity (recast)., No COM/2021/563 final (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021PC0563).

EC, 2021aa, Proposal for a Directive of the European Parliament and of the Council amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive 98/70/EC of the European Parliament and of the Council as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652, COM/2021/557 final, (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0557).

EC, 2021ab, Proposal for a Directive of the European Parliament and of the Council on common rules for the internal markets in renewable and natural gases and in hydrogen, COM/2021/803 final, (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0803&qid=1640002501099).

EC, 2021ac, Proposal for a Directive of the European Parliament and of the Councilon the energy performance of buildings (recast) COM/2021/802 final, (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52021PC0802).

EC, 2021ad, Proposal for a Regulation of the European Parliament and of the Council establishing a Social Climate Fund, COM(2021) 568 final.

EC, 2021ae, Proposal for a regulation of the European Parliament and of the Council on European green bonds (COM (2021) 391 final of 6 July 2021).

EC, 2021af, Proposal for a Regulation of the European Parliament and of the Council on methane emissions reduction in the energy sector and amending Regulation (EU) 2019/942, COM(2021) 805 final, (https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=COM:2021:805:FIN).

EC, 2021ag, Proposal for a Regulation of the European Parliament and of the Council on the internal markets for renewable and natural gases and for hydrogen (recast), COM/2021/804 final, (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2021%3A804%3AFIN&qid=1640001545187).

EC, 2021ah, Proposal for a Regulation of the European Parliament and of the Council on Union guidelines for the development of the trans-European transport network, amending Regulation (EU) 2021/1153 and Regulation (EU) No 913/2010 and repealing Regulation (EU) 1315/2013 (COM(2021) 812 final).

EC, 2021ai, Review of the Energy Taxation Directive (ETD): Questions and Answers (https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_3662).

EC, 2021aj, Supporting public administrations in EU Member States to deliver reforms and prepare for the future., Publications Office, LU.

EC, 2021ak, Urban Agenda for the EU Multi-level governance in action 2021 Update, (https://www.citiesforum2023.eu/docs/Urban/Urban%20Agenda%20for%20the%20EU%20-%20Brochure%202021.pdf).

EC, 2021al, Commission Staff Working Document Impact Assessment Report accompanying the document Directive of the European Parliament and of the Council amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union, Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading scheme and Regulation (EU) 2015/757 {COM(2021) 551 final} - {SEC(2021) 551 final} - {SWD(2021) 557 final} - {SWD(2021) 602 final}, (https://eur-lex.europa.eu/resource.html?uri=cellar:7b89687a-eec6-11eb-a71c-01aa75ed71a1.0001.01/DOC_1&format=PDF).

EC, 2021am, 'EU Mission: Climate-Neutral and Smart Cities' (https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/climate-neutral-and-smart-cities_en) accessed 8 June 2022.

EC, 2021an, 'Sustainable EU food system - new initiative', European Commission - Have your say (https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13174-Sustainable-EU-food-system-new-initiative_en) accessed 30 November 2023c.

EC, 2022a, Commission Decision (EU) 2022/589 of 6 April 2022 establishing the composition and the operational provisions of setting up the Commission Energy Poverty and Vulnerable Consumers Coordination Group (OJ L 112, 11.4.2022, p. 67–72).

EC, 2022b, Commission Delegated Regulation (EU) 2022/1214 of 9 March 2022 amending Delegated Regulation (EU) 2021/2139 as regards economic activities in certain energy sectors and Delegated Regulation (EU) 2021/2178 as regards specific public disclosures for those economic activities (Text with EEA relevance) (OJ L).

EC, 2022c, Commission Notice on the Guidance to Member States for the update of the 2021-2030 national energy and climate plans (2022/C 495/02), (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX%3A52022XC1229%2802%29&from=EN).

EC, 2022d, Commission Recommendation on speeding up permit-granting procedures for renewable energy projects and facilitating Power Purchase Agreements C/2022/3219 final, (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=PI_COM%3AC%282022%293219&qid=1653033569832).

EC, 2022e, Commission Staff Working Document - Evaluation of the CAP's impact on knowledge exchange and advisory activities, No SWD(2022) 137 final (https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/2132-EU-farm-policy-evaluation-of-its-impact-on-knowledge-exchange-and-advisory-activities_en).

EC, 2022f, Commission Staff Working Document Analysis of the national long-term renovation strategies SWD(2022) 375 final, European Commission (https://energy.ec.europa.eu/system/files/2022-12/SWD-Analysis-of-2020-LTRS.PDF).

EC, 2022g, Commission Staff Working Document Climate Mainstreaming Architecture in the 2021-2027 Multiannual Financial Framework. SWD(2022) 225 final, (https://commission.europa.eu/system/files/2022-06/swd_2022_225_climate_mainstreaming_architecture_2021-2027.pdf).

EC, 2022h, Commission Staff Working Document Impact Assessment Report Accompanying the documents Proposal for a Directive of the European Parliament and of the Council amending Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) and Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste and Proposal for a Regulation of the European Parliament and of the Council on reporting of environmental data from industrial installations and establishing an Industrial Emissions Portal SWD(2022) 111 final, (https://environment.ec.europa.eu/publications/proposal-revision-industrial-emissions-directive_en).

EC, 2022i, Communication from the Commission – Guidelines on State aid for climate, environmental protection and energy 2022 (C/2022/481), (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022XC0218(03)), European Commission.

EC, 2022j, Communication from the Commission Temporary Crisis Framework for State Aid measures to support the economy following the aggression against Ukraine by Russia 2022/C 131 I/01.

EC, 2022k, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Digitalising the energy system - EU action plan (COM/2022/552 final).

EC, 2022l, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions — better assessing the distributional impact of Member States' policies COM/2022/494 final, European Commision (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A494%3AFIN&qid=1664539714709).

EC, 2022m, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions 'REPowerEU Plan' (COM(2022) 230 final of 18 May 2022).

EC, 2022n, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions — 'save gas for a safe winter', (https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52022DC0360&from=EN).

EC, 2022o, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions EU Solar Energy Strategy (COM(2022)221).

EC, 2022p, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions 'REPowerEU plan' (COM (2022) 230 final of 18 May 2022).

EC, 2022q, Decision (EU) 2022/591 of the European Parliament and of the Council of 6 April 2022 on a General Union Environment Action Programme to 2030 (Decision (EU) 2022/591).

EC, 2022r, EU-US Joint Press Release on the Global Methane Pledge Energy Pathway, (https://ec.europa.eu/commission/presscorner/detail/en/IP_22_3793).

EC, 2022s, Implementing the REPowerEU action plan: investment needs, hydrogen accelerator and achieving the bio-methane targets, No SWD(2022) 230 final, European Commission (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022SC0230).

EC, 2022t, Proposal for a Directive of the European Parliament and of the Council amending Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) and Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste COM(2022) 156 final, (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022PC0156).

EC, 2022u, Proposal for a Regulation establishing a framework for setting ecodesign requirements for sustainable products and repealing Directive 2009/125/EC (COM(2022) 142).

EC, 2022v, Proposal for a Regulation of the European Parliament and of the Council establishing a framework for setting ecodesign requirements for sustainable products and repealing Directive 2009/125/EC (COM(2022)142).

EC, 2022w, Proposal for a Regulation of the European Parliament and of the Council establishing a Union certification framework for carbon removals (COM(2022) 672 final).

EC, 2022x, Proposal for a Regulation of the European Parliament and of the Council laying down harmonised conditions for the marketing of construction products, amending Regulation (EU) 2019/1020 and repealing Regulation (EU) 305/2011 (COM(2022)144).

EC, 2022y, Proposal for a Regulation of the European Parliament and of the Council on packaging and packaging waste, amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and repealing Directive 94/62/EC (COM/2022/677 final).

EC, 2022z, Proposal for a Regulation of the European Parliament and of the Council on reporting of environmental data from industrial installations and establishing an Industrial Emissions Portal COM(2022) 157 final, (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52022PC0157).

EC, 2022aa, Proposed CAP Strategic Plans and Commission obeservations. Summary overview for 27 Member States (https://agriculture.ec.europa.eu/cap-my-country/cap-strategic-plans_en).

EC, 2022ab, 'Questions and answers: Guidelines on State aid for climate, environmental protection and energy 2022' (https://ec.europa.eu/commission/presscorner/detail/en/qanda_22_566).

EC, 2022ac, Replies of the European Commission to the European Court of Auditors' Special Report 'Climate spending in the 2014-2020 EU Budget: not as high as reported'., European Commission (https://www.eca.europa.eu/Lists/ECAReplies/COM-Replies-SR-22-09/COM-Replies-SR-22-09_EN.pdf) accessed 17 November 2023.

EC, 2022ad, Report from the Commission to the European Parliament and the Council: Progress on competitiveness of clean energy technologies (COM(2022) 643 f inal).

EC, 2022ae, 'Revised EU rules on Industrial Emissions', European Commission - European Commission (https://ec.europa.eu/commission/presscorner/detail/en/QANDA_22_2239) accessed 3 December 2023.

EC, 2022af, 'September Infringements package: key decisions' (https://ec.europa.eu/commission/presscorner/detail/en/inf_23_4367) accessed 1 December 2024.

EC, 2022ag, 'Study on commitments pledged under the EU Code of Conduct on responsible food business and marketing practices' (https://food.ec.europa.eu/system/files/2023-03/f2f_sfpd_coc_report_mapping_2022.pdf).

EC, et al., 2022, Technical support for RES policy development and implementation: simplification of permission and administrative procedures for RES installations (RES simplify): interim report., Publications Office, LU.

EC, 2022ah, The Pact for Skills A Skills Partnership for the Agri-Food Ecosystem, (https://ec.europa.eu/social/main.jsp?langId=en&catId=1517&furtherNews=yes&newsId=10171).

EC, 2022ai, The possible implications of the green transition for the EU labour market., Publications Office, LU (https://data.europa.eu/doi/10.2765/583043).

EC, 2022aj, The possible implications of the green transition for the EU labour market., European Commission's Directorate-General for Economic and Financial Affairs, LU (https://data.europa.eu/doi/10.2765/583043).

EC, 2022ak, TSI 2023 Flagship Technical Support Project RENEWABLE PERMITS, (https://reform-support.ec.europa.eu/system/files/2022-05/2023%20Flagships%20Techical%20Support%20projects%20-%20rewable%20energy.pdf).

EC, 2022al, EU transport in figures: statistical pocketbook 2022., Publications Office, LU. doi:10.2832/92929
https://op.europa.eu/en/publication-detail/-/publication/f656ef8e-3e0e-11ed-92ed-01aa75ed71a1

EC, 2023a, Annual report on taxation 2023: review of taxation policies in Member States, No doi: 10.2778/982557 (https://op.europa.eu/s/y1Kk).

EC, 2023b, Approved 28 CAP Strategic Plans (2023-2027) - Summary overview for 27 member states, European Commission (DG ARD) (https://agriculture.ec.europa.eu/system/files/2023-06/approved-28-cap-strategic-plans-2023-27.pdf).

EC, 2023c, 'Buildings and construction' (https://single-market-economy.ec.europa.eu/industry/sustainability/buildings-and-construction_en).

EC, 2023d, Call for evidence and public consultation launched on industrial carbon management under European Green Deal, (https://energy.ec.europa.eu/news/call-evidence-and-public-consultation-launched-industrial-carbon-management-under-european-green-2023-06-09_en).

EC, 2023e, 'CAP at a glance' (https://agriculture.ec.europa.eu/common-agricultural-policy/cap-overview/cap-glance_en) accessed 19 September 2023.

EC, 2023f, 'Carbon Border Adjustment Mechanism' (https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en) accessed 9 October 2023.

EC, 2023g, 'Carbon leakage' (https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/free-allocation/carbon-leakage_en) accessed 9 October 2023.

EC, 2023h, Commission Delegated Regulation (EU) 2023/1184 of 10 February 2023 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by establishing a Union methodology setting out detailed rules for the production of renewable liquid and gaseous transport fuels of non-biological origin (OJ L 157, 20.6.2023).

EC, 2023i, Commission Recommendation (EU) 2023/2407 of 20 October 2023 on energy poverty C/2023/4080, (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202302407), European Commission.

EC, 2023j, Commission Staff Working Document Assessment of progress towards the objectives of the Energy Union and Climate Action Accompanying the document Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Commitee of the Regions State of the Energy Union 2023 Report (pursuant to Regulation (EU) 2018/1999 on the Governance of the Energy Union and Climate Action) {COM(2023) 650 final}, (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=SWD%3A2023%3A646%3AFIN&qid=1698236844015).

EC, 2023k, Commission Staff Working Document. Full-length report accompanying the document Fourth Annual Report from the European Commission on CO2 Emissions from Maritime Transport (period 2018-2021) (SWD(2023) 54 final).

EC, 2023l, Commission Staff Working Document. Investment needs assessment and funding availabilities to strengthen the EU's Net-Zero technology manufacturing capacity (SWD(2023) 68 final).

EC, 2023m, Communication from the Commission Temporary Crisis and Transition Framework for State Aid measures to support the economy following the aggression against Ukraine by Russia 2023/C 101/03 (C/2023/1711), (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.C_.2023.101.01.0003.01.ENG&toc=OJ%3AC%3A2023%3A101%3ATOC), European Commission.

EC, 2023n, Communication from the Commission to the European Parliament, the Council, the European Central Bank, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank. 2023 European Semester - Spring Package (COM(2023) 600 final).

EC, 2023o, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committe of the Regions - Enhancing the European Administrative Space (ComPAct), No COM(2023) 667 final, European Commission, Brussels (https://commission.europa.eu/system/files/2023-10/Communication_Enhancing%20the%20European%20Administrative%20Space.pdf).

EC, 2023p, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. EU wide assessment of the draft updated National Energy and Climate Plans - An important step towards the more ambitious 2030 energy and climate objectives under the European Green Deal and RePowerEU (COM(2023) 796 final).

EC, 2023q, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the European Hydrogen Bank, (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023DC0156&qid=1682349760946).

EC, 2023r, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions 'on the European Hydrogen Bank'

(COM(2023)156 final), (https://energy.ec.europa.eu/system/files/2023-03/COM_2023_156_1_EN_ACT_part1_v6.pdf), European Commission.

EC, 2023s, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions European Wind Power Action Plan, (https://energy.ec.europa.eu/system/files/2023-10/COM_2023_669_1_EN_ACT_part1_v8.pdf), European Commision.

EC, 2023t, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions on the findings adopted by the Aarhus Convention Compliance Committee in case ACCC/C/2015/128 as regards state aid: Analysing the implications of the findings and assessing the options available {SWD(2023) 307 final}, (https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX%3A52023DC0307).

EC, 2023u, Communication From the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions - A Green Deal Industrial Plan for the Net-Zero Age (COM(2023) 62 final).

EC, 2023v, 'Competitive bidding. A new tool for funding innovative low-carbon technologies under the Innovation Fund' (https://climate.ec.europa.eu/eu-action/funding-climate-action/innovation-fund/competitive-bidding_en#pilot-auction) accessed 11 August 2023.

EC, 2023w, 'Covenant of Mayors - Europe' (https://eu-mayors.ec.europa.eu/en/home) accessed 11 August 2023.

EC, 2023x, 'Energy Communities Repository' (https://energy-communities-repository.ec.europa.eu/index_en).

EC, 2023y, 'Energy Poverty Advisory Hub' (https://energy-poverty.ec.europa.eu/about-us/vision-and-mission_en).

EC, 2023z, 'EU climate target for 2040' (https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13793-EU-climate-target-for-2040_en) accessed 24 August 2023.

EC, 2023aa, 'EU funding instruments for upskilling and reskilling', Employment, Social Affairs & Inclusion (https://ec.europa.eu/social/main.jsp?catId=1530&langId=en).

EC, 2023ab, European Alternative Fuels Observatory, (https://alternative-fuels-observatory.ec.europa.eu/transport-mode/road/european-union-eu27) accessed 28 November 2023.

EC, 2023ac, European Critical Raw Materials Act, No COM(2023) 160, European Commission, Brussels, Belgium (https://single-market-economy.ec.europa.eu/publications/european-critical-raw-materials-act_en).

EC, 2023ad, 'European Social Fund Plus' (https://ec.europa.eu/european-social-fund-plus/en).

EC, 2023ae, 'European Year of Skills 2023' (https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-year-skills-2023_en).

EC, 2023af, 'Expert group on carbon removals' (https://climate.ec.europa.eu/eu-action/sustainable-carbon-cycles/expert-group-carbon-removals_en) accessed 20 October 2023.

EC, 2023ag, Exploring the main barriers and action drivers for the uptake of energy communities: Take-aways from our policy workshop, European Commission, DG Energy (https://energy-communities-repository.ec.europa.eu/energy-communities-repository-news-and-events/energy-communities-repository-news/exploring-main-barriers-and-action-drivers-uptake-energy-communities-take-aways-our-policy-workshop-2023-06-05_en).

EC, 2023ah, Green Deal Industrial Plan - Plugging the Skills Gap, Factsheet (https://op.europa.eu/en/publication-detail/-/publication/38990ae2-f07f-11ed-a05c-01aa75ed71a1?pk_campaign=OPNewsletter_June2023&pk_source=EUP) accessed 6 October 2023.

EC, 2023ai, 'Have your say: Energy Union and climate action – Review report on the Governance Regulation - results' (https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13799-Energy-Union-and-climate-action-Review-report-on-the-Governance-Regulation/feedback_en?p_id=32230584).

EC, 2023aj, 'Heat pumps' (https://energy.ec.europa.eu/topics/energy-efficiency/heat-pumps_en#:~:text=EU%20Heat%20Pump%20Action%20Plan,-There%20is%20an&text=The%20action%20plan%20will%20aim,and%20fine%2Dtune%20the%20initiative.).

EC, 2023ak, 'Innovation Fund - European Commission' (https://cinea.ec.europa.eu/programmes/innovation-fund_en) accessed 10 January 2024.

EC, 2023al, Innovation Fund Auction Terms and Conditions, (https://climate.ec.europa.eu/system/files/2023-08/innovationfund_pilotauction_termsandconditions_en.pdf).

EC, 2023am, 'Looking at how to mitigate emissions from agriculture' (https://climate.ec.europa.eu/news-your-voice/news/looking-how-mitigate-emissions-agriculture-2023-11-13_en) accessed 20 November 2023.

EC, 2023an, Member States agree new ambition for expanding offshore renewable energy (news announcement) (https://energy.ec.europa.eu/news/member-states-agree-new-ambition-expanding-offshore-renewable-energy-2023-01-19_en) accessed 28 July 2023.

EC, 2023ao, Net Zero Industry Act, No COM(2023) 161 (https://single-market-economy.ec.europa.eu/publications/net-zero-industry-act_en).

EC, 2023ap, Proposal for a directive of the European Parliament and of the Council amending Council Directive 92/106/EC as regards a support framework for intermodal transport of goods and Regulation (EU) 2020/1056 of the European Parliament and the Council as regards calculation of external costs savings and generation of aggregated data (COM(2023) 702 final).

EC, 2023aq, Proposal for a Directive of the European Parliament and of the Council amending Directive 2008/98/EC on waste (COM(2023) 420 final).

EC, 2023ar, Proposal for a Regulation of the European Parliament and of the Council amending Regulations (EU) 2019/943 and (EU) 2019/942 as well as Directives (EU) 2018/2001 and (EU) 2019/944 to improve the Union's electricity market design, COM(2023) 148 final, (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023PC0148&qid=1679410882233), European Commission.

EC, 2023as, Proposal for a Regulation of the European Parliament and of the Council establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) 168/2013, (EU) 2018/858, 2018/1724 and (EU) 2019/1020 COM/2023/160 final, (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023PC0160).

EC, 2023at, Proposal for a Regulation of the European Parliament and of the Council on circularity requirements for vehicle design and on management of end-of-life vehicles, amending Regulations (EU) 2018/858 and 2019/1020 and repealing Directives 2000/53/EC and 2005/64/EC (COM(2023) 451 final).

EC, 2023au, Proposal for a Regulation of the European Parliament and of the Council 'on the effective coordination of economic policies and multilateral budgetary surveillance and repealing Council Regulation (EC) No 1466/97' (COM(2023) 240 final), (https://economy-finance.ec.europa.eu/system/files/2023-04/COM_2023_240_1_EN.pdf), European Commission.

EC, 2023av, Proposal for a regulation of the European Parliament and of the Council on the use of railway infrastructure capacity in the single European railway area, amending Directive 2012/34/EU and repealing Regulation (EU) No 913/210 (COM(2023) 443/2).

EC, 2023aw, Report from the Commission to the European Parliament and the Council — 2023 Report on Energy Subsidies in the EU (COM(2023) 651 final).

EC, 2023ax, Report from the Commission to the European Parliament and the Council. EU Climate Action Progress Report 2023 (COM(2023) 653 final).

EC, 2023ay, Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions — New European Bauhaus Progress Report COM(2023) 24 final, European Commission (https://new-european-bauhaus.europa.eu/system/files/2023-01/CP-003%20-%20Report%20from%20the%20Commission%20%28EN%29%20Part%201.pdf).

EC, 2023ba, Report on renovation of the national stock of residential and non-residential buildings and on nearly zero-energy buildings. Annex to the Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions State of the Energy Union Report 2023 COM(2023) 650 final (https://energy.ec.europa.eu/system/files/2023-10/COM_2023_650_2_EN_annexe_autre_acte_part1_v5.pdf).

EC, 2023bb, REPowerEU: One year later, (https://energy.ec.europa.eu/system/files/2023-05/EU_REPowerEU.pdf), European Commission.

EC, 2023bc, 'Rural Energy Community Advisory Hub' (https://rural-energy-community-hub.ec.europa.eu/index_en).

EC, 2023bd, 'Share your views: putting a price on emissions and rewarding carbon removals in the land sector' (https://climate.ec.europa.eu/news-your-voice/news/share-your-views-putting-price-emissions-and-rewarding-carbon-removals-land-sector-2023-06-27_en) accessed 6 July 2023.

EC, 2023be, Study on the critical raw materials for the EU 2023: final report., Publications Office, LU.

EC, 2023bf, Summary of the CAP Strategic Plans for 2023-2027: joint effort and collective ambition, No COM(2023) 707 final (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2023:707:FIN).

EC, 2023bg, 'The Just Transition Mechanism: making sure no one is left behind' (https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/finance-and-green-deal/just-transition-mechanism_en).

EC, 2023bh, Union Bioenergy Sustainability Report (COM(2023) 650 final).

EC, 2023bi, 'LIFE programme - European Commission' (https://single-market-economy.ec.europa.eu/industry/strategy/hydrogen/funding-guide/eu-programmes-funds/life-programme_en) accessed 10 January 2024b.

EC, 2023bj, 'Young Farmers', Common agricultural policy - young farmers (https://agriculture.ec.europa.eu/common-agricultural-policy/income-support/young-farmers_en) accessed 6 October 2023.

EC, 2024, 'European Innovation Council' (https://eic.ec.europa.eu/index_en) accessed 10 January 2024.

EC and CINEA, 2023, PCI Transparency Platform, (https://ec.europa.eu/energy/infrastructure/transparency_platform/map-viewer/main.html) accessed 20 December, 2023.

EC DG Energy, 2023, EU Building Stock Observatory, (https://building-stock-observatory.energy.ec.europa.eu/database/) accessed 28 November 2023.

EC and EEFIG, 2022, Multiple benefits of energy efficiency investments for financial institutions: final report: October 2021., European Commission, Energy Efficiency Financial Institutions Group (EEFIG) (https://data.europa.eu/doi/10.2833/205185).

EC, Group of Chief Scientific Advisors, 2020, Towards a Sustainable Food System: moving from food as a commodity to food as more of a common good: independent expert report., Publications Office, LU (https://data.europa.eu/doi/10.2777/282386).

EC, Joint Research Centre, et al., 2021, Modelling environmental and climatic ambition in the agricultural sector with the CAPRI model: exploring the potential effects of selected farm to fork and biodiversity strategies targets in the framework of the 2030 climate targets and the post 2020 Common Agricultural Policy, Publications Office of the European Union (https://data.europa.eu/doi/10.2760/98160).

EC JRC, et al., 2022, Clean Energy Technology Observatory, Carbon capture utilisation and storage in the European union: status report on technology development, trends, value chains and markets: 2022, Joint Research Centre (https://op.europa.eu/en/publication-detail/-/publication/13eafc68-64a2-11ed-92ed-01aa75ed71a1/language-en/format-PDF/source-search).

ECA, 2016, The EU system for the certification of sustainable biofuels, Special report, European Court of Auditors (https://www.eca.europa.eu/en/publications/SR16_18).

ECA, 2020a, Energy efficiency in buildings: greater focus on cost-effectiveness still needed, Special report No 11, European Court of Auditors (https://www.eca.europa.eu/Lists/ECADocuments/SR20_11/SR_Energy_efficiency_in_buildings_EN.pdf).

ECA, 2020b, Special Report 18/2020: The EU's Emissions Trading System: free allocation of allowances needed better targeting, No 18/2020 (https://www.eca.europa.eu/en/publications?did=54392).

ECA, 2020c, Sustainable Urban Mobility in the EU: No substantial improvement is possible without Member States' commitments, Special Report No 06/2020 (https://op.europa.eu/webpub/eca/special-reports/urban-mobility-6-2020/en/#:~:text=Urban%20areas%20account%20for%2023%20%25%20of%20CO2%20emissions%20from%20transport.).

ECA, 2021, Common agricultural policy and climate: Half of EU climate spending but farm emissions are not decreasing, Special Report No 16, European Court of Auditors (https://www.eca.europa.eu/Lists/ECADocuments/SR21_16/SR_CAP-and-Climate_EN.pdf).

ECA, 2022a, EU support to coal regions Limited focus on socio-economic and energy transition, European Court of Auditors. Special report 22/2022 (https://www.eca.europa.eu/en/publications?did=62373).

ECA, 2022b, Review 01/2022: Energy taxation, carbon pricing and energy subsidies - European Court of Auditors, No Review 01/2022, European Court of Auditors, Brussels (https://www.eca.europa.eu/en/Pages/DocItem.aspx?did=60760).

ECA, 2022c, Climate spending in the 2014-2020 EU budget - Not as high as reported, Special Report No 09/2022, European Court of Auditors, Luxembourg (https://www.eca.europa.eu/en/publications?did=61103).

ECA, 2023a, Circular Economy. Slow transition by member states despite EU action, Special report No 17/2023, European Court of Auditors (https://www.eca.europa.eu/ECAPublications/SR-2023-17/SR-2023-17_EN.pdf).

ECA, 2023b, Intermodal freight transport. EU still far from getting freight off the road, Special Report No 2023/08, European Court of Auditors.

ECA, 2023c, Special report 26/2023: The Recovery and Resilience Facility's performance monitoring framework (http://www.eca.europa.eu/en/publications/sr-2023-26).

ECA, 2023d, The EU's industrial policy on batteries: New strategic impetus needed, Special report No 15/2023 (https://www.eca.europa.eu/en/publications/SR-2023-15).

ECB, 2022, Fiscal policies to mitigate climate change in the euro area, ECB economic bulletin, issue 6/2022, European Central Bank (https://www.ecb.europa.eu/pub/economic-bulletin/articles/2022/html/ecb.ebart202206_01~8324008da7.en.html).

ECB, 2023a, Benefits and costs of the ETS in the EU, a lesson learned for the CBAM design, No 2764 (https://ideas.repec.org/p/ecb/ecbwps/20232764.html).

ECB, 2023b, 'Key ECB interest rates' (https://www.ecb.europa.eu/stats/policy_and_exchange_rates/key_ecb_interest_rates/html/index.en.html) accessed 14 December 2023.

ECB, 2023c, 'A Kantian shift for the capital markets union' (https://www.ecb.europa.eu/press/key/date/2023/html/ecb.sp231117~88389f194b.en.html) accessed 30 October 2023.

ECE, 2021, Decision VII/8f concerning compliance by the European Union with its obligations under the Convention, (https://unece.org/sites/default/files/2021-12/Decision_VII.8f_eng.pdf), Economic Commission for Europe.

ECNO, 2023, 'Flagship Report: State of EU progress to climate neutrality. An indicator-based assessment across 13 building blocks for a climate neutral future', the European Climate Neutrality Observatory (https://www.ecologic.eu/19265)

Economidou, M., et al., 2020, 'Review of 50 years of EU energy efficiency policies for buildings', Energy and Buildings 225, p. 110322 (DOI: 10.1016/j.enbuild.2020.110322).

Ecorys, et al., 2023, Mapping and Analysis of CAP Strategic Plans Assessment of joint efforts for 2023-2027 (https://data.europa.eu/doi/10.2762/71556).

ECSO, 2020, Improving the human capital basis, European Construction Sector Observatory (https://single-market-economy.ec.europa.eu/document/download/6637d5a4-c932-4492-904d-caf5f1878264_en) accessed 28 November 2023.

Edenhofer, O., et al., 2022, 'Four ways to make the European Commission's carbon pricing proposal fitter for 55', in: Greening Europe's post-COVID-19 recovery, Bruegel, Brusselsn ISBN: 978-9-078910-53-4.

Edenhofer, O., et al., 2023, 'On the Governance of Carbon Dioxide Removal – a Public Economics Perspective', Rochester, NY (https://dx.doi.org/10.2139/ssrn.4422845).

EEA, 2019, Climate change adaptation in the agriculture sector, No 04/2019, European Environment Agency (https://www.eea.europa.eu/publications/cc-adaptation-agriculture).

EEA, 2020, 'Monitoring of CO2 emissions from passenger cars – Regulation (EU) 2019/631 — European Environment Agency, Copenhagen, Denmark' (https://www.eea.europa.eu/data-and-maps/data/co2-cars-emission-18) accessed 29 September 2020.

EEA, 2021a, Nature-based solutions in Europe: Policy, knowledge and practice for climate change adaptation and disaster risk reduction, EEA Report No 1/2021, Europe Environment Agency (https://www.eea.europa.eu/publications/nature-based-solutions-in-europe).

EEA, 2021b, The contribution of national advisory bodies to climate policy in Europe — European Environment Agency, EEA Briefing No 02/2021, European Environment Agency (https://www.eea.europa.eu/publications/the-contribution-of-national-advisory/).

EEA, 2022a, 'Building renovation: where circular economy and climate meet', European Environment Agency (https://www.eea.europa.eu/publications/building-renovation-where-circular-economy) accessed 10 October 2022.

EEA, 2022b, Cooling buildings sustainably in Europe: exploring the links between climate change mitigation and adaptation, and their social impacts, European Environment Agency (https://www.eea.europa.eu/publications/cooling-buildings-sustainably-in-europe) access 15 December 2023.

EEA, 2022c, 'Cooling buildings sustainably in Europe: exploring the links between climate change mitigation and adaptation, and their social impacts', European Environment Agency (https://www.eea.europa.eu/publications/cooling-buildings-sustainably-in-europe) accessed 28 November 2022.

EEA, 2022d, Decarbonising road transport — the role of vehicles, fuels and transport demand, EEA Report No 2/2022, EEA (https://www.eea.europa.eu/publications/transport-and-environment-report-2021).

EEA, 2022e, Energy prosumers in Europe — Citizen participation in the energy transition, Publication No 01/2022, European Envionment Agency (EEA) (https://www.eea.europa.eu/publications/the-role-of-prosumers-of).

EEA, 2022f, Methane emissions in the EU: the key to immediate action on climate change, European Environment Agency, Copenhagen, Denmark (https://www.eea.europa.eu/publications/methane-emissions-in-the-eu) accessed 5 February 2023.

EEA, 2022g, The role of (environmental) taxation in supporting sustainability transitions (https://www.eea.europa.eu/publications/the-role-of-environmental-taxation).

EEA, 2022h, Transforming Europe’s food system — Assessing the EU policy mix. Report No 14/2022, European Environment Agency, Copenhagen (https://www.eea.europa.eu/publications/transforming-europes-food-system).

EEA, 2022i, Trends and projections in Europe 2022, Publication No 10/2022, European Environment Agency, Copenhagen (https://www.eea.europa.eu/publications/trends-and-projections-in-europe-2022).

EEA, 2022j, ‘Use of renewable energy for transport in Europe’ (https://www.eea.europa.eu/ims/use-of-renewable-energy-for) accessed 23 June 2023.

EEA, 2022k, Zero pollution monitoring assessment, EEA Web Report No 03/2022, European Environment Agency (https://www.eea.europa.eu/publications/zero-pollution).

EEA, 2023a, Accelerating the energy efficiency renovation of residential buildings — a behavioural approach, briefing, European Environment Agency, Copenhagen, Denmark (https://www.eea.europa.eu/publications/accelerating-the-energy-efficiency/) accessed 02 December 2023.

EEA, 2023b, ‘Climate and Energy in the EU’ (https://climate-energy.eea.europa.eu/) accessed 15 August 2023.

EEA, 2023c, ‘CO2 emissions from new passenger cars’ (http://co2cars.apps.eea.europa.eu/) accessed 12 December 2023.

EEA, 2023d, ‘CO2 performance emissions of new vans in Europe’ (https://www.eea.europa.eu/en/analysis/indicators/co2-performance-emissions-of-new) accessed 17 September 2023.

EEA, 2023e, ‘Copernicus Land Monitoring Service’ (https://land.copernicus.eu/) accessed 13 March 2023.

EEA, 2023f, ‘EEA greenhouse gases - data viewer’ (https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer) accessed 10 August 2023.

EEA, 2023g, ‘EU Emissions Trading System (ETS) data viewer’ (https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1) accessed 10 August 2023.

EEA, 2023h, ‘European Union CRF tables 1990-2021’ (https://www.eea.europa.eu/publications/annual-european-union-greenhouse-gas-2/european-union-crf-tables-1990-2021/view) accessed 28 June 2023.

EEA, 2023i, ‘Fossil fuel subsidies’ (https://www.eea.europa.eu/en/analysis/indicators/fossil-fuel-subsidies) accessed 14 November 2023.

EEA, 2023j, Greenhouse gas emission intensity of electricity generation in Europe, (https://www.eea.europa.eu/en/analysis/indicators/greenhouse-gas-emission-intensity-of-1).

EEA, 2023k, ‘Greenhouse gas emissions from agriculture in Europe’ (https://www.eea.europa.eu/en/analysis/indicators/greenhouse-gas-emissions-from-agriculture) accessed 10 November 2023.

EEA, 2023l, Investments in the sustainability transition: leveraging green industrial policy against emerging constraints, EEA Briefing, European Environment Agency, Copenhagen (https://www.eea.europa.eu/publications/investments-into-the-sustainability-transition/) accessed 15 November 2023.

EEA, 2023m, 'Member States' greenhouse gas (GHG) emission projections' (https://www.eea.europa.eu/en/datahub/datahubitem-view/4b8d94a4-aed7-4e67-a54c-0623a50f48e8) accessed 9 January 2024.

EEA, 2023n, 'Share of energy consumption from renewable sources in Europe (8th EAP)' (https://www.eea.europa.eu/ims/share-of-energy-consumption-from) accessed 15 November 2023.

EEA, 2023o, The European biomass puzzle. Challenges, opportunities, and trade-offs around biomass production and use in the EU, No EEA Report 08/2023 (https://www.eea.europa.eu/publications/the-european-biomass-puzzle).

EEA, 2023p, Trends and projections in Europe 2023. EEA Report 07/2023, European Environment Agency, Copenhagen (https://www.eea.europa.eu/publications/trends-and-projections-in-europe-2023).

EEA, 2023q, 'Use of auctioning revenues generated under the EU Emissions Trading System' (https://www.eea.europa.eu/ims/use-of-auctioning-revenues-generated) accessed 10 July 2023.

EEA, 'Mapmytree' (https://mapmytree.eea.europa.eu/) accessed 8 August 2023.

EEA and ACER, 2023a, 'Flexibility solutions to support a decarbonised and secure EU Electricity System', European Environment Agency. EEA/ACER Report 09/2023 (https://www.eea.europa.eu/en/newsroom/news/rapid-growth-in-renewables-calls).

EEA and ACER, 2023b, Flexibility Solutions to Support a Decarbonised and Secure EU Electricity System. EEA/ACER Report 09/2023 (https://www.eea.europa.eu/publications/flexibility-solutions-to-support) European Envionment Agency and European Union Agency for the Cooperation of Energy Regulators.

EEA ETC/CM, 2022, ETC/CME Report: trends and projections in the EU ETS 2022. ETC CM Report 2022/5 (https://www.eionet.europa.eu/etcs/etc-cm/products/etc-cm-report-2022-05/@@download/file/ETC%20Eionet%20report%205%202022.pdf).

EEA and Eurofund, 2021, Exploring the social challenges of low-carbon energy policies in Europe, No Briefing No 11/2021 (https://www.eea.europa.eu/publications/exploring-the-social-challenges-of).

EEFIG, 2023, Collecting and monitoring data on energy efficiency investments and financing across EU Member States and targeted economic sectors: final report. DOI number 10.2833/114382 Energy Efficiency Financial Institutions Group (EEFIG), LU (https://data.europa.eu/doi/10.2833/114382).

EEIST, 2022, 'Ten Principles for Policy Making in the Energy Transition | Department of Land Economy', EEIST flagship report (https://www.landecon.cam.ac.uk/news/eeist-project-launches-flagship-report-ten-principles-policy-making-energy-transition) accessed 7 November 2023.

EESC, 2021, Social Climate Fund, European Economic and Social Committee (https://www.eesc.europa.eu/en/our-work/opinions-information-reports/opinions/social-climate-fund) accessed 15 November 2023.

EGFSN, 2021, Skills for Zero Carbon: The Demand for Renewable Energy, Residential Retrofit and Electric Vehicle Deployment Skills to 2030, Expert Group on Future Skills Needs, Dublin, Ireland (https://www.skillsireland.ie/all-publications/2021/5119-dete-egfsn-skills-for-zero-carbon-web_.pdf) accessed 14 November 2023.

Ehlers, T., et al., 2022, 'The pricing of carbon risk in syndicated loans: Which risks are priced and why?', Journal of Banking & Finance 136, p. 106180 (DOI: 10.1016/j.jbankfin.2021.106180).

EHPA, 2023, European heat pump market and statistics report, 2023 (https://www.ehpa.org/european-heat-pump-market-and-statistics-report-2023/).

EIB, 2023a, 'ELENA – European Local ENergy Assistance' (https://www.eib.org/en/products/advisory-services/elena/index.htm) accessed 08 December 2023.

EIB, 2023b, Investment report 2022/2023. Resilience and renewal in Europe. (https://doi.org/10.2867/307689). European Investment Bank.

EIB, 2023c, The state of local infrastructure investment in Europe: EIB municipalities survey 2022 2023., European Investment Bank, Frankfurt (https://data.europa.eu/doi/10.2867/84744).

EIT, 2024, 'European Institute of Innovation & Technology (EIT) | EIT' (https://eit.europa.eu/) accessed 10 January 2024.

Eker, S., et al., 2019, 'Modelling the drivers of a widespread shift to sustainable diets', Nature Sustainability 2(8), pp. 725-735 (DOI: 10.1038/s41893-019-0331-1).

ELA, 2023, Report on labour shortages and surpluses: 2022., European Labour Authority, LU. DOI 10.2883/50704

Energy Efficiency Watch, 2022, The missing 'why' – how narratives can improve energy efficiency and security in Europe. Key results from the Energy Efficiency Watch 4 project. (https://fedarene.org/the-missing-why-how-narratives-can-improve-energy-efficiency-and-security-in-europe-key-results-from-eew4/) accessed 04 December 2023.

EnergyCities, 2022, Human capacity in local governments: the bottleneck of the building stock transition (https://energy-cities.eu/wp-content/uploads/2022/06/EnergyCities_PolicyPaper_CapacityNeeds_EN_FINAL.pdf) accessed 30 September 2023.

ENTSO-E, 2022, European Resource Adequacy Assessment, European Network of Transmissions Systems Operators for Electricity, Brussels, Belgium. (https://www.entsoe.eu/outlooks/eraa/2022/) accessed 9 October 2023.

EP, et al., 2016, Interinstitutional Agreement between the European Parliament, the Council of the European Union and the European Commission on Better Law-Making (OJ L 123, 12.5.2016, p. 1–14) (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32016Q0512(01)).

EP, 2021, Review of the Energy Taxation Directive, European Parliament Think Tank (https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2021)662636) accessed 6 October 2023.

EP, 2023, 'Procedure File: 2021/0430(CNS) | Legislative Observatory | European Parliament' (https://oeil.secure.europarl.europa.eu/oeil/popups/ficheprocedure.do?reference=2021/0430(CNS)&l=en).

EPRS, 2023, Policy instruments to tackle social inequalities related to climate change (https://www.europarl.europa.eu/RegData/etudes/STUD/2023/740081/IPOL_STU(2023)740081_EN.pdf) accessed 17 October 2023.

ESABCC, 2022a, Annual work programme 2023, European Scientific Advisory Board on Climate Change (https://climate-advisory-board.europa.eu/about/description-of-the-ecl-and-the-legal-mandate/2023-work-programme-of-the.pdf/@@display-file/file).

ESABCC, 2022b, Towards a climate-neutral and climate-resilient EU energy infrastructure: advice on scenario guidelines for trans-European networks for energy + European Scientific Advisory Board on Climate Change (https://climate-advisory-board.europa.eu/reports-and-publications/towards-a-climate-neutral-and-climate-resilient-eu-energy-infrastructure-recommendations-to-acer).

ESABCC, 2023a, Aligning policy responses to rising energy prices with the long-term climate neutrality objective, European Scientific Advisory Board on Climate Change (https://climate-advisory-board.europa.eu/reports-and-publications/addressing-the-energy-crisis-while-delivering-on-eus-climate-objectives-recommendations-to-policy-makers/2023-02-07-recommendationspolicyresponsesenergycrisisclimateneutrality.pdf/@@display-file/file).

ESABCC, 2023b, Scientific advice for the determination of an EU-wide 2040 climate target and a greenhouse gas budget for 2030–2050, European Scientific Advisory Board on Climate Change (https://climate-advisory-board.europa.eu/reports-and-publications/scientific-advice-for-the-determination-of-an-eu-wide-2040).

ESABCC, 2023c, Towards a decarbonised and climate-resilient EU energy infrastructure: recommendations on an energy system-wide cost-benefit analysis, European Scientific Advisory Board on Climate Change (https://climate-advisory-board.europa.eu/reports-and-publications/towards-a-decarbonised-and-climate-resilient-eu-energy-infrastructure-recommendations-on-an-energy-system-wide-cost-benefit-analysis).

ESPON, 2021, Cross-fertilisation of cohesion policy and spatial planning. Policy brief (https://www.espon.eu/cohesion-policy-and-spatial-planning) accessed 22 November 2023.

ETIP Wind, et al., 2021, Getting fit for 55 and set for 2050. Electrifying Europe with wind energy., ETIP Wind, Brussels, Belgium (https://etipwind.eu/publications/getting-fit-for-55/) accessed 14 December 2023.

EU, 1992, Council Directive 92/106/EEC of 7 December 1992 on the establishment of common rules for certain types of combined transport of goods between Member States (Directive 92/106/EEC).

EU, 1999, Directive 1999/62/EC of the European Parliament and of the Council of 17 June 1999 on the charging of heavy goods vehicles for the use of certain infrastructures (OJ L 187, 20.7.1999, p. 42-50).

EU, 2001, Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market (Directive 2001/77/EC).

EU, 2003, Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport (Directive 2003/30/EC).

EU, 2005, Directive 2005/36/EC of the European Parliament and of the Council of 7 September 2005 on the recognition of professional qualifications (consolidated).

EU, 2007, Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE) (OJ L 108, 25.4.2007, p. 1–14).

EU, 2009a, Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006 (OJ L 140, 5.6.2009, p. 114–135).

EU, 2009b, Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products (recast) (Text with EEA relevance) (OJ L 285, 31.10.2009, p. 10–35).

EU, 2010a, Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast) (OJ L 153, 18.6.2010, p. 13–35).

EU, 2010b, Regulation (EU) No 913/2010 of the European Parliament and of the Council of 22 September 2010 concerning a European rail network for competitive freight (Regulation (EU) No 913/2010).

EU, 2011, Regulation (EU) No 1227/2011 of the European Parliament and of the Council of 25 October 2011 on wholesale energy market integrity and transparency Text with EEA relevance (OJ L 326, 8.12.2011, p. 1–16).

EU, 2012, Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC (OJ L 315, 14.11.2012, p. 1-56).

EU, 2013a, Decision No 1386/2013/EU of the European Parliament and of the Council of 20 November 2013 on a General Union Environment Action Programme to 2020 'Living well, within the limits of our planet' (OJ L 354, 28.12.2013, pp. 171-200).

EU, 2013b, Regulation (EU) No 1315/2013 of the European Parliament and of the Council of 11 December 2013 on Union guidelines for the development of the trans-European transport network and repealing Decision No 661/2010/EU. (OJ L 348, 20.12.2013, p. 1-128).

EU, 2014, Directive 2014/24/EU of the European Parliament and of the Council of 26 February 2014 on public procurement and repealing Directive 2004/18/EC (Directive 2014/24/EU).

EU, 2016, Consolidated version of the Treaty on the Functioning of the European Union#Part Three - Union Policies and Internal Actions#Title III - Agriculture and Fisheries#Article 39 (ex Article 33 TEC) (http://data.europa.eu/eli/treaty/tfeu_2016/art_39/oj/eng).

EU, 2018a, Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste (text with EEA relevance) (OJ L 150, 14.6.2018, p. 109-140).

EU, 2018b, Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast) (OJ L 328, 21.12.2018, p. 82–209).

EU, 2018c, Regulation (EU) 2018/842 of the European Parliament and of the Council of 30 May 2018 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and amending Regulation (EU) No 525/2013 (OJ L 156, 19.6.2018, p. 26-42).

EU, 2018d, Regulation (EU) 2018/956 of the European Parliament and of the Council of 28 June 2018 on the monitoring and reporting of CO2 emissions from and fuel consumption of new heavy-duty vehicles ((EU) 2018/956).

EU, 2018e, Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action (OJ L 328, 21.12.2018, p. 1-77).

EU, 2019a, Directive (EU) 2019/904 of the European Parliament and of the Council of 5 June 2019 on the reduction of the impact of certain plastic products on the environment (OJ L 155, 12.6.2019, p. 1-19).

EU, 2019b, Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU (recast) (OJ L 158, 14.6.2019, p. 125–199).

EU, 2019c, Directive (EU) 2019/1161 of the European Parliament and of the Council of 20 June 2019 amending Directive 2009/33/EC on the promotion of clean and energy-efficient road transport vehicles.

EU, 2019d, Regulation (EU) 2019/631 of the European Parliament and of the Council of 17 April 2019 setting CO2 emission performance standards for new passenger cars and for new light commercial vehicles, and repealing Regulations (EC) No 443/2009 and (EU) No 510/2011 (OJ L 111, 25.4.2019, p. 13-53).

EU, 2019e, Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity (recast) (OJ L 158, 14.6.2019, p. 54–124).

EU, 2019f, Regulation (EU) 2019/1242 of the European Parliament and of the Council of 20 June 2019 setting CO2 emission performance standards for new heavy-duty vehicles and amending Regulations (EC) No 595/2009 and (EU) 2018/956 of the European Parliament and of the Council and Council Directive 96/53/EC (OJ L 198, 25.7.2019, p. 202–240).

EU, 2020, Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088 (OJ L 198, 22.6.2020, p. 13-43).

EU, 2021a, Regulation (EU) 2021/241 of the European Parliament and of the Council of 12 February 2021 establishing the Recovery and Resilience Facility (OJ L 57, 18.2.2021, p. 17–75).

EU, 2021b, Regulation (EU) 2021/1056 of the European Parliament and of the Council of 24 June 2021 establishing the Just Transition Fund (OJ L 231, 30.6.2021, p. 1–20).

EU, 2021c, Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality (OJ L 243, 9.7.2021, p. 1–17).

EU, 2021d, Regulation (EU) 2021/2115 of the European Parliament and of the Council of 2 December 2021 establishing rules on support for strategic plans to be drawn up by Member States under the common agricultural policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD) and repealing Regulations (EU) No 1305/2013 and (EU) No 1307/2013 (http://data.europa.eu/eli/reg/2021/2115/oj/eng).

EU, 2022a, Commission Delegated Regulation (EU) 2022/1214 of 9 March 2022 amending Delegated Regulation (EU) 2021/2139 as regards economic activities in certain energy sectors and Delegated Regulation (EU) 2021/2178 as regards specific public disclosures for those economic activities

(C/2022/631), (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2022.188.01.0001.01.ENG).

EU, 2022b, Council Regulation (EU) 2022/1369 of 5 August 2022 on coordinated demand-reduction measures for gas (OJ L 206, 8.8.2022, p. 1–10).

EU, 2022c, Council Regulation (EU) 2022/2577 of 22 December 2022 laying down a framework to accelerate the deployment of renewable energy (OJ L 335, 29.12.2022, p. 36–44).

EU, 2022d, Directive (EU) 2022/362 of the European Parliament and of the Council of 24 February 2022 amending Directives 1999/62/EC, 1999/37/EC and (EU) 2019/520, as regards the charging of vehicles for the use of certain infrastructures (OJ L 69, 4.3.2022, p. 1-39).

EU, 2022e, Regulation (EU) 2022/869 of the European Parliament and of the Council of 30 May 2022 on guidelines for trans-European energy infrastructure (OJ L 152, 3.6.2022, p. 45–102).

EU, 2023a, Commission Recommendation of 14 March 2023 on Energy Storage – Underpinning a decarbonised and secure EU energy system ((2023/C 103/01)).

EU, 2023b, Decision (EU) 2023/852 of the European Parliament and of the Council of 19 April 2023 amending Decision (EU) 2015/1814 as regards the number of allowances to be placed in the market stability reserve for the Union greenhouse gas emission trading system until 2030 (Text with EEA relevance) (OJ L).

EU, 2023c, Directive (EU) 2023/959 of the European Parliament and of the Council of 10 May 2023 amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union and Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading system.

EU, 2023d, Directive (EU) 2023/959 of the European Parliament and of the Council of 10 May 2023 amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union and Decision (EU) 2015-1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading system (Directive (EU) 2023/959).

EU, 2023e, Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955 (recast) ((EU) 2023/1791).

EU, 2023f, Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652.

EU, 2023g, Directive of the European Parliament and of the Council on energy efficiency and amending Regulation (EU) 2023/955 (recast) (2021/0203 (COD)).

EU, 2023h, 'InvestEU Fund' (https://investeu.europa.eu/what-investeu-programme/investeu-fund_en).

EU, 2023i, Regulation (EU) 2023/435 of the European Parliament and of the Council of 27 February 2023 amending Regulation (EU) 2021/241 as regards REPowerEU chapters in recovery and resilience plans and amending Regulations (EU) No 1303/2013, (EU) 2021/1060 and (EU) 2021/1755, and Directive 2003/87/EC (2023/435).

EU, 2023j, Regulation (EU) 2023/839 of the European Parliament and of the Council of 19 April 2023 Amending Regulation (EU) 2018/841 as regards the scope, simplifying the reporting and compliance rules, and setting out the targets of the Member States for 2030, and Regulation (EU) 2018/1999 as regards improvements in monitoring, reporting, tracking of progress and review (Regulation (EU) 2023/839).

EU, 2023k, Regulation (EU) 2023/851 of the European Parliament and of the Council of 19 April 2023 amending Regulation (EU) 2019/631 as regards strengthening the CO2 emission performance standards for new passenger cars and new light commercial vehicles in line with the Union's increased climate ambition (OJ L 110, 25.4.2023, p. 5–20).

EU, 2023l, Regulation (EU) 2023/955 of the European Parliament and of the Council of 10 May 2023 establishing a Social Climate Fund and amending Regulation (EU) 2021/1060 (OJ L 130, 16.5.2023, p. 1–51).

EU, 2023m, Regulation (EU) 2023/955 of the European Parliament and of the Council of 10 May 2023 establishing a Social Climate Fund and amending Regulation (EU) 2021/1060 (OJ L 130, 16.5.2023, p. 1–51).

EU, 2023n, Regulation (EU) 2023/956 of the European Parliament and of the Council of 10 May 2023 establishing a carbon border adjustment mechanism ((EU) 2023/956).

EU, 2023o, 'Regulation (EU) 2023/1804 of the European Parliament and of the Council of 13 September 2023 on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU (Text with EEA relevance)' (https://eur-lex.europa.eu/eli/reg/2023/1804/oj) accessed 27 September 2023.

EU, 2023p, Regulation (EU) 2023/1805 of the European Parliament and of the Council of 13 September 2023 on the use of renewable and low-carbon fuels in maritime transport, and amending Directive 2009/16/EC (Regulation (EU) 2023/1805).

EU, 2023q, Regulation (EU) 2023/2405 of the European Parliament and of the Council of 18 October 2023 on ensuring a level playing field for sustainable air transport (ReFuelEU Aviation) (Regulation (EU) 2023/2405).

EUI, 2023, 'European Urban Initiative - Who we are' (https://www.urban-initiative.eu/what-european-urban-initiative) accessed 17 October 2023.

Euractiv, 2023, 'EU food systems law to lean on green labeling, procurement' (https://www.euractiv.com/section/agriculture-food/news/eu-food-systems-law-to-lean-on-green-labelling-procurement/) accessed 6 July 2023.

EurActiv, 2023, 'Why adopting the Social Climate Fund is the right choice for the EU', www.euractiv.com (https://www.euractiv.com/section/energy-environment/opinion/why-adopting-the-social-climate-fund-is-the-right-choice-for-the-eu/) accessed 22 November 2023.

Eurofer, 2022, European Steel in Figures 2022 (https://www.eurofer.eu/assets/publications/brochures-booklets-and-factsheets/european-steel-in-figures-2022/European-Steel-in-Figures-2022-v2.pdf) accessed 12 October 2023.

Eurofund, 2023, Living and working in Europe 2022., European Foundation for the Improvement of Living and Working Conditions, LU (https://data.europa.eu/doi/10.2806/65484).

Eurogas, et al., 2023, Challenges and Opportunities for Employment in the Gas Sector in the Context of the European Energy Transition: Ensuring a Just Transition for Workers (https://www.eurogas.org/wp-content/uploads/2023/01/Syndex_Final_Report_January_2023.pdf) accessed 14 September 2023.

European Construction Sector Observatory, 2018, Strengthening the Internal Market for Construction (https://single-market-economy.ec.europa.eu/document/download/71536b81-b70a-48ff-8edb-a75447548d1c_en) accessed 05 January 2024.

European Construction Sector Observatory, 2020, Improving the human capital basis, European Commission (https://single-market-economy.ec.europa.eu/document/download/6637d5a4-c932-4492-904d-caf5f1878264_en) accessed 25 November 2023.

European Parliament, 2023a, draft EP resolution on the proposal for a directive of the European Parliament and of the Council on common rules for the internal markets in renewable and natural gases and in hydrogen - recast (2021/0425(COD)).

European Parliament, 2023b, 'Legislative proposal on Corporate Sustainability Due Diligence | Legislative Train Schedule', European Parliament (https://www.europarl.europa.eu/legislative-train/theme-an-economy-that-works-for-people/file-legislative-proposal-on-sustainable-corporate-governance) accessed 30 November 2023.

European Parliament, 2023c, 'Revision of Regulation (EC) No 1831/2003 on additives for use in animal nutrition (REFIT) | Legislative Train Schedule', European Parliament (https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/file-revisio-of-the-feed-additives-regulation) accessed 30 November 2023.

European Parliament, 2023d, 'Revision of the EU waste framework directive - textiles and food waste | Legislative Train Schedule', European Parliament (https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/file-revision-of-the-eu-waste-framework) accessed 1 December 2023.

European University Institute, 2022, The 5th EU electricity market reform: a renewable jackpot for all Europeans package?, (https://data.europa.eu/doi/10.2870/407931), Publications Office.

European University Institute., 2022, The role of CCUS on the EU road to climate neutrality. Policy Brief., Publications Office, LU (https://fsr.eui.eu/publications/?handle=1814/73595) accessed 14 September 2023.

Eurostat, 2013, Environmental taxes. A statistical guide, No ISSN 2315-0815 (https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/ks-gq-13-005).

Eurostat, 2021, 'Energy intensity of GDP in chain linked volumes (2010) [NRG_IND_EI]' (https://ec.europa.eu/eurostat/databrowser/view/NRG_IND_EI__custom_930709/default/table) accessed 22 May 2021.

Eurostat, 2022a, Environmental tax statistics - detailed analysis (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Environmental_tax_statistics_-_detailed_analysis) accessed 6 October 2023.

Eurostat, 2022b, Farmers and the agricultural labour force - statistics, Eurostat (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Farmers_and_the_agricultural_labour_force_-_statistics) accessed 4 September 2023.

Eurostat, 2022c, 'Gross fixed capital formation by AN_F6 asset type' (https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nama_10_an6&lang=en) accessed 18 July 2022.

Eurostat, 2023a, Circular material use rate by material type, ENV_AC_CURM (https://ec.europa.eu/eurostat/databrowser/view/ENV_AC_CURM/default/table?lang=en) accessed 28 November 2023.

Eurostat, 2023b, 'Complete energy balances (NRG_BAL_C)' (https://ec.europa.eu/eurostat/databrowser/view/nrg_bal_c/default/table?lang=en) accessed 24 October 2023.

Eurostat, 2023c, 'Degree of urbanisation: background' (https://ec.europa.eu/eurostat/web/degree-of-urbanisation/background) accessed 13 March 2023.

Eurostat, 2023d, Electricity production capacities by main fuel groups and operator, NRG_INF_EPC (https://ec.europa.eu/eurostat/databrowser/view/NRG_INF_EPC/default/table?lang=en) accessed 28 November 2023.

Eurostat, 2023e, 'Energy balance visualisation tool', Energy balance visualisation tool (https://ec.europa.eu/eurostat/cache/infographs/energy_balances/enbal.html) accessed 24 April 2023.

Eurostat, 2023f, Environmental economy – statistics on employment and growth, (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Environmental_economy_%E2%80%93_statistics_on_employment_and_growth&oldid=583805#Employment_by_environmental_domain) accessed 22 July 2023.

Eurostat, 2023g, EU trade since 2002 by CPA 2.1 (DS-059268), (https://ec.europa.eu/eurostat/databrowser/view/ds-059268/legacyMultiFreq/table?lang=en) accessed 20 November 2023.

Eurostat, 2023h, Final energy consumption in the residential sector by use, EU, 2021, nrg_bal_c (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_consumption_in_households) accessed 15 September 2023.

Eurostat, 2023i, Food waste and food waste prevention by NACE Rev. 2 activity - tonnes of fresh mass, ENV_WASFW (https://ec.europa.eu/eurostat/databrowser/view/env_wasfw/default/table?lang=en) accessed 28 November 2023.

Eurostat, 2023j, GERD by sector of performance, RD_E_GERDTOT (https://ec.europa.eu/eurostat/databrowser/product/page/rd_e_gerdtot) accessed 28 November 2023.

Eurostat, 2023k, Government deficit/surplus, debt and associated data, gov_10dd_edpt1 (https://ec.europa.eu/eurostat/databrowser/view/gov_10dd_edpt1/default/table?lang=en) accessed 14 September 2023.

Eurostat, 2023l, 'Greenhouse gas emission statistics - carbon footprints' (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Greenhouse_gas_emission_statistics_-_carbon_footprints) accessed 26 September 2023.

Eurostat, 2023m, 'Gross value added and income by A*10 industry breakdown' (https://ec.europa.eu/eurostat/databrowser/view/NAMA_10_A10__custom_1841738/bookmark/table?lang=en&bookmarkId=45bdc71c-47da-4f49-b799-3d8855e3ddb0) accessed 17 October 2023.

Eurostat, 2023n, HICP - monthly data (annual rate of change), PRC_HICP_MANR (https://ec.europa.eu/eurostat/databrowser/view/PRC_HICP_MANR/default/table?lang=en) accessed 28 November 2023.

Eurostat, 2023o, Inability to keep home adequately warm - EU-SILC survey, ILC_MDES01 (https://ec.europa.eu/eurostat/databrowser/view/ILC_MDES01/default/table?lang=en).

Eurostat, 2023p, Median equivalised disposable income and magnitude of social transfers (PPS per inhabitant, 2022), ILC_DI03, ILC_DI13, ILC_DI14 (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:F1Median_equivalised_disposable_income_and_magnitude_of_social_transfers_(PPS_per_inhabitant,_2022).png) accessed 28 November 2023.

Eurostat, 2023q, Quarterly greenhouse gas emissions in the EU (ENV_AC_AIGG_Q), (https://ec.europa.eu/eurostat/databrowser/view/env_ac_aigg_q/default/table?lang=en) accessed 21 November 2023.

Eurostat, 2023r, Short assessment of renewable energy sources (SHARES), (https://ec.europa.eu/eurostat/documents/38154/4956088/SUMMARY-results-SHARES_2021.xlsx/a3ec29ed-95d3-8dfd-6f2f-4acd1eafdc91?t=1673009663750) accessed 21 November 2023.

Eurostat, 2023s, Sold production, exports and imports (DS-056120), (https://ec.europa.eu/eurostat/databrowser/view/DS-056120__custom_7015045/bookmark/table?lang=en&bookmarkId=f30845e4-5f1c-467b-a26a-133f3a366f9d) accessed 16 September 2023.

Evans, N., et al., 2023, Policy consistency: What it means, how to measure it, and links with other processes., Policy Paper, Ecologic (https://www.ecologic.eu/19265) accessed 22 June 2022.

Evans, N. and Duwe, M., 2021, Climate governance systems in Europe: the role of national advisory bodies, Ecologic Institute, Berlin (https://www.ecologic.eu/sites/default/files/publication/2021/Evans-Duwe-Climate-governance-in-Europe-the-role-of-national-advisory-bodies-2021-Ecologic-Institute.pdf) accessed 22 June 2022.

Evans, S., et al., 2020, Border Carbon Adjustments and Industrial Competitiveness in a European Green Deal, Energy Policy Research Group, University of Cambridge (https://www.jstor.org/stable/resrep30378) accessed 15 October 2023.

FAO, 2020, FAO Statistics on Forestry Production and Trade, FOASTAT-Forestry (https://www.fao.org/faostat/en/#data/FO), FAOSTAT.

FAO, 2023, FAO Food Balances, (https://www.fao.org/faostat/en/#data/FBS) accessed 29 June 2023, FAOSTAT.

Fawcett, T., et al., 2019, 'Energy efficiency obligation schemes: their future in the EU', Energy Efficiency 12(1), pp. 57-71 (DOI: 10.1007/s12053-018-9657-1).

Fellmann, T., et al., 2021, 'Greenhouse gas mitigation technologies in agriculture: Regional circumstances and interactions determine cost-effectiveness', Journal of Cleaner Production 317, p. 128406 (DOI: 10.1016/j.jclepro.2021.128406).

Feng, T., et al., 2022, 'Life cycle assessment of lithium nickel cobalt manganese oxide batteries and lithium iron phosphate batteries for electric vehicles in China', Journal of Energy Storage 52, p. 104767 (DOI: 10.1016/j.est.2022.104767).

Ferrari, A., 2023, 'Is the reformed ETS fit for the new EU climate ambition?', Florence School of Regulation (https://fsr.eui.eu/is-the-reformed-emissions-trading-system-fit-for-the-new-eu-climate-ambition/) accessed 16 October 2023.

Finger, M., et al., 2021, The Governance of Rail Freight Corridors, European University Institute. DOI 10.2870/800530 (https://op.europa.eu/en/publication-detail/-/publication/96fe7ce8-8088-11eb-9ac9-01aa75ed71a1).

Forzieri, G., et al., 2022, 'Emerging signals of declining forest resilience under climate change', Nature 608(7923), pp. 534-539 (DOI: 10.1038/s41586-022-04959-9).

Franco-German working group on EU institutional reform, 2023, Sailing on High Seas: Refoming and Enlarging the EU for the 21st Century, Paris-Berlin (https://www.auswaertiges-amt.de/blob/2617206/4d0e0010ffcd8c0079e21329bbbb3332/230919-rfaa-deu-fra-bericht-data.pdf) accessed 20 September 2023.

Friant, M. C., et al., 2020, 'A typology of circular economy discourses: Navigating the diverse visions of a contested paradigm', Resources, Conservation and Recycling 161, p. 104917 (DOI: 10.1016/j.resconrec.2020.104917).

FS-UNEP and BNEF, 2018, Global trends in renewable energy investment 2018, Frankfurt School-United Nations Environment Programme and Bloomberg New Energy Finance, Frankfurt, Germany (Global trends in renewable energy investment 2018).

FTI consulting, 2023, 'Approaching the ETS Endgame in Europe - Get Ready for EU', https://getready4.eu/ (https://getready4.eu/approaching-the-ets-endgame-in-europe/) accessed 16 October 2023.

Gaddy, B., et al., 2016, Venture capital and cleantech: the wrong model for clean energy innovation, MIT Energy Initiative, Cambridge, MA (https://energy.mit.edu/publication/venture-capital-cleantech/) accessed 29 September 2023.

Gaspard, A., et al., 2023, 'Introducing sufficiency in the building sector in net-zero scenarios for France', Energy and Buildings 278, p. 112590 (DOI: 10.1016/j.enbuild.2022.112590).

Gaud, P., et al., 2007, 'Debt-equity choice in Europe', International Review of Financial Analysis 16(3), pp. 201-222 (DOI: 10.1016/j.irfa.2006.08.003).

Gillespie, T. and Sorge, P., 2022, 'German power plants warn of coal shortage amid low river levels. Bloomberg' (https://www.bloomberg.com/news/articles/2022-09-02/german-power-plants-warn-of-coal-shortage-amid-low-river-levels?leadSource=uverify%20wall) accessed 3 October 2023.

Giuntoli, J. and Searle, S., 2019, Does bioenergy demand improve forest management?, White Paper, International Council on Clean Transportation (https://theicct.org/sites/default/files/publications/ICCT_bioenergy_demand_20190719.pdf).

Glachant, J.-M., 2022, 'Electricity market reform is no silver bullet for Europe's energy crisis', EurActiv, 16 December 2022 (https://www.euractiv.com/section/electricity/opinion/electricity-market-reform-is-no-silver-bullet-for-europes-energy-crisis/).

Glicker, J., et al., 2022, POSITIVE ENERGY NEIGHBOURHOODS DRIVERS OF TRANSFORMATIONAL CHANGE (https://www.bpie.eu/wp-content/uploads/2022/06/OpenLab-Positive-Energy-Neighbourhoods_9.pdf) accessed 18 November 2023.

Goldstein, A., et al., 2020, 'Patenting and business outcomes for cleantech startups funded by the Advanced Research Projects Agency-Energy', Nature Energy 5(10), pp. 803-810 (DOI: 10.1038/s41560-020-00683-8).

Gomez, J. and Vassallo, J. M., 2020, 'Has heavy vehicle tolling in Europe been effective in reducing road freight transport and promoting modal shift?', Transportation 47(2), pp. 865-892 (DOI: 10.1007/s11116-018-9922-3).

Gómez Vilchez, J. J., et al., 2023, 'The new electric SUV market under battery supply constraints: Might they increase CO2 emissions?', Journal of Cleaner Production 383, p. 135294 (DOI: 10.1016/j.jclepro.2022.135294).

Görlach, B., et al., 2022, A fair and solidarity-based EU Emissions Trading System for Buildings and Road Transport, Kopernikus Projekt Ariadne (https://ariadneprojekt.de/media/2022/06/Ariadne-Report_ETS2-SCF_June2022.pdf) accessed 12 October 2023.

Goulder, L. H. and Parry, I. W. H., 2008, 'Instrument Choice in Environmental Policy', Review of Environmental Economics and Policy 2(2), pp. 152-174 (DOI: 10.1093/reep/ren005).

Grassano, N., et al., 2020, The 2020 EU Industrial R&D Investment Scoreboard, Publications Office of the European Union, Luxembourg (https://iri.jrc.ec.europa.eu/sites/default/files/2020-12/EU%20RD%20Scoreboard%202020%20FINAL%20online.pdf) accessed 20 December 2022.

Grubb, M., et al., 2021, 'Induced innovation in energy technologies and systems: a review of evidence and potential implications for CO2 mitigation', Environmental Research Letters 16(4), p. 043007 (DOI: 10.1088/1748-9326/abde07).

Grubb, M., et al., 2022, Separating electricity from gas prices through Green Power Pools: Design options and evolution. Working paper 193, Institute for New Economic Thinking (https://www.ineteconomics.org/research/research-papers/separating-electricity-from-gas-prices-through-green-power-pools-design-options-and-evolution) accessed 20 November 2022.

GSIA, 2020, 'Trends Report 2020 | GSIA' (https://www.gsi-alliance.org/trends-report-2020/) accessed 23 November 2023.

Gurría Albusac, P., et al., 2021, Medium-term Outlook commodity flows, (http://data.europa.eu/89h/310ee8b3-a2bf-4cd7-9ae8-52582708bb1a), Joint Research Centre.

Guyomard, H., et al., 2021, 'Review: Why and how to regulate animal production and consumption: The case of the European Union', Animal 15, p. 100283 (DOI: 10.1016/j.animal.2021.100283).

Guyomard, H., et al., 2023, 'How the Green Architecture of the 2023–2027 Common Agricultural Policy could have been greener', Ambio 52(8), pp. 1327-1338 (DOI: 10.1007/s13280-023-01861-0).

Gylling, M., et al., 2023, Potential Danish biomass production and utilization in 2030, DCA Report No 2019, University of Copenhagen, Danish Centre for Food and Agriculture (https://static-curis.ku.dk/portal/files/373616325/DCArapport219.pdf).

Haegel, N. M., et al., 2023, 'Photovoltaics at multi-terawatt scale: Waiting is not an option', Science 380(6640), pp. 39-42 (DOI: 10.1126/science.adf6957).

Hancher, L., 2022, 'EU Energy Governance—Moving Targets and Flexible Ambitions between Opacity and Opportunism?', Yearbook of European Law, p. yeac010 (DOI: 10.1093/yel/yeac010).

Hancher, L. and Maria Salerno, F., 2021a, 'State aid in the energy sector', in: Hancher, L. and Piernas López, J. J. (eds), Research Handbook on European State Aid Law, Edward Elgar Publishing.

Hancher, L. and Maria Salerno, F., 2021b, 'State aid in the energy sector', in: Hancher, L. and Piernas López, J. J. (eds), Research Handbook on European State Aid Law, Edward Elgar Publishing. https://doi.org/10.4337/9781789909258.00011

Hänsel, M. C., et al., 2022, 'Optimal carbon taxation and horizontal equity: A welfare-theoretic approach with application to German household data', Journal of Environmental Economics and Management 116, p. 102730 (DOI: 10.1016/j.jeem.2022.102730).

Hao, H., et al., 2019, 'Impact of transport electrification on critical metal sustainability with a focus on the heavy-duty segment', Nature Communications 10(1), p. 5398 (DOI: 10.1038/s41467-019-13400-1).

He Waka Eke Noa, 2022, Recommendations for pricing agricultural emissions: report to ministers, No ISBN No: 978-0-473-63459-9, He Waka Eke Noa, New Zealand (https://hewakaekenoa.nz/report/).

Henderson, B. and Verma, M., 2021, Global assessment of the carbon leakage implications of carbon taxes on agricultural emissions, OECD, Paris (https://www.oecd-ilibrary.org/agriculture-and-food/global-assessment-of-the-carbon-leakage-implications-of-carbon-taxes-on-agricultural-emissions_fc304fad-en) accessed 26 October 2023.

Henze, V., 2022, 'ESG May Surpass $41 Trillion Assets in 2022, But Not Without Challenges, Finds Bloomberg Intelligence | Press | Bloomberg LP', Bloomberg L.P.

Hertwich, Edgar, et al., 2019, Resource Efficiency and Climate Change: Material Efficiency Strategies for a Low-Carbon Future, Zenodo (https://zenodo.org/record/3542680) accessed 14 August 2020.

Higham, C., et al., 2021, Accountability mechanisms in climate change framework laws, (https://www.lse.ac.uk/granthaminstitute/wp-content/uploads/2021/11/Accountability-mechanisms-in-climate-change-framework-laws.pdf), Grantham Research Institute on Climate Change and the Environment and Centre for Climate Change Economics and Policy.

Hintermann, B., et al., 2020, The effect of climate policy on productivity and cost pass-through in the German manufacturing sector, Working Paper No 2020/11, WWZ Working Paper (https://www.econstor.eu/handle/10419/240420) accessed 9 October 2023.

Holz, F., et al., 2021, 'A 2050 perspective on the role for carbon capture and storage in the European power system and industry sector', Energy Economics 104, p. 105631 (DOI: 10.1016/j.eneco.2021.105631).

Hood, C., 2011, Summing up the parts: combining policy instruments for least-cost climate mitigation strategies, IEA.

Hook, J. N., et al., 2023, 'Minimalism, voluntary simplicity, and well-being: A systematic review of the empirical literature', The Journal of Positive Psychology 18(1), pp. 130-141 (DOI: 10.1080/17439760.2021.1991450).

Howarth, R. W. and Jacobson, M. Z., 2021, 'How green is blue hydrogen?', Energy Science & Engineering 9(10), pp. 1676-1687 (DOI: 10.1002/ese3.956).

Humpenöder, F., et al., 2020, 'Peatland protection and restoration are key for climate change mitigation', Environmental Research Letters 15(10), p. 104093 (DOI: 10.1088/1748-9326/abae2a).

Huovila, A., et al., 2022, 'Carbon-neutral cities: Critical review of theory and practice', Journal of Cleaner Production 341, p. 130912 (DOI: 10.1016/j.jclepro.2022.130912).

ICCT, et al., 2021, Life-cycle Greenhouse Gas Emissions of Biomethane and Hydrogen Pathways in the European Union, International Council on Clean Transportation, Washington DC, US (https://theicct.org/wp-content/uploads/2021/10/LCA-gas-EU-white-paper-A4-v5.pdf) accessed 4 September 2023.

IEA, 2020, Energy Efficiency 2020, International Energy Agency, Paris, France (https://www.iea.org/reports/energy-efficiency-2020/energy-efficiency-jobs-and-the-recovery).

IEA, 2021a, Patents and the energy transition - Global trends in clean energy technology innovation April 2021, International Energy Agency, Paris (https://www.iea.org/reports/patents-and-the-energy-transition).

IEA, 2021b, The role of critical minerals in clean energy transitions, World Energy Outlook Special Report, International Energy Agency, Paris (https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions).

IEA, 2022a, 'Electric Vehicles: Total Cost of Ownership tool' (https://www.iea.org/data-and-statistics/data-tools/electric-vehicles-total-cost-of-ownership-tool) accessed 26 June 2023.

IEA, 2022b, Global EV Outlook 2022. Securing supplies for an electric future., International Energy Agency, Paris (https://iea.blob.core.windows.net/assets/ad8fb04c-4f75-42fc-973a-6e54c8a4449a/GlobalElectricVehicleOutlook2022.pdf).

IEA, 2022c, 'Investment spending on electricity grids, 2015-2021' (https://www.iea.org/data-and-statistics/charts/investment-spending-on-electricity-grids-2015-2021).

IEA, 2022d, Steering Electricity Markets Towards a Rapid Decarbonisation, International Energy Agency. (https://www.iea.org/reports/steering-electricity-markets-towards-a-rapid-decarbonisation), IEA.

IEA, 2022e, Steering Electricity Markets towards a Rapid Decarbonisation, (https://www.iea.org/reports/steering-electricity-markets-towards-a-rapid-decarbonisation), IEA.

IEA, 2022f, The Role of Critical Minerals in Clean Energy Transitions, World Energy Outlook Special Report, International Energy Agency, Paris, France (https://iea.blob.core.windows.net/assets/ffd2a83b-8c30-4e9d-980a-52b6d9a86fdc/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf).

IEA, 2022g, Wind Electricity, International Energy Agency, Paris, France (https://www.iea.org/reports/wind-electricity).

IEA, 2023a, CCUS Policies and Business Models Building a commercial market, International Energy Agency, Paris (https://iea.blob.core.windows.net/assets/d0cb5c89-3bd4-4efd-8ef5-57dc327a02d6/CCUSPoliciesandBusinessModels.pdf).

IEA, 2023b, Cost of Capital Observatory, Paris (https://www.iea.org/reports/cost-of-capital-observatory/dashboard).

IEA, 2023c, Energy Technology RD&D Budgets, (https://www.iea.org/data-and-statistics/data-product/energy-technology-rd-and-d-budget-database-2).

IEA, 2023d, 'Fossil fuels consumption subsidies 2022' (https://www.iea.org/reports/fossil-fuels-consumption-subsidies-2022)

IEA, 2023e, Global EV outlook 2023. Catching up with climate ambitions, International Energy Agency (https://iea.blob.core.windows.net/assets/dacf14d2-eabc-498a-8263-9f97fd5dc327/GEVO2023.pdf).

IEA, 2023f, 'Global EV Policy Explorer' (https://www.iea.org/data-and-statistics/data-tools/global-ev-policy-explorer) accessed 27 June 2023.

IEA, 2023g, Global Methane Tracker 2023, International Energy Agency, Paris (https://www.iea.org/reports/global-methane-tracker-2023).

IEA, 2023h, Renewable energy market update: outlook for 2023 and 2024 (https://www.iea.org/reports/renewable-energy-market-update-june-2023).

IEA, 2023i, Renewables 2022. Analysis and forecast to 2027., International Energy Agency, Paris, France (https://iea.blob.core.windows.net/assets/ada7af90-e280-46c4-a577-df2e4fb44254/Renewables2022.pdf).

IEA, 2023j, The State of Clean Technology Manufacturing., International Energy Agency (https://iea.blob.core.windows.net/assets/0a421001-6157-436d-893c-c37eeab54967/TheStateofCleanTechnologyManufacturing.pdf).

IEA and IRENA, 2017, Perspectives for the energy transition: investment needs for a low-carbon energy system, International Energy Agency and International Renewable Energy Agency, Paris (https://www.irena.org/publications/2017/Mar/Perspectives-for-the-energy-transition-Investment-needs-for-a-low-carbon-energy-system) accessed 13 August 2019.

IEAGHG, 2019, Zero-emission carbon capture and storage in power plants using higher capture rates, International Energy Agency (https://documents.ieaghg.org/index.php/s/CLIZIvBI6OdMFnf).

IEEP, 2021, Just transition in the EU agriculture and land use sector, Institute for European Environmental Policy (https://ieep.eu/publications/just-transition-in-the-eu-agriculture-and-land-use-sector/).

ILO, 2015, Guidelines for a just transition towards environmentally sustainable economies and societies for all, International Labour Organization, Geneva, Switzerland. ISBN 978-92-2-130627-6 (https://www.ilo.org/global/topics/green-jobs/publications/WCMS_432859/lang--en/index.htm).

IMF, 2019, Fiscal Monitor, October 2019: How to Mitigate Climate Change, ISBN 978-1-51351-532-8 (https://www.imf.org/en/Publications/FM/Issues/2019/09/12/fiscal-monitor-october-2019).

IMF, 2023, Support for Climate Action Hinges on Public Understanding of Policy, (https://www.imf.org/en/Blogs/Articles/2023/02/09/support-for-climate-action-hinges-on-public-understanding-of-policy) accessed 12 November 20223.

Ioakimidis, C., et al., 2019, 'Life Cycle Assessment of a Lithium Iron Phosphate (LFP) Electric Vehicle Battery in Second Life Application Scenarios', Sustainability 11(9), p. 2527 (DOI: 10.3390/su11092527).

IPCC, 2006, 2006 IPCC guidelines for national greenhouse gas inventories, Institute for Global Environmental Strategies, Hanawa, Japan. ISBN 4-88788-032-4 (https://www.ipcc-nggip.iges.or.jp/public/2006gl/).

IPCC, 2007a, Changes in Atmospheric Constituents and in Radiative Forcing. Chapter 2 of Climate Change 2007: the Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the IPCC, Intergovernmental Panel Climate Change (https://www.ipcc.ch/report/ar4/wg1/).

IPCC, 2007b, Climate Change 2007: Working Group I: The Physical Science Basis, (https://archive.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html).

IPCC, 2013, Anthropogenic and Natural Radiative Forcing. Chapter 8 of Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC (https://www.ipcc.ch/report/ar5/wg1/).

IPCC, 2018, Global warming of 1.5 °C, Intergovernmental Panel on Climate Change, Geneva (http://www.ipcc.ch/report/sr15/).

IPCC, 2022a, 'Agriculture, Forestry and Other Land Uses (AFOLU)'. Chapter 7 in Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, NY, USA.

IPCC, 2022b, 'Buildings', Chapter 9 in Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, NY, USA.

IPCC, 2022c, Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change., Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2022d, Climate Change 2022: Mitigation of Climate Change - Working Group III contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Intergovernmental Panel on Climate (https://www.ipcc.ch/report/sixth-assessment-report-working-group-3/).

IPCC, 2022e, 'Cross-sectoral perspectives'. Chapter 12 in Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, NY, USA.

IPCC, 2022f, 'Demand, Services and Social Aspects of Mitigation'. Chapter 5 in Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, NY, USA.

IPCC, 2022g, 'Energy Systems'. Chapter 6 in Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, NY, USA.

IPCC, 2022h, 'Industry'. Chapter 11 in IPCC 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, NY, USA.

IPCC, 2022i, 'Mitigation pathways compatible with long-term goals'. Chapter 3 in Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, NY, USA.

IPCC, 2022j, 'Transport'. Chapter 10 in Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, NY, USA.

IPCC, 2022k, 'Urban Systems and Other Settlements'. Chapter 8 in Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, NY, USA.

IPCC, 2022l, Working Group III contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change -Summary for Policy Makers, Cambridge University Press, Cambridge, UK and New York, NY, USA.

IPCC, 2022m, 'Investment and Finance'. Chapter 15 in Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, NY, USA.

IPCC, 2022n, Working Group III contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change -Technical Summary, Cambridge University Press, Cambridge, UK and New York, NY, USA.

IPCC, 2022o, 'Innovation, Technology Development and Transfer'. Chapter 16 in Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, NY, USA.

IPCC, 2022p, 'National and sub-national policies and institutions.', Chapter 13 in Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, NY, USA.

IRENA, 2022a, Renewable Energy and Jobs Annual Review 2022, International Renewable Energy Agency and International Labour Organization. ISBN 978-92-9260-364-9 (https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Sep/IRENA_Renewable_energy_and_jobs_2022.pdf?rev=7c0be3e04bfa4cddaedb4277861b1b61).

IRENA, 2022b, Renewable solutions in end-uses: Heat pump costs and markets, International Renewable Energy Agency, Abu Dhabi, UAE. ISBN 978-92-9260-486-8 (https://www.irena.org/Publications/2022/Nov/Renewable-solutions-in-end-uses-Heat-pump-costs-and-markets).

IRP, 2020, Resource efficiency and climate change. Material efficiency strategies for a low-carbon future, International Resource Panel (https://www.resourcepanel.org/reports/resource-efficiency-and-climate-change).

Isermeyer, F., et al., 2021, 'Integrating agriculture into carbon pricing', Thünen Working Paper 136a (https://ideas.repec.org/p/ags/jhimwp/310017.html).

Iturrondobeitia, M., et al., 2022, 'Environmental Impact Assessment of LiNi 1/3 Mn 1/3 Co 1/3 O 2 Hydrometallurgical Cathode Recycling from Spent Lithium-Ion Batteries', ACS Sustainable Chemistry & Engineering 10(30), pp. 9798-9810 (DOI: 10.1021/acssuschemeng.2c01496).

Ivanova, D. and Büchs, M., 2022, 'Implications of shrinking household sizes for meeting the 1.5 °C climate targets', Ecological Economics 202, p. 107590 (DOI: 10.1016/j.ecolecon.2022.107590).

Jaffe, A. B., et al., 2005, 'A tale of two market failures: Technology and environmental policy', Ecological Economics 54(2), pp. 164-174 (DOI: 10.1016/j.ecolecon.2004.12.027).

Jakob, M., et al., 2020, 'The future of coal in a carbon-constrained climate', Nature Climate Change 10(8), pp. 704-707 (DOI: 10.1038/s41558-020-0866-1).

Jakob, M., 2022, Handbook on Trade Policy and Climate Change, Edward Elgar Publishing Ltd. (https://doi.org/10.4337/9781839103247).

Jakob, M., 2023, 'The political economy of carbon border adjustment in the EU', Oxford Review of Economic Policy 39(1), pp. 134-146 (DOI: 10.1093/oxrep/grac044).

Jenkins, J. D., 2014, 'Political economy constraints on carbon pricing policies: What are the implications for economic efficiency, environmental efficacy, and climate policy design?', Energy Policy 69, pp. 467-477 (DOI: 10.1016/j.enpol.2014.02.003).

Jiborn, M., et al., 2018, 'Decoupling or delusion? Measuring emissions displacement in foreign trade', Global Environmental Change 49, pp. 27-34 (DOI: 10.1016/j.gloenvcha.2017.12.006).

Johansson, N., 2021, 'Does the EU's Action Plan for a Circular Economy Challenge the Linear Economy?', Environmental Science & Technology 55(22), pp. 15001-15003 (DOI: 10.1021/acs.est.1c06194).

Jonsdottir, B., et al., 2022, 'Barriers to Using ESG Data for Investment Decisions', Sustainability 14(9), p. 5157 (DOI: 10.3390/su14095157).

JRC, 2019a, Accelerating energy renovation investments in buildings: financial and fiscal instruments across the EU., Publications Office, LU (https://dx.doi.org/10.2760/086805).

JRC, 2019b, Housing taxation: a new database for Europe. JRC Working Papers on Taxation and Structural Reforms No 08/2019, Joint Research Centre (https://joint-research-centre.ec.europa.eu/system/files/2019-10/jrc118277.pdf).

JRC, 2020a, Building energy renovation for decarbonisation and Covid-19 recovery: a snapshot at regional level., Publications Office, LU (https://dx.doi.org/10.2760/08629).

JRC, 2020b, Economic assessment of GHG mitigation policy options for EU agriculture, (https://publications.jrc.ec.europa.eu/repository/handle/JRC120355).

JRC, 2021a, Brief on the role of the forest-based bioeconomy in mitigating climate change through carbon storage and material substitution (https://publications.jrc.ec.europa.eu/repository/handle/JRC124374).

JRC, 2021b, Modelling environmental and climatic ambition in the agricultural sector with the CAPRI model: exploring the potential effects of selected farm to fork and biodiversity strategies targets in the framework of the 2030 climate targets and the post 2020 common agricultural policy, JRC Technical Report, Joint Research Centre, Publications Office of the European Union, Luxembourg (https://data.europa.eu/doi/10.2760/98160).

JRC, 2021c, Progress of the Member States in implementing the energy performance of Building Directive., Joint Research Centre, European Commission (https://data.europa.eu/doi/10.2760/914310).

JRC, 2021d, Recent trends in EU coal, peat and oil shale regions., European Commission, LU (https://data.europa.eu/doi/10.2760/510714).

JRC, 2022a, The role of hydrogen in decarbonisation energy scenarios: views on 2030 and 2050., Publications Office, LU (https://dx.doi.org/10.2760/899528).

JRC, 2022b, 'Wood Resource Balances of European Union and Member States. Years 2009-2017' (https://knowledge4policy.ec.europa.eu/sites/default/files/WRB_EU_v2021.pdf) accessed 26 September 2023.

JRC, 2023a, Ecodesign for sustainable products regulation - preliminary study on new product priorities. (https://susproc.jrc.ec.europa.eu/product-bureau/sites/default/files/2023-01/Preliminary%20ESPR%20WP%20Report_MERGED_CLEAN_.pdf) accessed 15 October 2023.

JRC, 2023b, Flexibility requirements and the role of storage in future European power systems., Publications Office, LU (https://data.europa.eu/doi/10.2760/384443) accessed 9 July 2023.

JRC, 2023c, GHG emissions of all world countries: 2023., Publications Office, LU (https://doi.org/10.2760/953322).

JRC, 2023d, 'Medium-term outlook commodity flows' (https://datam.jrc.ec.europa.eu/datam/mashup/AGRI_MTO_FLOWS/index.html) accessed 29 June 2023.

Kalkuhl, M., et al., 2012, 'Learning or lock-in: Optimal technology policies to support mitigation', Resource and Energy Economics 34(1), pp. 1-23 (DOI: 10.1016/j.reseneeco.2011.08.001).

Kalkuhl, M., et al., 2013, 'Renewable energy subsidies: Second-best policy or fatal aberration for mitigation?', Resource and Energy Economics 35(3), pp. 217-234 (DOI: 10.1016/j.reseneeco.2013.01.002).

Kander, A., et al., 2015, 'National greenhouse-gas accounting for effective climate policy on international trade', Nature Climate Change 5(5), pp. 431-435 (DOI: 10.1038/nclimate2555).

Karlsson, M., et al., 2020, 'Climate policy co-benefits: a review', Climate Policy 20(3), pp. 292-316 (DOI: 10.1080/14693062.2020.1724070).

Kay, S., et al., 2019, 'Agroforestry creates carbon sinks whilst enhancing the environment in agricultural landscapes in Europe', Land Use Policy 83, pp. 581-593 (DOI: 10.1016/j.landusepol.2019.02.025).

Kehlbacher, A., et al., 2016, 'The distributional and nutritional impacts and mitigation potential of emission-based food taxes in the UK', Climatic Change 137(1), pp. 121-141 (DOI: 10.1007/s10584-016-1673-6).

Kemp, R., 2016, Scope for reduction in transport CO2 emissions by modal shift, Lancaster University - Energy Technologies Institute (https://s3-eu-west-1.amazonaws.com/assets.eti.co.uk/legacyUploads/2016/02/Scope-for-reduction-in-transport-CO2-emissions-by-modal-shift-ETI-Comms.pdf).

Kim, T. and Langpap, C., 2015, 'Incentives for Carbon Sequestration Using Forest Management', Environmental and Resource Economics 62(3), pp. 491-520 (DOI: 10.1007/s10640-014-9827-3).

Kirkegaard, J. K., et al., 2023, 'Tackling grand challenges in wind energy through a socio-technical perspective', Nature Energy (DOI: 10.1038/s41560-023-01266-z).

Kitzing, L., et al., 2021, Wind energy policy and economics, Danmarks Tekniske Universitet, Institut for Vindenergi, Risø Campus, 4000, Roskilde, Danmark (https://doi.org/10.11581/DTU.00000204).

Klenert, D., et al., 2023, 'Meat taxes in Europe can be designed to avoid overburdening low-income consumers', Nature Food 4(10), pp. 894-901 (DOI: 10.1038/s43016-023-00849-z).

Klimarådet, 2023, Landbrugets omstilling ved en drivhusgasafgift (https://klimaraadet.dk/da/analyse/landbrugets-omstilling-ved-en-drivhusgasafgift).

Koch, N., et al., 2022, 'Attributing agnostically detected large reductions in road CO2 emissions to policy mixes', Nature Energy 7(9), pp. 844-853 (DOI: 10.1038/s41560-022-01095-6).

Kölbel, J. F., et al., 2020, 'Can Sustainable Investing Save the World? Reviewing the Mechanisms of Investor Impact', Organization & Environment 33(4), pp. 554-574 (DOI: 10.1177/1086026620919202).

König, L. M. and Araújo‐Soares, V., 2021, 'Will the Farm to Fork strategy be effective in changing food consumption behavior? A health psychology perspective', Applied Economic Perspectives and Policy, p. aepp.13220 (DOI: 10.1002/aepp.13220).

Korosuo, A., et al., 2023, 'The role of forests in the EU climate policy: are we on the right track?', Carbon Balance and Management 18(1), p. 15 (DOI: 10.1186/s13021-023-00234-0).

Krause, A., et al., 2020, 'A regional assessment of land‐based carbon mitigation potentials: Bioenergy, BECCS, reforestation, and forest management', GCB Bioenergy 12(5), pp. 346-360 (DOI: 10.1111/gcbb.12675).

Kryszk, H., et al., 2023, 'Barriers and Prospects for the Development of Renewable Energy Sources in Poland during the Energy Crisis', Energies 16(4), p. 1724 (DOI: 10.3390/en16041724).

Kuh, K. F., 2020, 'The Legitimacy of Judicial Climate Engagement', (DOI: 10.15779/Z38M03XX8R).

Kulovesi, K. and Oberthür, S., 2020, 'Assessing the EU's 2030 Climate and Energy Policy Framework: Incremental change toward radical transformation?', Review of European, Comparative & International Environmental Law 29(2), pp. 151-166 (DOI: 10.1111/reel.12358).

Larcker, D. F. and Watts, E. M., 2020, 'Where's the greenium?', Journal of Accounting and Economics 69(2), p. 101312 (DOI: 10.1016/j.jacceco.2020.101312).

LeadIT, 'Green Steel Tracker' (https://www.industrytransition.org/green-steel-tracker/) accessed 27 July 2023.

Leahy, S., et al., 2020, 'Challenges and Prospects for Agricultural Greenhouse Gas Mitigation Pathways Consistent With the Paris Agreement', Frontiers in Sustainable Food Systems 4 (https://doi.org/10.3389/fsufs.2020.00069).

Lebastard, L., et al., 2023, GVC exporter performance during the COVID-19 pandemic: the role of supply bottlenecks Working Paper Series, No 2766, ECB, European Central Bank.

Lebedeva, N., et al., 2021, 'Batteries - Technology Development Report 2020', JRC Publications Repository (https://dx.doi.org/10.2760/24401).

Leip, A., et al., 2015, 'Impacts of European livestock production: nitrogen, sulphur, phosphorus and greenhouse gas emissions, land-use, water eutrophication and biodiversity', Environmental Research Letters 10(11), p. 115004 (DOI: 10.1088/1748-9326/10/11/115004).

Lenschow, A., et al., 2018, 'Understanding coherence between policy spheres', Environmental Policy and Governance 28(5), pp. 323-328 (DOI: 10.1002/eet.1818).

Linsenmeier, M., et al., 2023, 'Global benefits of the international diffusion of carbon pricing policies', Nature Climate Change 13(7), pp. 679-684 (DOI: 10.1038/s41558-023-01710-8).

Liu, L.-J., et al., 2023, 'Carbon emissions and economic impacts of an EU embargo on Russian fossil fuels', Nature Climate Change 13(3), pp. 290-296 (DOI: 10.1038/s41558-023-01606-7).

Löffler, K. U., et al., 2021, 'Drivers of green bond issuance and new evidence on the "greenium"', Eurasian Economic Review 11(1), pp. 1-24 (DOI: 10.1007/s40822-020-00165-y).

Lorek, S. and Spangenberg, J. H., 2019, 'Energy sufficiency through social innovation in housing', Energy Policy 126, pp. 287-294 (DOI: 10.1016/j.enpol.2018.11.026).

Lowe, R. J. and Drummond, P., 2022, 'Solar, wind and logistic substitution in global energy supply to 2050 – Barriers and implications', Renewable and Sustainable Energy Reviews 153, p. 111720 (DOI: 10.1016/j.rser.2021.111720).

Ludemann, C. I., et al., 2023, 'A global reference database in FAOSTAT of cropland nutrient budgets and nutrient use efficiency: nitrogen, phosphorus and potassium, 1961-2020', Earth System Science Data Discussions, pp. 1-24 (DOI: 10.5194/essd-2023-206).

Lund, J. F., et al., 2023, 'Net zero and the unexplored politics of residual emissions', Energy Research & Social Science 98, p. 103035 (DOI: 10.1016/j.erss.2023.103035).

Maestre-Andrés, S., et al., 2019, 'Perceived fairness and public acceptability of carbon pricing: a review of the literature', Climate Policy 19(9), pp. 1186-1204 (DOI: 10.1080/14693062.2019.1639490).

Magrini, A., et al., 2020, 'From nearly zero energy buildings (NZEB) to positive energy buildings (PEB): The next challenge - The most recent European trends with some notes on the energy analysis of a forerunner PEB example', Developments in the Built Environment 3, p. 100019 (DOI: 10.1016/j.dibe.2020.100019).

Mai-Moulin, T., et al., 2021, 'Effective sustainability criteria for bioenergy: Towards the implementation of the european renewable directive II', Renewable and Sustainable Energy Reviews 138, p. 110645 (DOI: 10.1016/j.rser.2020.110645).

Maiti, M., 2021, 'Is ESG the succeeding risk factor?', Journal of Sustainable Finance & Investment 11(3), pp. 199-213 (DOI: 10.1080/20430795.2020.1723380).

Malico, I., et al., 2019, 'Current status and future perspectives for energy production from solid biomass in the European industry', Renewable and Sustainable Energy Reviews 112, pp. 960-977 (DOI: 10.1016/j.rser.2019.06.022).

Malins, C., 2023, The fat of the land. The impact of biofuel demand on the European market for rendered animal fats., Report for Transport & Environment (https://www.cerulogy.com/the-fat-of-the-land) accessed 29 October 2023.

Marin, G. and Vona, F., 2019, 'Climate policies and skill-biased employment dynamics: Evidence from EU countries', Journal of Environmental Economics and Management 98, p. 102253 (DOI: 10.1016/j.jeem.2019.102253).

Mata Pérez, M. D. L. E., et al., 2019, 'The multi-speed energy transition in Europe: Opportunities and challenges for EU energy security', Energy Strategy Reviews 26, p. 100415 (DOI: 10.1016/j.esr.2019.100415).

Material Economics, 2018, The Circular Economy - a Powerful Force for Climate Mitigation, Stockholm, Sweden (https://materialeconomics.com/s//s/s.com/s/s.com///s//s/s.com/s/s.com/s//s/s.com/s/s.com/s//s/s.com/s/s.com/publications/the-circular-economy-a-powerful-force-for-climate-mitigation-1).

Material Economics, 2019, Industrial Transformation 2050. Pathways to Net-Zerro Emissions from EU Heavy Industry (https://materialeconomics.com/latest-updates/industrial-transformation-2050).

Material Economics, 2021, EU biomass use in a net-zero economy, (https://materialeconomics.com/s//s/s.com/s/s.com///s//s/s.com/s/s.com/s//s/s.com/s/s.com/s//s/s.com/s/s.com/latest-updates/eu-biomass-use).

Material Economics, 2022, Scaling up Europe. Bringing Low-CO2 Materials from Demonstration to Industrial Scale. Report commissioned by Breakthrough Energy (https://materialeconomics.com/publications/scaling-up-europe).

Mather-Gratton, Z. J., et al., 2021, 'Understanding the sustainability debate on forest biomass for energy in Europe: A discourse analysis' Dwivedi, P. (ed.), PLOS ONE 16(2), p. e0246873 (DOI: 10.1371/journal.pone.0246873).

Matthes, F. and Graichen, J., 2022, Policy Brief: Emissions trading system for road transport and buildings in the policy mix for achieving climate neutrality in the EU. (https://www.oeko.de/fileadmin/oekodoc/Emissions-trading-system-for-transport-and-buildings-RefFix.pdf) accessed 5 November 2023.

Matthews, A., 2021, 'Can the new CAP help EU agriculture to meet the targets in the European Green Deal?', European Court of Auditors Journal (2/2021), pp. 13-29 (https://eca.europa.eu/da/Pages/news.aspx?nid=15671).

Mauler, L., et al., 2021, 'Battery cost forecasting: a review of methods and results with an outlook to 2050', Energy & Environmental Science 14(9), pp. 4712-4739 (DOI: 10.1039/D1EE01530C).

Mazzucato, M., 2018, 'Mission-oriented innovation policies: challenges and opportunities', Industrial and Corporate Change 27(5), pp. 803-815 (DOI: 10.1093/icc/dty034).

McDonald, H., et al., 2023, 'QU.A.L.ITY Soil Carbon Removals?', Ecologic Institute (https://www.ecologic.eu/19080) accessed 25 November 2023.

Meckling, J., et al., 2022, 'Energy innovation funding and institutions in major economies', Nature Energy 7(9), pp. 876-885 (DOI: 10.1038/s41560-022-01117-3).

Meeus, L., 2020, The evolution of electricity markets in Europe, Edward Elgar Publishing, Cheltenham, UK; Northampton, MA. ISBN: 978 1 78990 546 5.

Metternicht, G., 2018, Land Use and Spatial Planning, Springer International Publishing, Cham (https://doi.org/10.1007/978-3-319-71861-3).

Michalak, J. and Michałowski, B., 2022, 'Understanding Sustainability of Construction Products: Answers from Investors, Contractors, and Sellers of Building Materials', Sustainability 14(5), p. 3042 (DOI: 10.3390/su14053042).

Midler, E., et al., 2023, Environmental and climate assessments of CAP Strategic Plans. Summary of impact based on four key Member States, Institute for European Environmental Policy and Ecologic (https://ieep.eu/wp-content/uploads/2023/04/Environmental-and-climate-assessements-of-CAP-Strategic-Plans_IEEP-2023.pdf).

Ministers responsible for Spatial Planning and Territorial Development and/or Territorial Cohesion, 2021, Territorial Agenda 2030: A future for all places (https://ec.europa.eu/regional_policy/sources/brochure/territorial_agenda_2030_en.pdf).

Mišík, M. and Oravcová, V., 2022, 'Ex Ante Governance in the European Union: Energy and climate policy as a "test run" for the post-pandemic recovery', Energy Policy 167, p. 113076 (DOI: 10.1016/j.enpol.2022.113076).

Moaniba, I. M., et al., 2018, 'Does reverse causality explains the relationship between economic performance and technological diversity?', Technological and Economic Development of Economy 24(3), pp. 859-892 (DOI: 10.3846/tede.2018.1429).

Moesker, K. and Pesch, U., 2022, 'The just transition fund – Did the European Union learn from Europe's past transition experiences?', Energy Research & Social Science 91, p. 102750 (DOI: 10.1016/j.erss.2022.102750).

Mollière, M., 2023, Ready or not. Who are the frontrunners in the global race to clean up trucks and gain technology leadership, Transport & Environment (https://www.transportenvironment.org/wp-content/uploads/2023/06/202306_truckmakers_ZE_readiness_report.pdf).

Monti, A. and Martinez Romera, B., 2020, 'Fifty shades of binding: Appraising the enforcement toolkit for the EU's 2030 renewable energy targets', Review of European, Comparative & International Environmental Law 29(2), pp. 221-231 (DOI: 10.1111/reel.12330).

Moschitz, H., et al., 2021, 'How can the EU Farm to Fork strategy deliver on its organic promises? Some critical reflections', EuroChoices 20(1), pp. 30-36 (DOI: 10.1111/1746-692X.12294).

Moskowitz, E., et al., 2023, 'How biofuel scams have undermined a flagship EU climate policy' (https://www.occrp.org/en/investigations/how-biofuels-scams-have-undermined-a-flagship-eu-climate-policy) accessed 4 September 2023.

Mosquera-Losada, M. R., et al., 2023, 'Policy challenges for agroforestry implementation in Europe', Frontiers in Forests and Global Change 6, p. 1127601 (DOI: 10.3389/ffgc.2023.1127601).

Moura, R. and Brito, M. C., 2019, 'Prosumer aggregation policies, country experience and business models', Energy Policy 132, pp. 820-830 (DOI: 10.1016/j.enpol.2019.06.053).

Muellbauer, J., 2023, Why we need a green land value tax and how to design it. INET Oxford Working Paper No. 2023-12., (https://www.inet.ox.ac.uk/publications/why-we-need-a-green-land-value-tax-and-how-to-design-it/), Institute for New Economic Thinking at the Oxford Martin School.

Mulholland, E. and Rodriguez, F., 2023, Europe's proposed heavy-duty CO2 standards: room for improvement., Factsheet, The International Council on Clean Transportation (https://theicct.org/wp-content/uploads/2023/05/fs-europe-heavy-duty-vehicle-co2-standards-may23.pdf).

Murphy, A., 2022, Risk issues within the Agricultural sector on the island of Ireland: mapping for a sectoral Just Transition, NERI Report Series No 15, Nevin Economic Research Institute (https://www.nerinstitute.net/sites/default/files/research/2022/7811%20NERI%20Report%20Series%20no%2015.pdf).

Nadin, V. and Fernández-Maldonado, A. M., 2023, 'Spatial planning systems in Europe: multiple trajectories', Planning Practice & Research 38(5), pp. 625-638 (DOI: 10.1080/02697459.2023.2258568).

NECPlatform, 2023, Multi-Level Governance in EU Energy and Climate Policy – First findings from NECPlatform, (https://energy-cities.eu/project/necplatform-resources/) accessed 14 September 2023.

Nemet, G. and Greene, J., 2022, 'Innovation in low-energy demand and its implications for policy', Oxford Open Energy 1, p. oiac003 (DOI: 10.1093/ooenergy/oiac003).

NESC, 2023, Just Transition in Agriculture and Land Use, Council Report No 162, National Economic & Social Council (https://www.nesc.ie/app/uploads/2023/06/162_just_transition_in_ag_land_use-1.pdf).

Neuhoff, K., et al., 2019, Building blocks for a climate-neutral European industrial sector. Policies to create markets for climate-friendly materials to boost EU global competitiveness and jobs. (https://climatestrategies.org/wp-content/uploads/2019/10/Building-Blocks-for-a-Climate-Neutral-European-Industrial-Sector.pdf).

Neuhoff, K. and Ritz, R. A., 2019, Carbon cost pass-through in industrial sectors, Energy Policy Research Group, University of Cambridge (https://www.jstor.org/stable/resrep30282) accessed 22 November 2023.

New Zealand government, 2022, Pricing agricultural emissions: report under section 215 of the climate change response act 2002 (https://environment.govt.nz/publications/pricing-agricultural-emissions-report-under-section-215-of-the-climate-change-response-act-2002/) accessed 12 September 2023.

Niamir, L., et al., 2020, 'Demand-side solutions for climate mitigation: Bottom-up drivers of household energy behavior change in the Netherlands and Spain', Energy Research & Social Science 62, p. 101356 (DOI: 10.1016/j.erss.2019.101356).

Nilsson, L. J., et al., 2021, 'An industrial policy framework for transforming energy and emissions intensive industries towards zero emissions', Climate Policy 21(8), pp. 1053-1065 (DOI: 10.1080/14693062.2021.1957665).

Noriega, J. A., et al., 2018, 'Research trends in ecosystem services provided by insects', Basic and Applied Ecology 26, pp. 8-23 (DOI: 10.1016/j.baae.2017.09.006).

Norton, M., et al., 2019, 'Serious mismatches continue between science and policy in forest bioenergy', GCB Bioenergy 11(11), pp. 1256-1263 (DOI: 10.1111/gcbb.12643).

Novotny, V., 2023, 'Blue hydrogen can be a source of green energy in the period of decarbonization', International Journal of Hydrogen Energy 48(20), pp. 7202-7218 (DOI: 10.1016/j.ijhydene.2022.11.095).

Nowag, J., et al., 2021, 'Phasing out fossil fuel subsidies in the EU? Exploring the role of state aid rules', Climate Policy 21(8), pp. 1037-1052 (DOI: 10.1080/14693062.2021.1965523).

Nowak, M. J., et al., 2022, 'The Role of Spatial Policy Tools in Renewable Energy Investment', Energies 15(7), p. 2393 (DOI: 10.3390/en15072393).

Nykvist, B. and Olsson, O., 2021, 'The feasibility of heavy battery electric trucks', Joule (DOI: 10.1016/j.joule.2021.03.007).

Oberthür, S., 2019, 'Hard or Soft Governance? The EU's Climate and Energy Policy Framework for 2030', Politics and Governance 7(1), pp. 17-27 (DOI: 10.17645/pag.v7i1.1796).

Oberthür, S., et al., 2023, Towards an EU Climate Governance Framework to Deliver on the European Green Deal (https://brussels-school.be/sites/default/files/Policy%20options%20paper%20EU%20Climate%20Governance%20Framework%202023-compressed.pdf) accessed 20 September 2023.

Ocean Energy Europe, 2023, Ocean Energy. Key trends and statistics 2022 (https://www.oceanenergy-europe.eu/wp-content/uploads/2023/03/Ocean-Energy-Key-Trends-and-Statistics-2022.pdf) accessed 02 September 2023.

O'Connor, D., 2023, New emissions reduction plan will future-proof NZ's largest export sector (https://www.beehive.govt.nz/release/new-emissions-reduction-plan-will-future-proof-nz%E2%80%99s-largest-export-sector) accessed 20 October 2023.

Odyssee-Mure project, 2023, Odyssee database (https://www.odyssee-mure.eu/private/) accessed 9 August 2023.

OECD, 2021, Pricing Greenhouse Gas Emissions: Turning Climate Targets into Climate Action - OECD, (https://doi.org/10.1787/e9778969-en).

OECD, 2022, Housing Taxation in OECD Countries, OECD (https://doi.org/10.1787/03dfe007-en).

OECD, 2023a, Effective Carbon Rates. Extracted from OECD.Stat database (https://stats.oecd.org) accessed 17 October 2023.

OECD, 2023b, Green Growth Indicators, (https://stats.oecd.org/Index.aspx?DataSetCode=green_growth) accessed 14 October 2023.

OECD, 2023c, Gross domestic spending on R&D (indicator), Main Science and Technology Indicators (https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htm) accessed 12 October 2023.

OECD and IISD, 2023, 'Fossil Fuel Subsidy Tracker' (https://fossilfuelsubsidytracker.org/) accessed 14 November 2023.

Osieczko, K., et al., 2021, 'Factors that influence the expansion of electric delivery vehicles and trucks in EU countries', Journal of Environmental Management 296, p. 113177 (DOI: 10.1016/j.jenvman.2021.113177).

Pahle, M., 2023, 'Pricing carbon for a fair and effective low-carbon road transport transition in the EU', One Earth 6(1), pp. 7-10 (DOI: 10.1016/j.oneear.2022.12.005).

Pahle, M., et al., 2023, 'The Emerging Endgame: The EU ETS on the Road Towards Climate Neutrality', Rochester, NY (https://papers.ssrn.com/abstract=4373443).

Pantzar, M. and Suljada, T., 2020, Delivering a circular economy within the planet's boundaries - An analysis of the new EU Circular Economy Action Plan, Institute for European Enviornmental Policy and Stockholm Environment Institute (https://ieep.eu/publications/an-analysis-of-the-new-eu-circular-economy-action-plan/) accessed 29 July 2023.

Partridge, C. and Medda, F. R., 2020, 'Green Bond Pricing: The Search for Greenium', The Journal of Alternative Investments 23(1), pp. 49-56 (DOI: 10.3905/jai.2020.1.096).

Pasichnyi, O., et al., 2019, 'Data-driven strategic planning of building energy retrofitting: The case of Stockholm', Journal of Cleaner Production 233, pp. 546-560 (DOI: 10.1016/j.jclepro.2019.05.373).

Pastori, E., et al., 2018, Research for TRAN Committee — Modal shift in European transport: a way forward, European Union (https://www.europarl.europa.eu/RegData/etudes/STUD/2018/629182/IPOL_STU(2018)629182_EN.pdf) access 18 November 2023.

Patacca, M., et al., 2023, 'Significant increase in natural disturbance impacts on European forests since 1950', Global Change Biology 29(5), pp. 1359-1376 (DOI: 10.1111/gcb.16531).

Pe'er, G., et al., 2019, 'A greener path for the EU Common Agricultural Policy', Science 365(6452), pp. 449-451 (DOI: 10.1126/science.aax3146).

Pe'er, G., et al., 2022, 'How can the European Common Agricultural Policy help halt biodiversity loss? Recommendations by over 300 experts', Conservation Letters (DOI: 10.1111/conl.12901).

Peeters, M. and Athanasiadou, N., 2020, 'The continued effort sharing approach in EU climate law: Binding targets, challenging enforcement?', Review of European, Comparative & International Environmental Law 29(2), pp. 201-211 (DOI: 10.1111/reel.12356).

Peñasco, C., et al., 2017, 'Analysing the Role of International Drivers for Eco-innovators', Journal of International Management 23(1), pp. 56-71 (DOI: 10.1016/j.intman.2016.09.001).

Peñasco, C., et al., 2021, 'Systematic review of the outcomes and trade-offs of ten types of decarbonization policy instruments', Nature Climate Change 11(3), pp. 257-265 (DOI: 10.1038/s41558-020-00971-x).

Pérez Dominguez, I., et al., 2020, 'Economic assessment of GHG mitigation policy options for EU agriculture: A closer look at mitigation options and regional mitigation costs (EcAMPA 3)', JRC Research Reports (https://data.europa.eu/doi/10.2760/4668).

Philippidis, G., et al., 2019, 'Waste not, want not: A bio-economic impact assessment of household food waste reductions in the EU', Resources, Conservation and Recycling 146, pp. 514-522 (DOI: 10.1016/j.resconrec.2019.04.016).

Pilli, R., et al., 2022, 'The European forest carbon budget under future climate conditions and current management practices', Biogeosciences 19(13), pp. 3263-3284 (DOI: 10.5194/bg-19-3263-2022).

Pomponi, F., et al., 2021, 'Decoupling density from tallness in analysing the life cycle greenhouse gas emissions of cities', npj Urban Sustainability 1(1), p. 33 (DOI: 10.1038/s42949-021-00034-w).

Poore, J. and Nemecek, T., 2018, 'Reducing food's environmental impacts through producers and consumers', Science 360(6392), pp. 987-992 (DOI: 10.1126/science.aaq0216).

Popp, D. and Newell, R., 2012, 'Where does energy R&D come from? Examining crowding out from energy R&D', Energy Economics 34(4), pp. 980-991 (DOI: 10.1016/j.eneco.2011.07.001).

Potoćnik, J. and Teixeira, I., 2022, Making climate targets achievable. Improving wellbeing through reduced absolute resource use, A think piece of the International Resource Panel Co-Chairs, International Resource Panel (https://www.resourcepanel.org/reports/making-climate-targets-achievable) accessed 14 December 2023.

PPCA, 2017, PPCA Declaration, (https://poweringpastcoal.org/wp-content/uploads/PPCA-Declaration_Text-1.pdf) accessed 19 October 2023.

Prettico, G., et al., 2021, Distribution System Operator Observatory 2020. An in-depth look on distribution grids in Europe, JRC Science for Policy Report, Publications Office of the European Union, Luxembourg (https://data.europa.eu/doi/10.2760/311966).

Probst, B., et al., 2021, 'Global trends in the invention and diffusion of climate change mitigation technologies', Nature Energy 6(11), pp. 1077-1086 (DOI: 10.1038/s41560-021-00931-5).

Puga, D., 2010, 'The magnitude and causes of agglomeration economies', Journal of Regional Science 50(1), pp. 203-219 (DOI: 10.1111/j.1467-9787.2009.00657.x).

Ramos, V., et al., 2021, 'Legal framework of marine renewable energy: A review for the Atlantic region of Europe', Renewable and Sustainable Energy Reviews 137, p. 110608 (DOI: 10.1016/j.rser.2020.110608).

Re Cecconi, F., et al., 2022, 'Data-driven decision support system for building stocks energy retrofit policy', Journal of Building Engineering 54, p. 104633 (DOI: 10.1016/j.jobe.2022.104633).

Reis, V., et al., 2013, 'Rail and multi-modal transport', Research in Transportation Economics 41(1), pp. 17-30 (DOI: 10.1016/j.retrec.2012.10.005).

Reisinger, A., et al., 2021, 'How necessary and feasible are reductions of methane emissions from livestock to support stringent temperature goals?', Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 379(2210), p. 20200452 (DOI: 10.1098/rsta.2020.0452).

Renders, N., et al., 2021, 'Standardized savings calculations within Europe: exchanging practices to streamline theory and practice', ECEEE Summer study proceedings, 2021. ISBN: 978-91-983878-9-3 (https://www.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2021/4-monitoring-and-evaluation-for-a-wise-just-and-inclusive-transition/standardized-savings-calculations-within-europe-exchanging-practices-to-streamline-theory-and-practice/).

RGI, 2023, 'Public Acceptance', Renewables Grid Initiative (https://renewables-grid.eu/topics/public-acceptance.html?L=) accessed 14 September 2023.

Rickels, W., et al., 2022, 'Procure, Bank, Release: Carbon Removal Certificate Reserves to Manage Carbon Prices on the Path to Net-Zero', Energy Research & Social Science 94, p. 102858 (DOI: 10.1016/j.erss.2022.102858).

Rickels, W., et al., 2023, Potential efficiency gains from the introduction of an emissions trading system for the buildings and road transport sectors in the European Union, Working Paper No 2249, Kiel Working Paper (https://www.econstor.eu/handle/10419/273080).

Rietig, K., 2019, 'The importance of compatible beliefs for effective climate policy integration', Environmental Politics 28(2), pp. 228-247 (DOI: 10.1080/09644016.2019.1549781).

Ritchie, H., 2020, The carbon footprint of foods: are differences explained by the impacts of methane? (https://ourworldindata.org/carbon-footprint-food-methane) accessed 10 November 2023.

Rivers, N. and Schaufele, B., 2015, 'Salience of carbon taxes in the gasoline market', Journal of Environmental Economics and Management 74, pp. 23-36 (DOI: 10.1016/j.jeem.2015.07.002).

Roberts, C. and Geels, F. W., 2019, 'Conditions and intervention strategies for the deliberate acceleration of socio-technical transitions: lessons from a comparative multi-level analysis of two historical case studies in Dutch and Danish heating', Technology Analysis and Strategic Management, pp. 1-23 (DOI: 10.1080/09537325.2019.1584286).

Rogelj, J., et al., 2021, 'Net-zero emissions targets are vague: three ways to fix', Nature 591(7850), pp. 365-368 (DOI: 10.1038/d41586-021-00662-3).

Rogge, K. S. and Reichardt, K., 2016, 'Policy mixes for sustainability transitions: an extended concept and framework for analysis', Research Policy 45(8), pp. 1620-1635 (DOI: 10.1016/j.respol.2016.04.004).

Rosenbloom, D., et al., 2020, 'Why carbon pricing is not sufficient to mitigate climate change—and how "sustainability transition policy" can help', Proceedings of the National Academy of Sciences 117(16), pp. 8664-8668 (DOI: 10.1073/pnas.2004093117).

Rosenow, J., et al., 2023, 'Levelling the playing field: Aligning heating energy taxes and levies in Europe with climate goals', Regulatory Assistance Project (https://www.raponline.org/knowledge-center/aligning-heating-energy-taxes-levies-europe-climate-goals/) accessed 17 October 2023.

Rosenthal, S. and Strange, W., 2004, 'Evidence on the nature and sources of agglomeration economies', in: Henderson, J. V. and Thisse, J. F. (eds), Handbook of Regional and Urban Economics, , pp. 2120-2171.

Ruiz, M. A., et al., 2023, 'Regulatory Challenges for Energy Infrastructure—Do Electricity Distribution Remuneration Schemes in Europe Promote the Use of Flexibility from Connected Users?', Current Sustainable/Renewable Energy Reports (DOI: 10.1007/s40518-023-00214-5).

Ruiz, P., et al., 2019, 'ENSPRESO - an open, EU-28 wide, transparent and coherent database of wind, solar and biomass energy potentials', Energy Strategy Reviews 26, p. 100379 (DOI: 10.1016/j.esr.2019.100379).

Runge-Metzger, A. and Van Ierland, T., 2019, 'The Effort Sharing Regulation', in: Towards a Climate-Neutral Europe, Delbeke J and Vis P, Routledge ISBN 9789276082613.

Salvia, M., et al., 2021, 'Improving policy making and strategic planning competencies of public authorities in the energy management of municipal public buildings: The PrioritEE toolbox and its application in five mediterranean areas', Renewable and Sustainable Energy Reviews 135, p. 110106 (DOI: 10.1016/j.rser.2020.110106).

SAPEA, 2020, 'A sustainable food system for the European Union', Science Advice Policy by European Academies, DOI: 10.2777/282386 (https://scientificadvice.eu/advice/a-sustainable-food-system-for-the-european-union/).

SAPEA, 2023, Towards sustainable food consumption: Evidence review report, Zenodo (https://zenodo.org/doi/10.5281/zenodo.8031938).

Sapir, A., et al., 2022, 'Green Public Procurement: A Neglected Tool in the European Green Deal Toolbox?', Intereconomics 57(3), pp. 175-178 (DOI: 10.1007/s10272-022-1044-7).

Schebesta, H. and Candel, J. J. L., 2020, 'Game-changing potential of the EU's Farm to Fork Strategy', Nature Food 1(10), pp. 586-588 (DOI: 10.1038/s43016-020-00166-9).

Schiavina, M., et al., 2022, 'Land use efficiency of functional urban areas: Global pattern and evolution of development trajectories', Habitat International 123, p. 102543 (DOI: 10.1016/j.habitatint.2022.102543).

Schlacke, S., et al., 2022, 'Implementing the EU Climate Law via the "Fit for 55" package', Oxford Open Energy 1, p. oiab002 (DOI: 10.1093/ooenergy/oiab002).

Schneider, E., 2023, 'Germany's Industrial strategy 2030, EU competition policy and the Crisis of New Constitutionalism. (Geo-)political economy of a contested paradigm shift', New Political Economy 28(2), pp. 241-258 (DOI: 10.1080/13563467.2022.2091535).

Schoenefeld, J. J. and Knodt, M., 2021, 'Softening the surface but hardening the core? Governing renewable energy in the EU', West European Politics 44(1), pp. 49-71 (DOI: 10.1080/01402382.2020.1761732).

Schumacher, K., 2019, 'Approval procedures for large-scale renewable energy installations: Comparison of national legal frameworks in Japan, New Zealand, the EU and the US', Energy Policy 129, pp. 139-152 (DOI: 10.1016/j.enpol.2019.02.013).

Schütze, F. and Stede, J., 2021, 'The EU sustainable finance taxonomy and its contribution to climate neutrality', Journal of Sustainable Finance & Investment, pp. 1-33 (DOI: 10.1080/20430795.2021.2006129).

Schwerhof, G., et al., 2022, Equity and efficiency effects of land value taxation. IMF Working Paper No. 2022/263, (https://www.imf.org/en/Publications/WP/Issues/2022/12/17/Equity-and-Efficiency-Effects-of-Land-Value-Taxation-527079), International Monetary Fund.

Searchinger, T., et al., 2022a, 'EU climate plan sacrifices carbon storage and biodiversity for bioenergy', Nature 612(7938), pp. 27-30 (DOI: 10.1038/d41586-022-04133-1).

Searchinger, T., et al., 2022b, Europe's land future? Opportunities to use Europe's land to fight climate change and improve biodiversity - and why proposed policies could undermine both, Princeton University (https://searchinger.princeton.edu/sites/g/files/toruqf4701/files/searchinger-james-dumas_europes_land_future_full_report_2022.pdf) accessed 26 November 2023.

Searle, S., 2021, Intermediate crops in the Renewable Energy Directive, ICCT Fact Sheet, The International Council on Clean Transportation (https://theicct.org/sites/default/files/publications/intermediate-crops-RED-II-eu-oct21.pdf).

Segreto, M., et al., 2020, 'Trends in Social Acceptance of Renewable Energy Across Europe—A Literature Review', International Journal of Environmental Research and Public Health 17(24), p. 9161 (DOI: 10.3390/ijerph17249161).

Seidl, R., et al., 2017, 'Forest disturbances under climate change', Nature Climate Change 7(6), pp. 395-402 (DOI: 10.1038/nclimate3303).

Semieniuk, G., et al., 2022, 'Stranded fossil-fuel assets translate to major losses for investors in advanced economies', Nature Climate Change 12(6), pp. 532-538 (DOI: 10.1038/s41558-022-01356-y).

Senf, C. and Seidl, R., 2020, 'Mapping the forest disturbance regimes of Europe', Nature Sustainability 4(1), pp. 63-70 (DOI: 10.1038/s41893-020-00609-y).

Serafimova, T., et al., 2022, Modal shift: the moment of truth. Main takeaways and lessons learnt from the European year of rail, (https://fsr.eui.eu/publications/?handle=1814/74040) accessed 17 October 2022.

Sesana, M. M., et al., 2020, 'Overview of the Available Knowledge for the Data Model Definition of a Building Renovation Passport for Non-Residential Buildings: The ALDREN Project Experience', Sustainability 12(2), p. 642 (DOI: 10.3390/su12020642).

Seto, K. C., et al., 2016, 'Carbon Lock-In: Types, Causes, and Policy Implications', Annual Review of Environment and Resources 41(1), pp. 425-452 (DOI: 10.1146/annurev-environ-110615-085934).

Shishlov, I. and Censkowsky, P., 2022, 'Definitions and accounting of climate finance: between divergence and constructive ambiguity', Climate Policy 22(6), pp. 798-816 (DOI: 10.1080/14693062.2022.2080634).

Shoman, W., et al., 2023, 'Battery electric long-haul trucks in Europe: Public charging, energy, and power requirements', Transportation Research Part D: Transport and Environment 121, p. 103825 (DOI: 10.1016/j.trd.2023.103825).

Sikkema, R., et al., 2021, 'How can solid biomass contribute to the EU's renewable energy targets in 2020, 2030 and what are the GHG drivers and safeguards in energy- and forestry sectors?', Renewable Energy 165, pp. 758-772 (DOI: 10.1016/j.renene.2020.11.047).

Simon, M., et al., 2022, 'What is missing for large scale deployment of CCS in Europe?', SSRN Electronic Journal (DOI: 10.2139/ssrn.4276193).

Skinner, C., et al., 2014, 'Greenhouse gas fluxes from agricultural soils under organic and non-organic management — A global meta-analysis', Science of The Total Environment 468-469, pp. 553-563 (DOI: 10.1016/j.scitotenv.2013.08.098).

Slominski, P., 2016, 'Energy and climate policy: does the competitiveness narrative prevail in times of crisis?', Journal of European Integration 38(3), pp. 343-357 (DOI: 10.1080/07036337.2016.1140759).

SolarPower Europe, 2022a, EU market outlook for solar power: 2022-2026 (https://www.solarpowereurope.org/insights/market-outlooks/eu-market-outlook-for-solar-power-2022-2026-2) accessed 19 October 2023.

SolarPower Europe, 2022b, EU Solar Jobs Report 2022 - Addressing the solar skills challenge (https://api.solarpowereurope.org/uploads/SPE_EU_Solar_Jobs_Report_September_2022_5925da42fc.pdf?updated_at=2022-09-20T14:05:03.808Z) accessed 6 October 2023.

Stepanyan, D., et al., 2023, 'Impacts of national vs European carbon pricing on agriculture', Environmental Research Letters 18(7), p. 074016 (DOI: 10.1088/1748-9326/acdcac).

Stephan, A., et al., 2017, 'The sectoral configuration of technological innovation systems: Patterns of knowledge development and diffusion in the lithium-ion battery technology in Japan', Research Policy 46(4), pp. 709-723 (DOI: 10.1016/j.respol.2017.01.009).

Stiglitz, J. E., 2019, 'Addressing climate change through price and non-price interventions', European Economic Review 119, pp. 594-612 (DOI: 10.1016/j.euroecorev.2019.05.007).

Strefler, J., et al., 2021, 'Alternative carbon price trajectories can avoid excessive carbon removal', Nature Communications 12(1), p. 2264 (DOI: 10.1038/s41467-021-22211-2).

Sykes, A. J., et al., 2020, 'Characterising the biophysical, economic and social impacts of soil carbon sequestration as a greenhouse gas removal technology', Global Change Biology 26(3), pp. 1085-1108 (DOI: 10.1111/gcb.14844).

Szabo, J., 2022, 'Energy transition or transformation? Power and politics in the European natural gas industry's trasformismo', Energy Research & Social Science 84, p. 102391 (DOI: 10.1016/j.erss.2021.102391).

Tagliapietra, S., et al., 2019, 'The European union energy transition: Key priorities for the next five years', Energy Policy 132, pp. 950-954 (DOI: 10.1016/j.enpol.2019.06.060).

Teixidó, J., et al., 2019, 'The impact of the EU Emissions Trading System on low-carbon technological change: The empirical evidence', Ecological Economics 164, p. 106347 (DOI: 10.1016/j.ecolecon.2019.06.002).

Temme, E. H. M., et al., 2020, 'Demand-Side Food Policies for Public and Planetary Health', Sustainability 12(15), p. 5924 (DOI: 10.3390/su12155924).

Thies, C., et al., 2022, 'Project portfolio planning under CO 2 fleet emission restrictions in the automotive industry', Journal of Industrial Ecology 26(3), pp. 937-951 (DOI: 10.1111/jiec.13228).

Thomas, S., et al., 2019, 'Energy sufficiency policy for residential electricity use and per-capita dwelling size', Energy Efficiency 12(5), pp. 1123-1149 (DOI: 10.1007/s12053-018-9727-4).

Thomson, H., et al., 2019, 'Energy poverty and indoor cooling: An overlooked issue in Europe', Energy and Buildings 196, pp. 21-29 (DOI: 10.1016/j.enbuild.2019.05.014).

Toreti, A., et al., 2022, Drought in Europe: July 2022 : GDO analytical report. Technical Report by the JRC., Publications Office, LU (https://dx.doi.org/10.2760/014884).

Trinomics, 2020, Final Report Energy Taxes. Energy costs, taxes and the impact of government interventions on investments (https://trinomics.eu/wp-content/uploads/2020/11/Final-Report-Energy-Taxes.pdf).

Trinomics, 2023a, Applying the polluter-pays principle to agricultural emissions, No DOI: 10.2834/200 (https://climate.ec.europa.eu/document/996c24d8-9004-4c4e-b637-60b384ae4814_en).

Trinomics, 2023b, Assessment of the potential of sustainable fuels in transport, Study requested by the TRAN Committee, European Parliament. DOI: 10.2833/36298 (https://www.europarl.europa.eu/RegData/etudes/STUD/2023/733103/IPOL_STU(2023)733103_EN.pdf).

Tsemekidi Tzeiranaki, S., et al., 2019, 'Analysis of the EU Residential Energy Consumption: Trends and Determinants', Energies 12(6), p. 1065 (DOI: 10.3390/en12061065).

Tuomisto, H. L., et al., 2012, 'Does organic farming reduce environmental impacts? – A meta-analysis of European research', Journal of Environmental Management 112, pp. 309-320 (DOI: 10.1016/j.jenvman.2012.08.018).

UK CCC, 2022, 'CCC Monitoring Framework: assessing UK progress in reducing emissions' (https://www.theccc.org.uk/publication/ccc-monitoring-framework/?chapter=3-buildings#3-buildings) accessed 24 June 2023.

UNFCCC, 2015, The Paris Agreement, United Nations Framework Convention on Climate Change, Paris (https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement) accessed 7 March 2021.

UNFCCC, 2021, World Leaders Kick Start Accelerated Climate Action at COP26, (https://unfccc.int/news/world-leaders-kick-start-accelerated-climate-action-at-cop26) accessed 14 April 2023.

UNFCCC, 2023, Technical dialogue of the first global stocktake Synthesis report by the co-facilitators on the technical dialogue, United Nations Framework Convention on Climate Change (https://unfccc.int/documents/631600) accessed 20 October 2023.

UNEP and CCAC, 2021, Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions., Nairobi. ISBN: 978-92-807-3854-4 (https://www.unep.org/resources/report/global-methane-assessment-benefits-and-costs-mitigating-methane-emissions).

Unterreiner, L., et al., 2016, 'Recycling of Battery Technologies – Ecological Impact Analysis Using Life Cycle Assessment (LCA)', Energy Procedia 99, pp. 229-234 (DOI: 10.1016/j.egypro.2016.10.113).

URBACT, 2023, 'URBACT' (https://urbact.eu/taxonomy/term/1364) accessed 27 November 2023.

Urban Agenda for the EU, 2021, Mainstreaming functional urban areas cooperation as a tool to mitigate urban sprawl. Guidelines and recommendations. (https://futurium.ec.europa.eu/sites/default/files/2021-09/2.5.5-Action%205-%20Promoting%20FUA%20cooperation%20%20as%20a%20tool%20to%20mitigate%20sprawl-Guidebook.pdf) accessed 08 September 2023.

Valin, H., et al., 2015, The land use change impact of biofuels consumed in the EU. Quantification of area and greenhouse as impacts, Study by Ecofys, IIASA and E4Tech for the European Commission (https://energy.ec.europa.eu/publications/land-use-change-impact-biofuels-consumed-eu_en) accessed 12 October 2023.

Van Den Oever, A. E. M., et al., 2022, 'Systematic review on the energy conversion efficiency of biomass-based Fischer-Tropsch plants', Fuel 324, p. 124478 (DOI: 10.1016/j.fuel.2022.124478).

Van Der Linden, S., et al., 2021, 'Behavioural climate policy', Behavioural Public Policy 5(4), pp. 430-438 (DOI: 10.1017/bpp.2020.44).

van Grinsven, A., et al., 2020, Used Cooking Oil (UCO) as biofuel feedstock in the EU. CE Delft report for Transport & Environment, (https://www.regenwald-statt-palmoel.de/images/pdf/CE_Delft_UCO.pdf).

Velten, E. et al., 2021, 'Measuring progress towards climate neutrality. Part I: assessing structural change through net zero indicators', Ecologic and IDDRI, (https://www.ecologic.eu/sites/default/files/publication/2021/Net_Zero_Indicators_Part_1-Technical_Proposal.pdf)

Venmans, F. M. J., 2016, 'The effect of allocation above emissions and price uncertainty on abatement investments under the EU ETS', Journal of Cleaner Production 126, pp. 595-606 (DOI: 10.1016/j.jclepro.2016.02.108).

Verde, S. F., et al., 2019, 'Free allocation rules in the EU emissions trading system: what does the empirical literature show?', Climate Policy 19(4), pp. 439-452 (DOI: 10.1080/14693062.2018.1549969).

Villarejo, P., et al., 2021, 'Building Renovation Passports in Spain: Integrating exiting instruments for building conservation, renovation and heritage protection', Energy Policy 157, p. 112506 (DOI: 10.1016/j.enpol.2021.112506).

Vogl, V., et al., 2021, 'The making of green steel in the EU: a policy evaluation for the early commercialization phase', Climate Policy 21(1), pp. 78-92 (DOI: 10.1080/14693062.2020.1803040).

Von Malmborg, F., 2023, 'First and last and always: Politics of the "energy efficiency first" principle in EU energy and climate policy', Energy Research & Social Science 101, p. 103126 (DOI: 10.1016/j.erss.2023.103126).

Vonsée, B., et al., 2019, 'Energy technology dependence - A value chain analysis of geothermal power in the EU', Energy 178, pp. 419-435 (DOI: 10.1016/j.energy.2019.04.043).

Voulis, N., et al., 2019, 'Rethinking European energy taxation to incentivise consumer demand response participation', Energy Policy 124, pp. 156-168 (DOI: 10.1016/j.enpol.2018.09.018).

Wagner, C., et al., 2020, 'A methodology for the assessment of multiple benefits of industrial energy efficiency measures', SN Applied Sciences 2(2), p. 270 (DOI: 10.1007/s42452-020-2071-2).

Wallace, N., 2019, 'EU member states agree on €38B InvestEU loans programme', Science Business, 25 February 2019 (https://sciencebusiness.net/news/eu-member-states-agree-eu38b-investeu-loans-programme) accessed 28 October 2023.

Watkins, E. and Meysner, A., 2022, European Circular Economy policy landscape overview. A report for PBL Netherlands Environmental Assessment Agency, Institute for European Environmental Policy (https://ieep.eu/wp-content/uploads/2022/11/European-Circular-Economy-policy-landscape-overview.pdf).

WCRF, 'Red and processed meat and cancer risks' (https://www.wcrf-uk.org/preventing-cancer/what-can-increase-your-risk-of-cancer/red-and-processed-meat-and-cancer-risk/#:~:text=This%20includes%20foods%20like%20steak,750g%20raw%20weight)%20a%20week.) accessed 29 June 2023.

Weikmans, R. and Roberts, J. T., 2019, 'The international climate finance accounting muddle: is there hope on the horizon?', Climate and Development 11(2), pp. 97-111 (DOI: 10.1080/17565529.2017.1410087).

Weitzel, M., et al., 2023, 'A comprehensive socio-economic assessment of EU climate policy pathways', Ecological Economics 204, p. 107660 (DOI: 10.1016/j.ecolecon.2022.107660).

Wells, G., et al., 2023, 'Confronting deep uncertainty in the forest carbon industry', Science 382(6666), pp. 41-43 (DOI: 10.1126/science.adh8117).

Wendler, M. and Halkier, B., 2023, 'Dietary transition requires work: exploring the practice-transition processes of young Danish meat reducers', Food, Culture & Society 0(0), pp. 1-19 (DOI: 10.1080/15528014.2023.2193501).

Wiehe, J., et al., 2020, 'How to achieve the climate targets? Spatial planning in the context of the German energy transition', Energy, Sustainability and Society 10(1), p. 10 (DOI: 10.1186/s13705-020-0244-x).

Willett, W., et al., 2019, 'Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems', The Lancet 393(10170), pp. 447-492 (DOI: 10.1016/S0140-6736(18)31788-4).

Willis, R., et al., 2022, 'Deliberative democracy and the climate crisis', WIREs Climate Change 13(2), p. e759 (DOI: 10.1002/wcc.759).

WindEurope, 2022, 'What is the wind industry doing on skills and education to deliver a fair transition?' (https://windeurope.org/newsroom/news/what-is-the-wind-industry-doing-on-skills-and-education-to-deliver-a-fair-transition/) accessed 6 October 2023.

WindEurope, 2023, 'Wind energy in Europe: 2022 statistics and the outlook for 2023-2027, (https://windeurope.org/intelligence-platform/product/wind-energy-in-europe-2022-statistics-and-the-outlook-for-2023-2027/)

WindEurope and Eurofer, 2023, Ensuring access to critical materials for steel and wind sectors essential for EU clean-tech economy, (https://windeurope.org/newsroom/press-releases/ensuring-access-to-critical-materials-for-steel-and-wind-sectors-essential-for-eu-clean-tech-economy/) accessed 6 November 2023.

Winter, G., 2020, 'Armando Carvalho and Others v. EU: Invoking Human Rights and the Paris Agreement for Better Climate Protection Legislation', Transnational Environmental Law 9(1), pp. 137-164 (DOI: 10.1017/S2047102520000072).

World Bank, 2023, State and trends of carbon pricing, 2023 (https://blogs.worldbank.org/climatechange/state-and-trends-carbon-pricing-2023).

WPKS, 2022, Auf dem Weg zur Klimaneutralität: Umsetzung des European Green Deal und Reform der Klimapolitik in Deutschland. Jahresgutachten 2021, Wissenschaftsplattform Klimaschutz (https://www.wissenschaftsplattform-klimaschutz.de/de/Jahresgutachten2021.html).

Wyns, T. and Khandekar, G., 2019, 'Industrial Climate Neutrality in the EU: Outline of an Integrated Industrial Green Deal', Intereconomics 54(6), pp. 325-332 (DOI: 10.1007/s10272-019-0848-6).

Wyns, T. and Khandekar, G., 2020, Metals for a climate neutral Europe: A 2050 blueprint, Institute for European Studies (https://www.eurometaux.eu/media/2005/full-report-8-56-17.pdf) accessed 14 October 2020.

Yeo, S., 2019, 'Where climate cash is flowing and why it's not enough', Nature 573(7774), pp. 328-332.

Zakeri, B., et al., 2022, 'Pandemic, War, and Global Energy Transitions', Energies 15(17), p. 6114 (DOI: 10.3390/en15176114).

Zaklan, A., 2023, 'Coase and Cap-and-Trade: Evidence on the Independence Property from the European Carbon Market', American Economic Journal: Economic Policy 15(2), pp. 526-558 (DOI: 10.1257/pol.20210028).

Zangheri, P., et al., 2019, 'Progress in the Implementation of the EU Energy Efficiency Directive through the Lens of the National Annual Reports', Energies 12(6), p. 1107 (DOI: 10.3390/en12061107).

Zannakis, M., et al., 2019, 'On the Relationship between Pro-Environmental Behavior, Experienced Monetary Costs, and Psychological Gains', Sustainability 11(19), p. 5467 (DOI: 10.3390/su11195467).

Zech, K. M. and Schneider, U. A., 2019, 'Carbon leakage and limited efficiency of greenhouse gas taxes on food products', Journal of Cleaner Production 213, pp. 99-103 (DOI: 10.1016/j.jclepro.2018.12.139).

Zell-Ziegler, C., et al., 2021, 'Enough? The role of sufficiency in European energy and climate plans', Energy Policy 157, p. 112483 (DOI: 10.1016/j.enpol.2021.112483).

Zhang, J. and Asutosh, A. T., 2023, 'A Sustainability Analysis Based on the LCA–Emergy–Carbon Emission Approach in the Building System', Applied Sciences 13(17), p. 9707 (DOI: 10.3390/app13179707).

Annex I - Sources and details for the assessment of progress

Indicator	*Historic progress*	*2030 benchmark*		*2050 benchmark*	
	Source	*source*	*type*	*source*	*type*
O1: overall GHG emission reductions	EU GHG inventory, 2022 based on proxy data	European Climate Law	legal objective	European Climate Law	legal objective
O2: primary and final energy consumption	Eurostat (nrg_bal_c)	Energy Efficiency Directive	legal objective	CTP MIX scenario	EC scenario output
O3: % of fossils in EU gross inland energy consumption	Eurostat (nrg_bal_c)	CTP MIX scenario	EC scenario output	CTP MIX scenario	EC scenario output
E1: energy supply GHG emissions	EU GHG inventory, 2022 based on proxy data	FF55 MIX scenario	EC scenario output	ACP4A 1.5LIFE and 1.5 TECH scenario	EC scenario output
E2a: share of fossils in the electricity mix	Eurostat (nrg_bal_c)	FF55 MIX scenario	EC scenario output	CTP MIX scenario	EC scenario output
E2b: share of fossils in the electricity mix	Eurostat (nrg_bal_c)	FF55 MIX scenario	EC scenario output	CTP MIX scenario	EC scenario output
E3: average electricity GHG intensity	EEA data	FF55 MIX scenario	EC scenario output	ACP4A 1.5LIFE and 1.5TECH scenario	EC scenario output
E4a: solar PV deployment	Eurostat (nrg_inf_epcrw)	FF55 MIX scenario, REPowerEU	EC scenario output	CTP MIX scenario	EC scenario output
E4b: onshore wind energy deployment	Eurostat (nrg_inf_epcrw)	FF55 MIX scenario	EC scenario output	CTP MIX scenario	EC scenario output
E4c: offshore wind energy deployment	Eurostat (nrg_inf_epcrw)	FF55 MIX scenario	EC scenario output	CTP MIX scenario	EC scenario output
E5: electrification rate	Eurostat (nrg_bal_c)	FF55 MIX scenario	EC scenario output	CTP MIX scenario	EC scenario output
E6: energy-related methane emissions	EU GHG inventory	FF55 MIX scenario	EC scenario output	ACP4A 1.5LIFE scenario	EC scenario output
I1: industry GHG emissions	EU GHG inventory, EU ETS data for cement	FF55 MIX scenario	EC scenario output	CTP MIX scenario	EC scenario output

Indicator	Historic progress	2030 benchmark		2050 benchmark	
	Source	source	type	source	type
I2a: steel use	Eurofer for production and use, Eurostat (DS-059268) for trade	*no benchmark*	*no benchmark*	*no benchmark*	*no benchmark*
I2b: cement use	Eurofer for production and use, Eurostat (DS-059268) for trade	*no benchmark*	*no benchmark*	*no benchmark*	*no benchmark*
I2c: chemicals use	Eurostat for production and trade, use estimated by the Advisory Board	*no benchmark*	*no benchmark*	*no benchmark*	*no benchmark*
I3: Circular Material Use Rate	EEA	8th EAP	policy objective	*no benchmark*	*no benchmark*
I4a: GHG intensity steel	Eurofer for production, EU GHG inventories for emissions	*no benchmark*	*no benchmark*	*no benchmark*	*no benchmark*
I4b: GHG intensity cement	Cembureau for production, EU ETS data for GHG emissions	*no benchmark*	*no benchmark*	*no benchmark*	*no benchmark*
I4c: GHG intensity chemicals	Eurostat for production, EU ETS data for GHG emissions	*no benchmark*	*no benchmark*	*no benchmark*	*no benchmark*
I5: final energy use	Eurostat (nrg_bal_c)	FF55 MIX scenario, REPowerEU	EC scenario output	CTP MIX scenario	EC scenario output
I6a: % of fossils in final energy consumption	Eurostat (nrg_bal_c)	CTP MIX scenario	EC scenario output	CTP MIX scenario	EC scenario output
I6b: % of renewables in final energy consumption	Eurostat (nrg_bal_c)	CTP MIX scenario	EC scenario output	CTP MIX scenario	EC scenario output
I6c: % of electricity in final energy consumption	Eurostat (nrg_bal_c)	CTP MIX scenario	EC scenario output	CTP MIX scenario	EC scenario output
I7a: low-carbon projects in steel	Green Steel Tracker	*no benchmark*	*no benchmark*	*no benchmark*	*no benchmark*
I7b: low-carbon projects in cement	Cembureau	*no benchmark*	*no benchmark*	*no benchmark*	*no benchmark*

Indicator	Historic progress Source	2030 benchmark source	2030 benchmark type	2050 benchmark source	2050 benchmark type
I7c: low-carbon projects in chemicals	CEFIC	*no benchmark*	*no benchmark*	*no benchmark*	*no benchmark*
T1: transport GHG emissions	EU GHG inventory, 2022 based on proxy data	FF55 MIX scenario	EC scenario output	Sustainable and smart mobility strategy	proposed objective
T2a: Passenger transport demand	Eurostat Statistical Pocketbook 2022	FF55 MIX scenario	EC scenario output	ACP4A 1.5TECH and 1.5LIFE scenario	EC scenario output
T2b: Freight transport demand	Eurostat Statistical Pocketbook 2022	FF55 MIX scenario	EC scenario output	ACP4A 1.5TECH and 1.5LIFE scenario	EC scenario output
T3a: % of cars in passenger transport	Eurostat Statistical Pocketbook 2022	FF55 MIX scenario	EC scenario output	ACP4A 1.5TECH and 1.5LIFE scenario	EC scenario output
T3b: % of lorries in freight transport	Eurostat Statistical Pocketbook 2022	FF55 MIX scenario	EC scenario output	ACP4A 1.5TECH and 1.5LIFE scenario	EC scenario output
T3c: aviation passenger transport	Eurostat Statistical Pocketbook 2022	FF55 MIX scenario	EC scenario output	ACP4A 1.5TECH and 1.5LIFE scenario	EC scenario output
T3d: high-speed rail passenger transport	Eurostat Statistical Pocketbook 2022	Sustainable and smart mobility strategy	proposed objective	Sustainable and smart mobility strategy	proposed objective
T3e: rail freight transport	Eurostat Statistical Pocketbook 2022	Sustainable and smart mobility strategy	proposed objective	Sustainable and smart mobility strategy	proposed objective
T3f: IWW freight transport	Eurostat Statistical Pocketbook 2022	Sustainable and smart mobility strategy	proposed objective	Sustainable and smart mobility strategy	proposed objective

Indicator	Historic progress Source	2030 benchmark source	2030 benchmark type	2050 benchmark source	2050 benchmark type
T4a: CO_2 intensity new passenger cars	EEA	CO_2 performance standards cars and vans	Legal objective	CO_2 performance standards cars and vans	Legal objective
T4b: CO_2 intensity new vans	EEA	CO_2 performance standards cars and vans	Legal objective	CO_2 performance standards cars and vans	Legal objective
T5a: % of ZEVs in new cars	EEA	CO_2 performance standards cars and vans (2035 target)	Legal objective	CO_2 performance standards cars and vans (2035 target)	Legal objective
T5b: % of ZEVs in new vans	EEA	CO_2 performance standards cars and vans (2035 target)	Legal objective	CO_2 performance standards cars and vans (2035 target)	Legal objective
T5c: # of ZEVs in lorries fleet	Alternative Fuels Observatory	Sustainable and smart mobility strategy	proposed objective	*no benchmark*	*no benchmark*
T6a: % of fossil fuels in transport FEC	Eurostat (nrg_bal_c)	FF55 MIX scenario	EC scenario output	CTP MIX scenario	EC scenario output
T6b: % of 1st gen biofuels in transport FEC	SHARES, Eurostat	FF55 MIX scenario	EC scenario output	CTP MIX scenario	EC scenario output
B1: building GHG emissions	EU GHG inventory, 2022 based on proxy data	FF55 MIX scenario	EC scenario output	ACP4A 1.5LIFE	EC scenario output
B2a: residential buildings final energy use	Eurostat (nrg_bal_c)	FF55 scenarios/REPowerEU	EC scenario output	CTP MIX scenario	EC scenario output
B2b: tertiary buildings final energy use	Eurostat (nrg_bal_c)	FF55 scenarios/REPowerEU	EC scenario output	CTP MIX scenario	EC scenario output
B3a: Type 1 renovation rate residential	CTP impact assessment	CTP MIX scenario	EC scenario output	*no benchmark*	*no benchmark*
B3b: Type 1 renovation rate tertiary	CTP impact assessment	CTP MIX scenario	EC scenario output	*no benchmark*	*no benchmark*

Indicator	*Historic progress*	*2030 benchmark*		*2050 benchmark*	
	Source	*source*	*type*	*source*	*type*
B4a: residential built surface areas	European Building Stock Observatory, Odyssee database	*no benchmark*	*no benchmark*	*no benchmark*	*no benchmark*
B4b: tertiary built surface areas	European Building Stock Observatory, Odyssee database	*no benchmark*	*no benchmark*	*no benchmark*	*no benchmark*
B5a: % of fossils in residential energy use	Eurostat (nrg_bal_c)	CTP MIX scenario	EC scenario output	CTP MIX scenario	EC scenario output
B5b: % of fossils in tertiary energy use	Eurostat (nrg_bal_c)	CTP MIX scenario	EC scenario output	CTP MIX scenario	EC scenario output
B6: heat pump stock	EHPA	REPowerEU	proposed objective	*no benchmark*	*no benchmark*
A1: agriculture GHG emissions	EU GHG inventory, 2022 based on proxy data	FF55 MIX scenario	EC scenario output	CTP MIX scenario	EC scenario output
A2a: bovine meat GHG intensity	GHG emissions based on EU GHG inventories, production based on FAOSTAT	*no benchmark*	*no benchmark*	*no benchmark*	*no benchmark*
A2b: dairy GHG intensity	GHG emissions based on EU GHG inventories, production based on FAOSTAT	*no benchmark*	*no benchmark*	*no benchmark*	*no benchmark*
A2c: pig meat GHG intensity	GHG emissions based on EU GHG inventories, production based on FAOSTAT	*no benchmark*	*no benchmark*	*no benchmark*	*no benchmark*
A3a: total fertiliser use	EU GHG inventories	Farm to Fork Strategy	proposed objective	*no benchmark*	*no benchmark*
A3b: nitrogen use efficiency		Farm to Fork Strategy	proposed objective	*no benchmark*	*no benchmark*
A4a: total bovine meat production	FAOSTAT	*no benchmark*	*no benchmark*	*no benchmark*	*no benchmark*
A4b: total dairy production	FAOSTAT	*no benchmark*	*no benchmark*	*no benchmark*	*no benchmark*
A4c: total pig meat production	FAOSTAT	*no benchmark*	*no benchmark*	*no benchmark*	*no benchmark*

Indicator	***Historic progress***	***2030 benchmark***		***2050 benchmark***	
	Source	*source*	*type*	*source*	*type*
A5a: bovine meat consumption	FAOSTAT	*no benchmark*	*no benchmark*	ACP4A 1.5 (diet 5)	EC scenario output
A5b: dairy consumption	FAOSTAT	*no benchmark*	*no benchmark*	ACP4A 1.5 (diet 5)	EC scenario output
A5c: pig meat consumption	FAOSTAT	*no benchmark*	*no benchmark*	ACP4A 1.5 (diet 5)	EC scenario output
A6: food waste	Eurostat (env_wasfw)	Farm to Fork Strategy	proposed objective	*no benchmark*	*no benchmark*
A7: agricultural feedstock use for biofuels	JRC MTO commodity flows	CTP MIX scenario	EC scenario output	CTP MIX scenario	EC scenario output
L1: overall net emissions	EU GHG inventory, 2022 based on proxy data	LULUCF Regulation	legal objective	LULUCF Regulation IA	EC scenario output
L2a: land-use change: forests	EU GHG inventory	*no benchmark*	*no benchmark*	*no benchmark*	*no benchmark*
L2b: land-use change: wetlands	EU GHG inventory	*no benchmark*	*no benchmark*	*no benchmark*	*no benchmark*
L3: gross deforestation	EU GHG inventory	*no benchmark*	*no benchmark*	*no benchmark*	*no benchmark*
L4: gross afforestation	EU GHG inventory	*no benchmark*	*no benchmark*	*no benchmark*	*no benchmark*
L5: net land take	EU GHG inventory	*no benchmark*	*no benchmark*	7th EAP	proposed objective
L6: forest carbon sink	EU GHG inventory	CTP MIX scenario	EC scenario output	CTP MIX scenario	EC scenario output
L7: emissions from non-forest lands	EU GHG inventory	CTP MIX scenario	EC scenario output	CTP MIX scenario	EC scenario output
L8: bioenergy use	Eurostat (nrg_bal_c)	CTP MIX scenario	EC scenario output	CTP MIX scenario	EC scenario output

Annex II - Errata

Overview of corrections made since the first publication of the report (18 January 2024).

Last updated: 12 April 2024

Section	Correction
Overall	Minor changes to layout. Cross-references corrected throughout the report.
Recommendations and summary	Correction to numbering of headings.
Recommendations and summary, p. 24	Correction to the required reductions under the EU ETS by 2030 compared to 2005 (-62% instead of -43%, which is the former required reduction under the 2018 ETS Directive).
Table 4	Correction to historical progress (based on 2005-2022 instead of 2017-2021) and the corresponding progress category for indicator E1.
Figures 12, 22, 62, 78, 80, 85, 86	Minor corrections to formatting.
Chapter 5 – Key messages	Small edits on page 51 to clarify that fugitive CH_4 emissions from coal operations, fossil gas operations and biomass combustion are the three largest sources of energy-related CH_4 emissions.
4.3	Factual corrections made to the respective shares of solar PV and wind in the EU energy supply (pages 61 and 62).
Figure 17	Right graph (offshore): corrected alignment of data on the horizontal axis.
Chapter 5	Cross-reference to Chapter 13 and section 13.3 corrected on page 86.
Figure 24	Imports and exports removed from legend (no data provided).
Figure 25	Correction to the title of the vertical axis, and to the date range of the horizontal axis to 2010-2030.
Figures 35 to 38	Correction to the reference for the 2030 benchmarks in the underlying notes and sources (Fit for 55 MIX scenario instead of the MIX scenario of the Climate Target Plan).
6.3	Correction to the cross-reference to section 6.2 on page 112.
Figure 40	Correction to the underlying data for the right graph (vans).
Figure 41	Correction to the title of the vertical axis and correction to the 2010 marker on the horizontal axis of the right graph (vans).
Figure 44	Data converted from Mtoe to TWh. Data source for the 2050 benchmark is corrected to the MIX scenario of the Climate Target Plan.
Figure 52	Correction to the title of the vertical axis.
Figure 58	Correction to the title of the figure.
Figure 61	Correction to the title of the vertical axis.
12.2	Page 240: for REPowerEU, the required annual investments were estimated at EUR 1450 billion, which was calculated as EUR 1241 bn per year under (Fit for 55) + an additional EUR 210 bn annually under REPowerEU. This was incorrect, as the EUR 210 bn figure for REPowerEU are the cumulative additional required investments in 2022-2027. The figure is now corrected to EUR 1276 bn (= EUR 1241 bn under Fit for 55 + EUR 35 bn additional per year under REPowerEU, based on an additional EUR 300 bn for the entire period 2022 to 2030).
Figure 77	Correction to the underlying data: - The data for CTP ’21-’30 and FF55 ’21-’30 was switched (correct data: EUR 1205 bn for CTP ’21-’30 and EUR 1241 bn for FF55 ’21-’30).

	- The data for REPowerEU '21-'30 is corrected from EUR 1450 bn to EUR 1276 bn (see above).
Footnote (9)	Correction to the required additional annual investments under the Net-Zero Industry Act to EUR 12 bn per year (92 cummulatively to 2030).

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