# Towards EU climate neutrality

## Progress, policy gaps and opportunities

## Chapter 4: Energy supply

Assessment Report 2024

European Scientific
Advisory Board on
Climate Change

# Contents

# 4 Energy supply

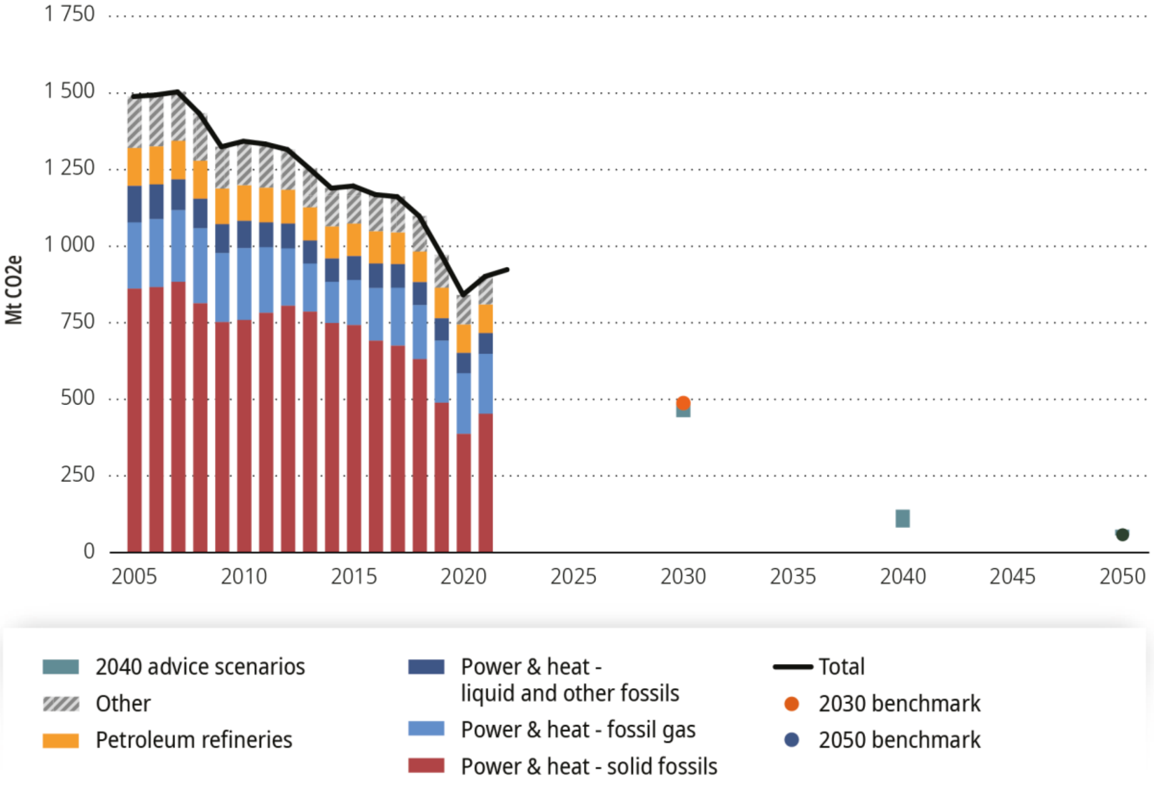
## Key messages

**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 (1). 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.

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(1) 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.

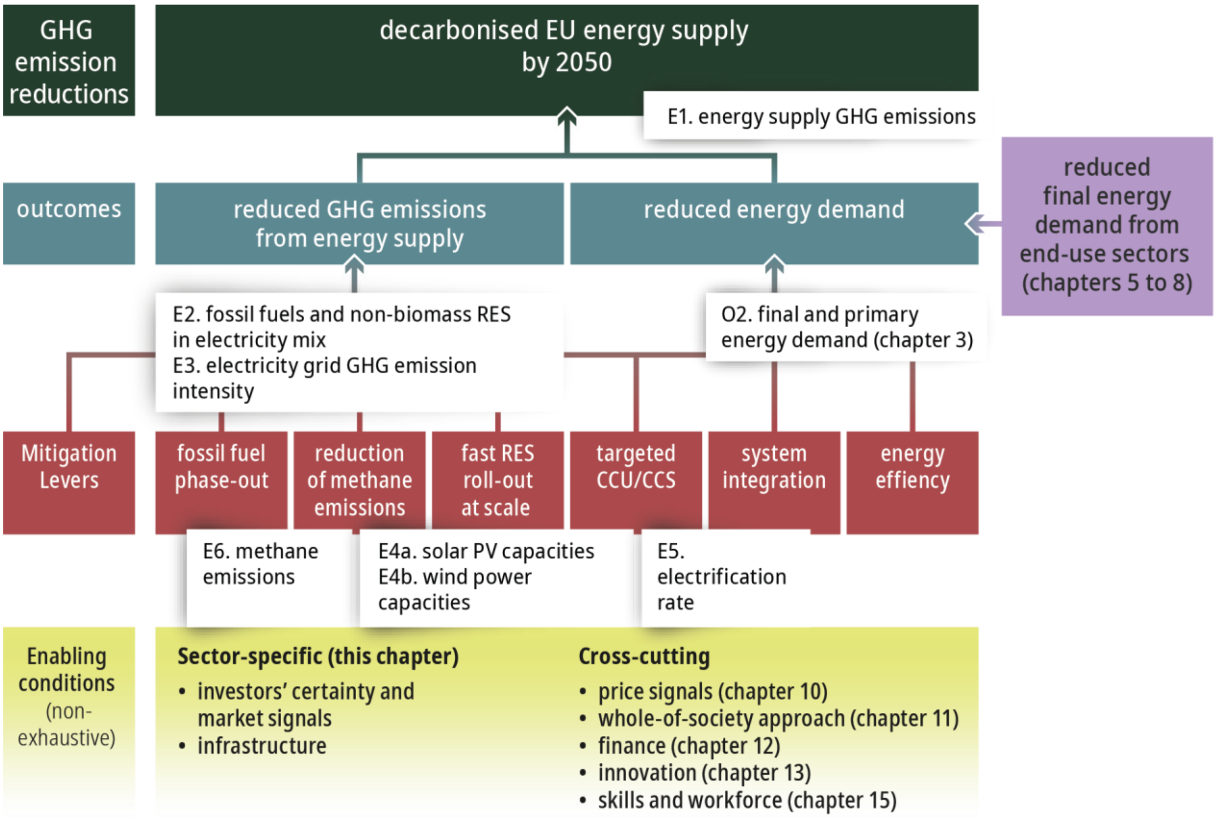
- **Targeted carbon capture and utilisation/storage.** Apply CCU/CCS in a number of industrial processes and the fossil fuel electricity sector where non-fossil mitigation options have been exhausted, based on a scientifically led definition of residual emissions.
- **Reduction of $CH_4$ emissions.** $CH_4$ 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*

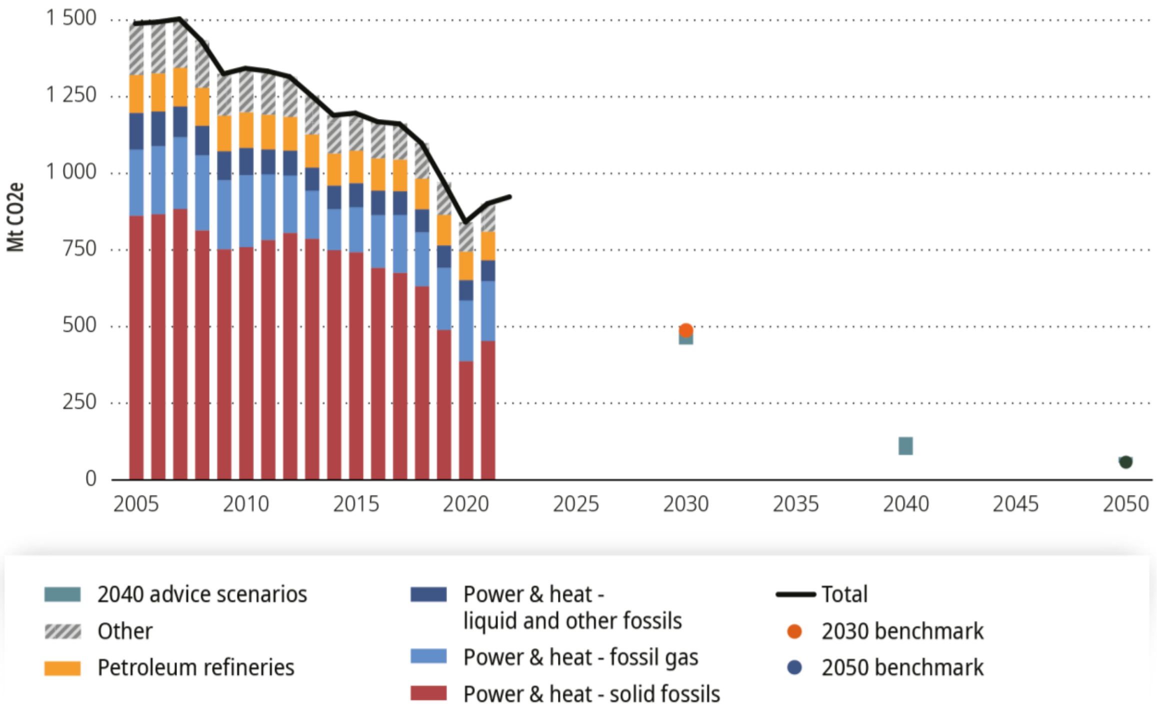


**Source:** Advisory Board (2024).

## 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 (2). Looking ahead, meeting the EU's climate goals for 2030 and 2050 (as represented by the Fit

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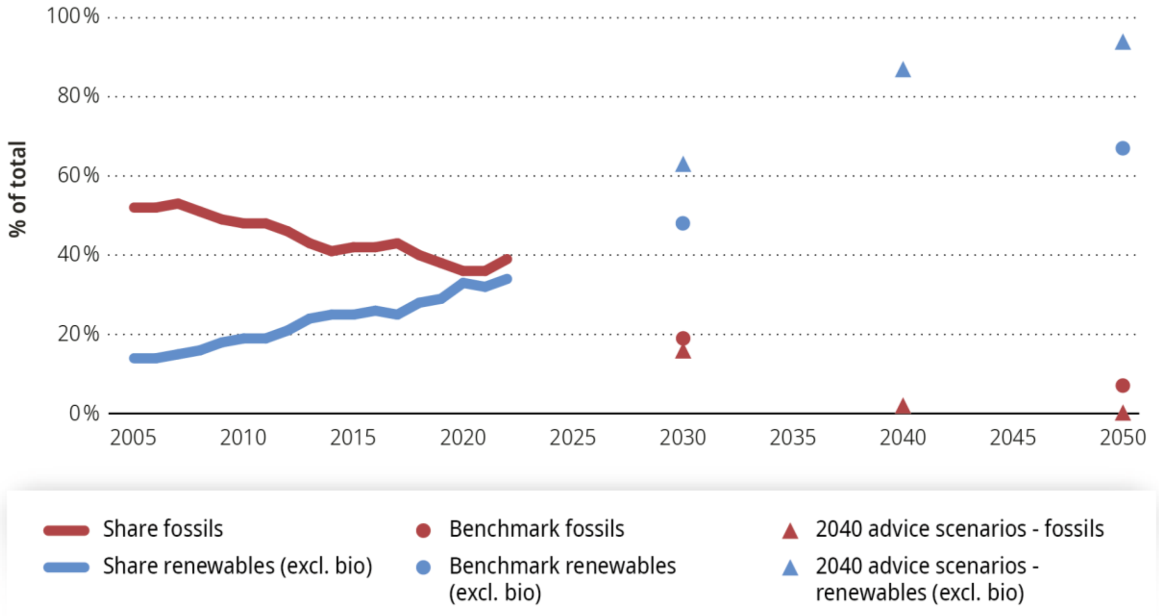
(2) The assessment of recent trends in these indicators excludes 2022 because in that year output from hydroelectric and nuclear plants was exceptionally low owing to a combination of hot, dry weather and technical outages (IEA, 2023h). The resultant increase in fossil fuel generation (from coal) is 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***

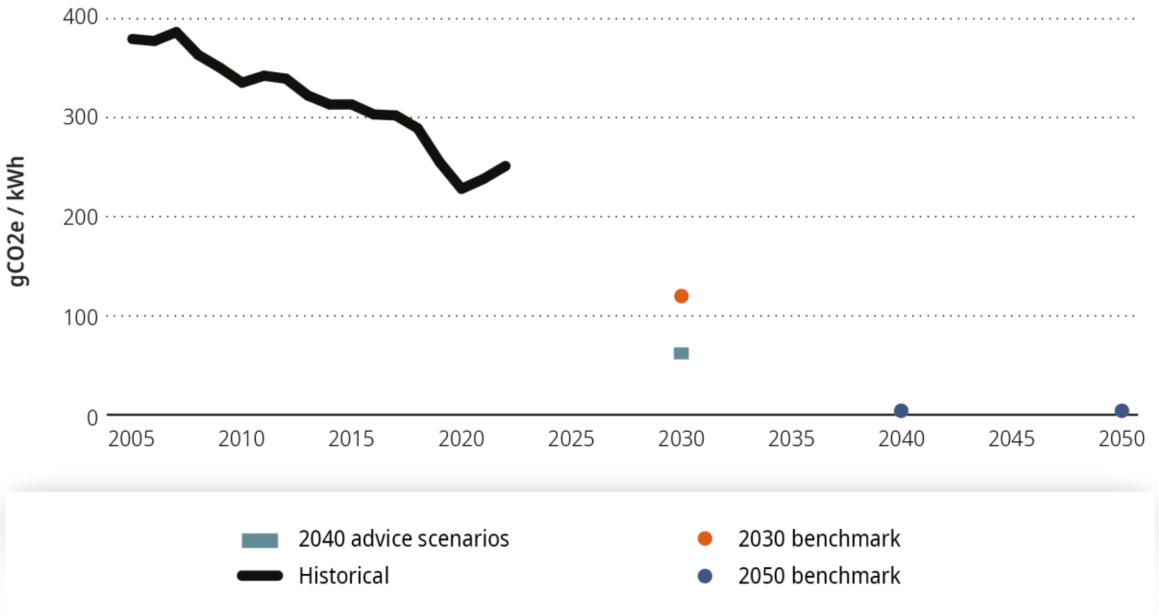


**Notes:** Historic data refers to gross electricity generation reported in the Eurostat energy balances. The 2030 benchmark and breakdown are based on the Fit for 55 MIX scenario. The 2050 benchmarks are based on the MIX Scenario from the Climate Target Plan impact assessment (see figure 46). For 2040, 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 5g$CO_2e$/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) (3). 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 Section 12.4). 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

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(3) 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) (4). 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

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(4) 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') (5).

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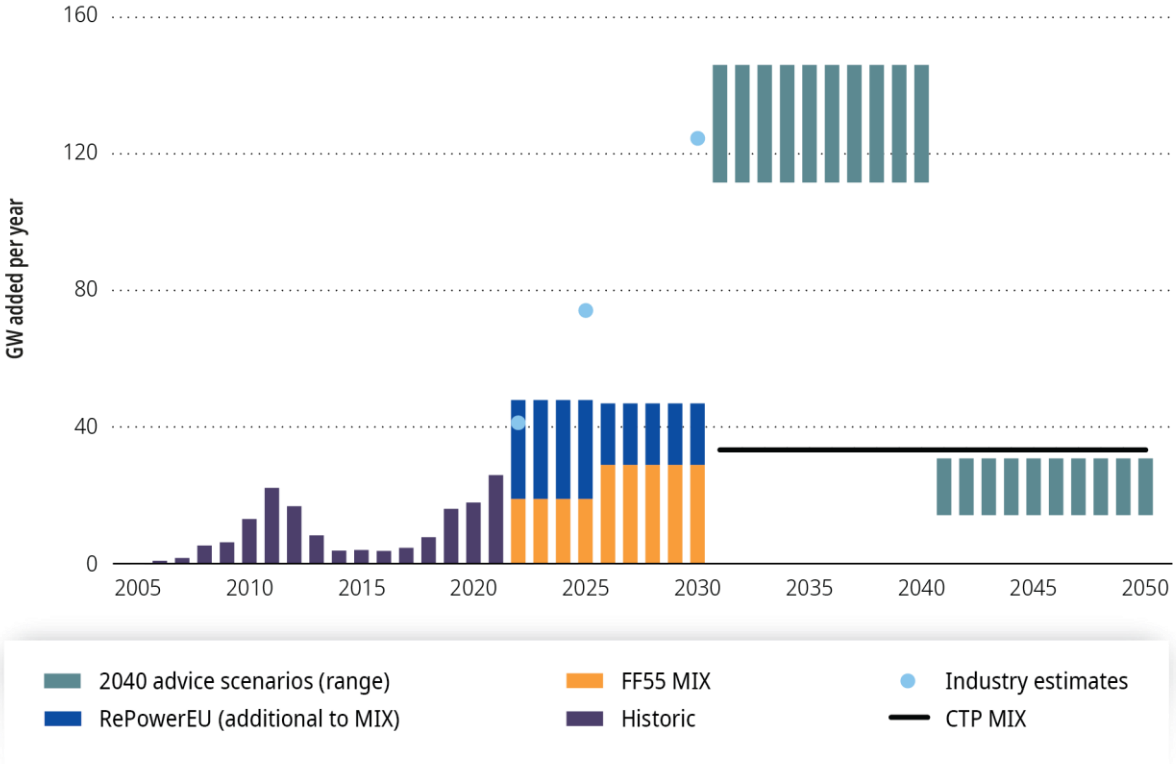
(5) Other explanations for higher PV estimates include REPowerEU's emphasis on the need to reduce reliance on imported fossil gas, and the Advisory Board's emphasis on reducing emissions by 2040 (to 90–95 % below the 1990 level) rather than aiming for a slower path towards climate neutrality by 2050.

*Figure 16 Indicator E4a – annual solar PV capacity additions*



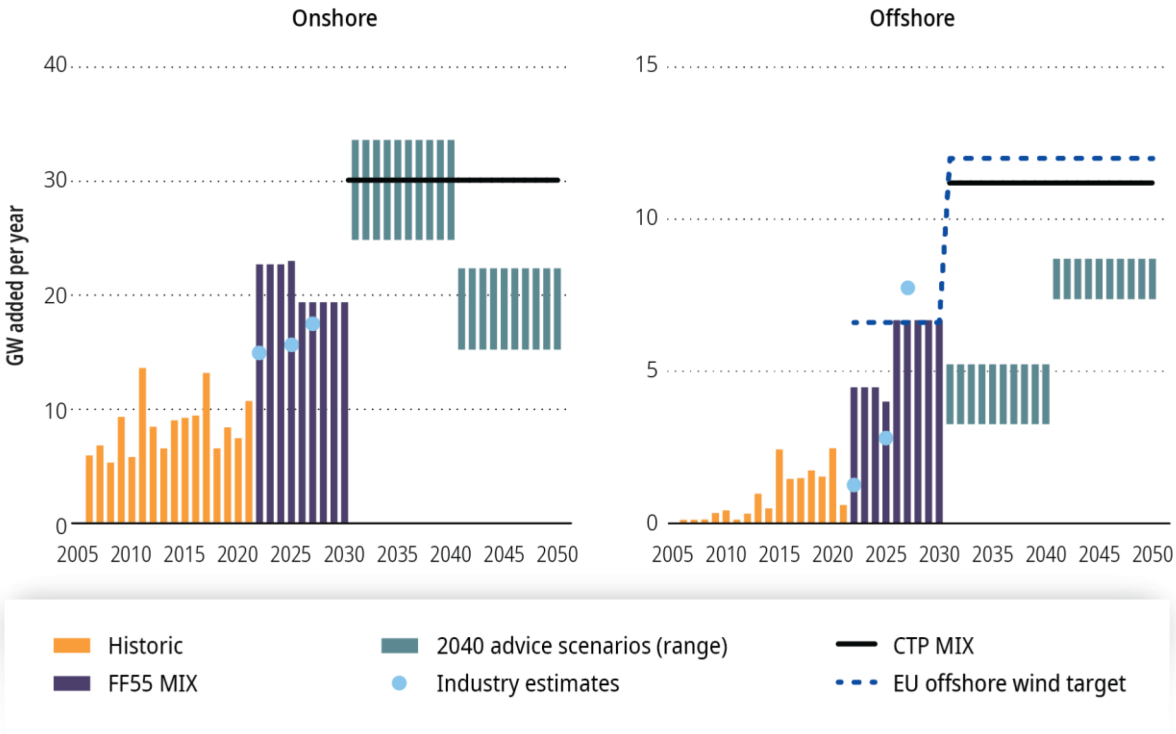
**Notes:** Historic annual additions based on solar production capacity data from Eurostat (nrg_inf_epcrw). The 2030 benchmarks are based on the European Commission's Fit for 55 MIX and REPowerEU scenarios for solar PV. Post-2030, the bars show the average annual additions needed to reach the total capacity 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).

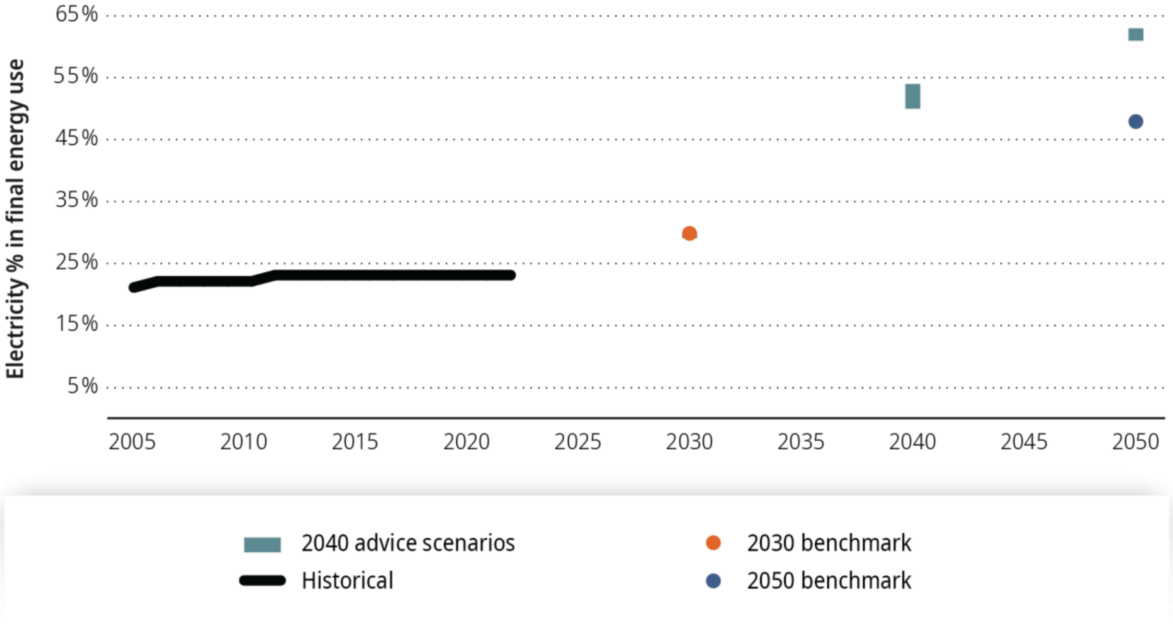
**Accelerated electrification of energy demand is not yet on track to reach the EU's climate objectives.**

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 (6). 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).

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(6) 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.**

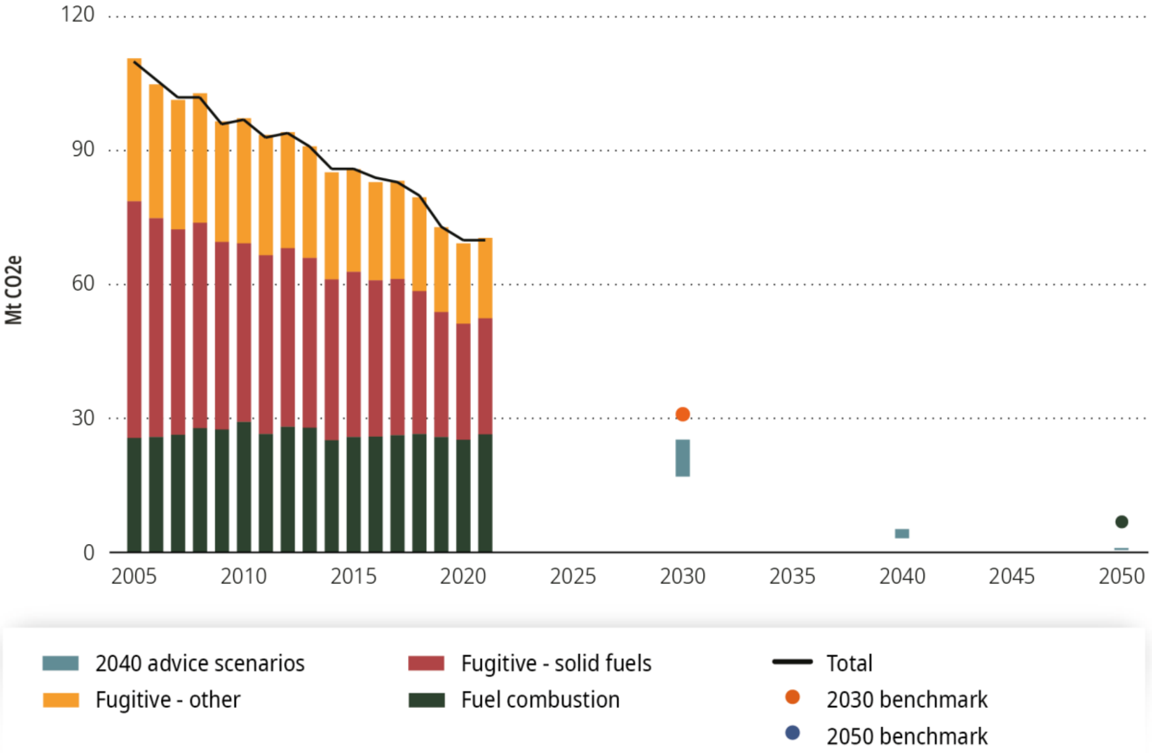
$CH_4$ is a potent GHG with high global warming potential (IPCC, 2007b). The energy supply sector is the third-biggest source of $CH_4$ emissions in the EU (11 % of total), after agriculture (55 % of total) and waste (23 %). The largest sources of $CH_4$ in the energy sector in 2021, as shown in Figure 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 $CO_2$e/yr | – 55 Mt $CO_2$e/yr | – 24 Mt $CO_2$e/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 $CO_2$e/kWh/yr | – 16 g $CO_2$e/kWh/yr | – 12 g $CO_2$e/kWh/yr (a) |
| E4: renewables capacity deployment | | | | |
| E4a: solar PV | 2018–2022 | + 22 GW/yr | + 25 GW/yr Fit for 55<br>+ 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 $CO_2$e/yr | – 4 Mt $CO_2$e/yr | – 1 Mt $CO_2$e/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.<br>– Residual emissions (from so-called hard-to-abate sectors) are currently not defined at the EU or Member State level.<br>– Fugitive $CH_4$ emissions in the energy sector have not been addressed by EU policies (dedicated regulation in the lawmaking process).<br>– 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.<br>– The EU still lacks planning and operation of the energy system as a whole.<br>– Market upscaling of innovative renewable energy technologies is making slow progress. |

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