# EU 2040 Climate Target:

# Contributions of the Energy Supply Sector

## Part 7 of 7 studies on sectoral contributions to the 2040 target


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## Abbreviations

| | |
|---|---|
| **BECCS** | Bioenergy with Carbon Capture and Storage |
| **CA** | Climate Analytics |
| **CCfDs** | Carbon Contracts for Differences |
| **CCTS** | Carbon Capture, Transport and Storage |
| **CCU** | Carbon Capture and Utilisation |
| **CDR** | Carbon Dioxide Removal |
| **CEF** | Connecting Europe Facility |
| **CHP** | Combined Heat and Power |
| **$CO_2$** | Carbon Dioxide |
| **$CO_2e$** | Carbon Dioxide Equivalent |
| **DAC** | Direct Air Capture |
| **DACCS** | Direct Air Carbon Capture and Storage |
| **EC** | European Commission |
| **ECL** | European Climate Law |
| **ESABCC** | European Scientific Advisory Board on Climate Change |
| **EU** | European Union |
| **EU ETS** | EU Emissions Trading System |
| **EUA** | European Allowance |
| **EUR** | Euro |
| **GDP** | Gross Domestic Product |
| **GHG** | Greenhouse Gas |
| **GW** | Gigawatt |
| **GWe** | Gigawatt-Electric |
| **HED** | High Energy Demand |
| **$H_2$** | Hydrogen |
| **IA** | Impact Assessment |
| **IEA** | International Energy Agency |
| **IPCEI** | Important Projects of Common European Interest |
| **KVBG** | Kohleverstromungsbeendigungsgesetz (German Coal Phase-out Act) |

| | |
|---|---|
| **kWh** | Kilowatt Hour |
| **LCA** | Life-Cycle Analysis |
| **LED** | Low Energy Demand |
| **LHV** | Lower Heating Value |
| **MJ** | Megajoules |
| **MSR** | Market Stability Reserve |
| **Mt** | Megaton |
| **MW** | Megawatt |
| **MWh** | Megawatt hour |
| **MWhth** | Megawatt thermal |
| **$m^2$** | Metre(s) squared |
| **NECPs** | National Energy and Climate Plans |
| **NZIA** | Net Zero Industry Act |
| **PCIs** | Projects of Common Interest |
| **PMIs** | Projects of Mutual Interest |
| **PtX** | Power-to-X |
| **PV** | Photovoltaic |
| **RFNBO** | Renewable Fuels of Non-Biogenic Origin |
| **RED** | Renewable Energy Directive |
| **RES-E** | Renewable Energy - Electricity |
| **SFRs** | Sodium-cooled Fast Reactors |
| **SMRs** | Small Modular Reactors |
| **TEN-E** | Trans-European Networks for Energy |
| **TRL-X** | Technology Readiness Level X |
| **TWh** | Terawatt hour |

# 1 Executive Summary

### The 2040 climate target

The European Union (EU) is legally obliged to achieve climate neutrality by 2050 and has an interim target for 2030 of reducing net Greenhouse Gas (GHG) emissions by 55% compared to 1990. The European Climate Law also requires the EU to adopt a climate target for 2040.

In its Communication of 6 February 2024, the European Commission proposed a net emission reduction of 90% by 2040 compared to 1990 levels. The ESABCC (2023) recommends 90-95% net reductions. The indicated target range means that all sectors will have to contribute significant emission reductions.

This paper explores the past contribution of the energy supply sector[1] to already achieved emission reductions as well as the contribution of the energy sector to the upcoming 2040 climate target and what it takes to achieve the related emission reductions.

### Emission trends

In 2022, the energy supply sector accounted for 25% of total GHG emissions in the EU-27. This corresponds to a 43% reduction of emissions between 1990 to 2022. The latest national projections of future emissions trends which incorporated both existing and planned additional measures (WAM scenarios) show a reduction of 78% by 2040 compared to 1990 levels. The contribution of Member States differs significantly, with the highest emissions in 2040 attributable to Poland, Italy, Germany and France, all of which continue to exceed 30 $MtCO_2e$.

### Implications of the 2040 target for the energy supply sector

However, achieving climate-neutrality by 2050 in all Member States will require a substantial increase in decarbonisation efforts. According to various scenarios detailed below, the energy supply sector needs to reduce emissions by between 81% and 100% by 2040 compared to 1990 to be in line with the trajectory leading to climate-neutrality by 2050.

### Key challenges

- unprecedented RES-E expansion
- quick phase-out of coal-fired generation
- transition of natural gas-fired generation to climate-neutral energy carriers
- clarification of the role of nuclear power generation
- rapid ramp-up of hydrogen production capacities and transport and storage infrastructure
- rapid expansion of non-fossil fuel-based flexibility option
- targeted and cost-effective contribution of $CO_2$ capture, transport and storage for waste incineration and direct air capture.

[1] The energy sector is defined as CRF categories 1.A.1 and 1.B.

### Current relevant EU legislation

The EU's Renewable Energy Directive (RED) will remain a central element and driver of expanding renewable energies in the energy sector in the future. It currently mandates a minimum of 42.5% renewable energy in EU total energy consumption by 2030, with an aspirational goal of reaching 45%. The RED is supported by accompanying regulations and action plans for permitting, onshore, and offshore wind energy, and solar energy.

The RED also sets firm targets for hydrogen used in the industry and transportation sectors to comply with the Renewable Fuels of Non-Biogenic Origin (RFNBO) regulation. With most of the domestically produced hydrogen to originate from electrolysers, this has great implications for the energy supply sector. In order to leapfrog the chicken-and-egg problem of green hydrogen demand and supply, the EU has started auctions through the European Hydrogen Bank. Hydrogen transport and storage infrastructure are covered by the Hydrogen and Decarbonised Gas Market Package.

With the linear reduction factor leading to zero new emission allowances issued by 2039, the EU Emissions Trading System (EU ETS) is the clear driver in phasing out coal-fired generation. In order to smooth the transition for regions with domestic coal or other emission-intensive fossil fuel resources, the Just Transition Mechanism provides targeted guidance and financial support. Moreover, state aid regulation allow for financial support to support the closure of units and mines.

Only with alternative dispatchable units available and given that the respective support scheme is sensitive to $CO_2$ pricing, the EU ETS will also be the driving force in phasing-out natural gas. The role of non-fossil fuel flexibility options, which can also include gas-fired capacities switching to climate-neutral fuel alternatives, is governed by the EU electricity market reform.

The EU Taxonomy and the Guidelines on State Aid for climate, environmental protection and energy set strict rules on financial support to fossil fuel-based electricity generation, including that which is natural gas-fired. Rules on financial support for carbon dioxide removal technologies are also provided by the EU Taxonomy. It allows financial support for the lifetime expansion of existing nuclear power plants and for the construction of new ones. Also, substantial financial resources are available to achieve further steps in commercialisation of small modular reactors (SMRs).

### Policies, measures and options to further reduce emissions in the energy supply sector

Clear, legally binding targets for installed renewables capacities (as currently set out in the EU Solar Strategy, and the Offshore Wind strategy) or Renewable Energy - Electricity (RES-E) electricity generation will help to create a clear framework for future investments. While there is a consensus on the need to drastically increase wind and solar photovoltaic (PV) capacities, a RES-E generation target might still be hard to agree on the EU level, as there are diverging views among the Member States on the role of other technologies, most notably nuclear and bioenergy.

Financial support is needed to bridge the operational costs gap for CDR technologies. Accompanying this, a comprehensive debate and assessment of sustainable levels of annual $CO_2$ storage is needed, among other things. This debate should take into account total available storage volumes and future definitions and levels of hard-to-abate emissions. A clear exclusion of carbon capture for fossil fuel-fired generation, avoids lock-in for fossil fuel infrastructure, additional emissions from methane leakages in the supply chain, and wrong incentives for the layout and dimensioning for future common $CO_2$ transport infrastructure.

The EU ETS can be used as a vehicle to provide financial incentives for industrial carbon sinks such as Bioenergy with Carbon Capture and Storage (BECCS) and Direct Air Carbon Capture and Storage (DACCS). However, BECCS should not be supported uniformly; rather, tailored approaches need to take into account the multitude of challenges around nature-based solutions (see Meyer-Ohlendorf et al. (2023)). A first but important step towards increasing sustainability in the use of bioenergy could be changing its emission factor in the EU ETS. The current zero emission factor for bioenergy creates an incentive for the use of biomass for installations under the EU ETS.

The role of nuclear electricity generation in the transition towards climate-neutrality in 2050 needs to be assessed critically. Maintaining current capacity levels up to 2040 is associated with large-scale lifetime extensions and the construction of more than 15 GWe of new installations. Given high and increasing construction and resulting electricity costs, and lead times of 15 years and more, this is not a reliable option. Moreover, much of the nuclear supply chain is dominated by Russia, thereby increasing import dependency and raising supply risks. Nuclear fuel does not count towards fuel import dependence in the EU impact assessment. This should be changed to account for strong dependencies in the supply chains.

The achievement of the 2040 climate target necessitates substantial expansion and upgrades to the European Union's power grids and energy storage systems. The transition to a different energy mix will require significant investments over the next 10-15 years. Success hinges on establishing an appropriate regulatory framework, on integrated infrastructure planning, and on providing incentives for resilient supply chains.

# Introduction and conclusion

The EU will adopt a climate target for 2040 in the years ahead. This is a legal obligation set out in the European Climate Law (ECL). With a view to achieving the ECL's climate neutrality objective, Article 4.4 of the ECL stipulates that "a Union-wide climate target for 2040 shall be set". Once the target is adopted, the EU is also set to adopt a legislative package to implement this target. This package will reform relevant EU laws and policies.

This paper is part of a group of sectoral papers, published in the context of a project funded by the German Federal Ministry for Economic Affairs and Climate Action. In this project, Ecologic Institute and Oeko-Institut analyse the ambition level of the 2040 target and examine the impacts of a new 2040 target on Member States, sectors, and instruments. For more information about this project see: EU 2040 Climate Target. Level of ambition and implications. Besides other outputs of this project, these sectoral papers explore the contributions of respective sectors to the upcoming 2040 climate target and what it takes for these sectors to achieve the related emission reductions. Relying on various emission reduction scenarios, the papers discuss different measures and policies that could help achieve the necessary contributions.

Following the sector definition of EEA (e.g. in (EEA 2023b)) the, the energy supply sector subsumes CRF categories 1.A.1 and 1.B. These include public electricity, heat, and combined heat and power generation, petroleum refining and manufacturing of other energy fuels, as well as fugitive emissions from coal mining and handling of oil and gas along the supply chains prior to final consumption. All sector-related figures presented in this report take this sector definition as a basis, unless stated otherwise. Electricity, heat and combined heat and power generation for industrial applications is further addressed in the industry paper (Kögel et al. 2024). However, most of the challenges, governing regulations and potential additional measures mentioned in this report also apply to industrial electricity, heat and co-generation. Heat from combined heat and power generation and from large-scale heat plants that provide network-bound heat supply is also included in this sector. However, key challenges and necessary regulatory and other interventions are addressed in detail in the Buildings Paper (Hesse, Tilman, Sibylle Braungardt 2024). Key challenges and policies for the fossil fuel supply chains will not be a focus of this paper but are rather addressed in other accompanying publications. In particular, methane leakage will be addressed in Moosmann et al. (2024). Currently, most hydrogen production based on natural gas via steam methane reforming is subsumed in the industry sector, whereby the hydrogen is used as feedstock particularly in ammonia production, and in the basic chemicals industry, while another significant portion is used in petroleum refining and therefore subsumed in the energy sector. In the future, low carbon and renewable hydrogen will be produced more centrally and supplied to final consumers in different sectors via a dedicated infrastructure. Following the previous sector allocation logic, this activity will hence be subsumed in the energy sector.

This paper explores the necessary steps in terms of the transformation of the energy supply sector towards climate neutrality, and where the sector needs to stand by 2040, with regards to both emissions and central sector elements, but also the necessary legislative framework.

With regards to the central sector elements, the transformation is essentially based on four pillars:

- phasing out the use of domestically available (peat, oil shale, lignite and hard coal) and imported (hard coal and natural gas) fossil fuels in electricity and combined electricity and heat generation;
- expansion of renewable energies;
- provision of climate-neutral flexibility options; and
- provision of climate-neutral electricity-based energy carriers and negative emission technologies.

EU regulation sets the central guard rails for all four pillars. There is a clear and binding reduction path for $CO_2$ emissions from the energy sector via the EU Emission Trading Directive (2003/87/EC) and recent adjustments and tightening measures (rebasing, adjustment of the LRF, expiry of free allocation, adherence to the Market Stability Reserve (MSR) mechanism). Under the current regulations, the emissions cap in the EU ETS reaches zero by 2039, meaning that no new certificates will be issued from that year onwards. This results in a clear phase-out path for the use of fossil fuels in the energy supply sector.

However, further measures may be necessary to drive forward the phase-out of the use of regional fossil fuel resources as demonstrated, for example, by the compensation payments to lignite-fired power generation companies under the German Act to Reduce and End Coal-Fired Power Generation (Kohleverstromungsbeendigungsgesetz - KVBG 2020). Some of the socio-economic factors can be provided by the Just Transition Mechanism (EC 2020b). The outlook is less clear for plants powered by natural gas, as a switch to climate-neutral energy sources is possible, in some cases at additional cost. The EU Taxonomy (EU 2020) and the Guidelines on State Aid for climate, environmental protection and energy (EU 2022a) provide the legal framework for the promotion of natural gas-powered plants as a bridging technology. The former stipulates, for example, that plants for which planning permission has been granted by the end of 2030 must be converted to renewable or low-emission fuels by the end of 2036. The latter also refers to the taxonomy and stipulates a lock-in test, for example.

A centrepiece for achieving climate neutrality is a further huge expansion of renewable electricity and heat generation capacities. In this regard, the Renewable Energy Directive (EC 2023f) represents a central guard rail. The directive defines the overarching EU target for renewable energies and contains rules to ensure the use of renewable energies in the transport sector and in the heating and cooling sector. It also sets common principles and rules for support schemes for renewable energy, the right to produce and consume renewable energy and sustainability criteria for biomass. Moreover, the directive contains provisions to remove barriers, promote investment and reduce the cost of renewable energy technologies. By setting overarching targets and further reducing barriers, for example in the area of approval procedures, the RED will remain a central element and driver of the expansion of renewable energies in the energy sector in the future. However, the directive does not set explicit targets for renewable electricity generation for the EU Member States of for the Union as a whole. Doing so will help to create a clear framework for future investments.

The Hydrogen and Decarbonised Gas Market Package (Directive (EU) 2024/1788 2024; Regulation (EU) 2024/1789 2024) is intended to create the infrastructural and regulatory conditions for the provision of gaseous energy sources. The Important Projects of Common European Interest (IPCEI) (EC 2023m) can also serve as crystallisation points here.

For the first time the EU Directive (EU 2024/1711) and the Regulation (EU 2024/1747) define EU-level measures for non-fossil flexibility (EC 2024b). Substantial expansion and enhancement of the EU power grids, and energy storage systems is required to enable the transition towards a RES-E-based system, which entails significant capital investments over the next 10-15 years. An appropriate regulatory framework takes care of integrated infrastructure planning, fosters competitive manufacturing, and providing and incentives for resilient supply chains (EC 2024f).

Even if the use of natural gas in energy transformation and end-use sectors is phased out, methane emissions remain an important issue if, for example, biogas is used as a replacement. Necessary regulations and policy interventions included those directed towards methane slip from combustion are described in the accompanying paper of Moosmann et al. (2024).

As the energy supply sector is most advanced in its transformation towards climate neutrality and most of the other sectors rely on it for their transformation, many of the regulatory frameworks and adjustments are already set or are in a very advanced state. Implementation, and powerful and fast-acting remedies are needed in case of delays or infringements. Clear targets for installed renewables capacities or RES-E electricity generation could help to create a clear framework for future investments.

# 2 Sectoral trends

## 2.1 Historical emission trends on the EU level

**Historically**, the energy supply sector – which includes power and heat production (energy industry), oil and gas extraction and refining, gas transport and distribution, and coal mining – accounted for a quarter of the total EU-27 greenhouse gas emissions in 2022. It is the sector that has made the largest contribution to reducing EU emissions. While emissions from the sector decreased by only 8% between 1990 and 2005, emissions have been declining at a rapid pace since 2005, with multiple annual reductions of more than 5% recorded over the last decade, and with a total reduction of -43% for the 1990 to 2022 period. The replacement of coal by less $CO_2$-intensive natural gas is an important driver of these emission reductions, but in recent decades the roll-out of renewable energy has been the primary driver. Without the deployment of renewable energy, cumulative greenhouse gas emissions in the 2005 to 2022 period in the energy sector would have been about 18% higher. For 2022, emissions in the energy supply sector would have been 52% higher than actual emissions (authors' own calculations based on (European Environment Agency 2023)). Contrary to their overall downward trend, greenhouse gas emissions in 2021 increased by 7% on a year-by-year basis, mainly as a result of post-Covid recovery. Figures for 2022 indicate a further 3% increase in GHG emissions for this sector compared to 2021. This increase can be attributed to the low output of hydro and nuclear installations during the summer months of 2022, which was partly compensated by a 3% increase in fossil fuel-based energy production. At the same time, the price surge of natural gas made coal relatively cheaper, resulting in a temporary increase in the use of solid fossil fuels (EEA 2023b).

Clearly, the dynamics of emission trends are dominated by the energy industry (CRF 1.A.1), which accounts for more than 90% of emissions in the energy sector. Reductions in fugitive emissions from fuels come from improved materials and improvements in leak detection and repair but also from ceasing oil and natural gas production, with is a major source of fugitive emissions. For more details on fugitive emissions from fuels, see the accompanying paper (Moosmann et al. 2024). Fugitive methane is one of the major GHG gases in this context[2]. Following the trends of the energy sector, fugitive methane emissions have decreased by 67% since 1990 (EEA 2022). This trend mainly comes from a reduction in mining, but also less oil and gas production. Emissions from oil and natural gas systems have also decreased due to technological improvements and better pipeline networks, including the replacement of cast iron pipes, as well as lower losses from gas distribution networks.

Moreover, petroleum refining can be singled out from the general trend of the energy sector (CRF 1.A.1.b). Emissions from this activity had an increasing trend from approx. 107 Mt $CO_2e$ in 1990 to a peak of 126 Mt carbon dioxide equivalent ($CO_2e$) in 2007. Since then, with the wake of the financial crisis of 2008, and the subsequent euro crisis in 2011-2013, emissions from this subsector had been on a declining trend (EEA 2023a). Other drivers of emissions from this subsector is a tax-incentivised shift towards more use of diesel instead of gasoline, a decline in primary refining capacity of 19% since 2009, and low utilisation rates, especially during the Covid pandemic in 2020 (Cooper 2022). In 2021, emissions from petroleum refining in the EU-27 totalled 93 Mt $CO_2e$, a reduction of 25% compared to 2005 levels, but only 14% compared to 1990 levels.

## 2.2 Projected emission trends on the EU level up to 2030 and 2040

**Future projections** by the EU Member States including existing and additional measures (WAM scenario) indicate a continuation of past declining trends. For 2030, their joint projections result in a 68% emissions reduction for the energy sector. Up to 2040, there is a further 10% reduction of emissions, with the energy sector reaching an emission level of 360 Mt $CO_2e$ in 2040. Barely any further aggregate reduction occurs after that year, with emissions still totalling 350 Mt $CO_2e$ in 2050.

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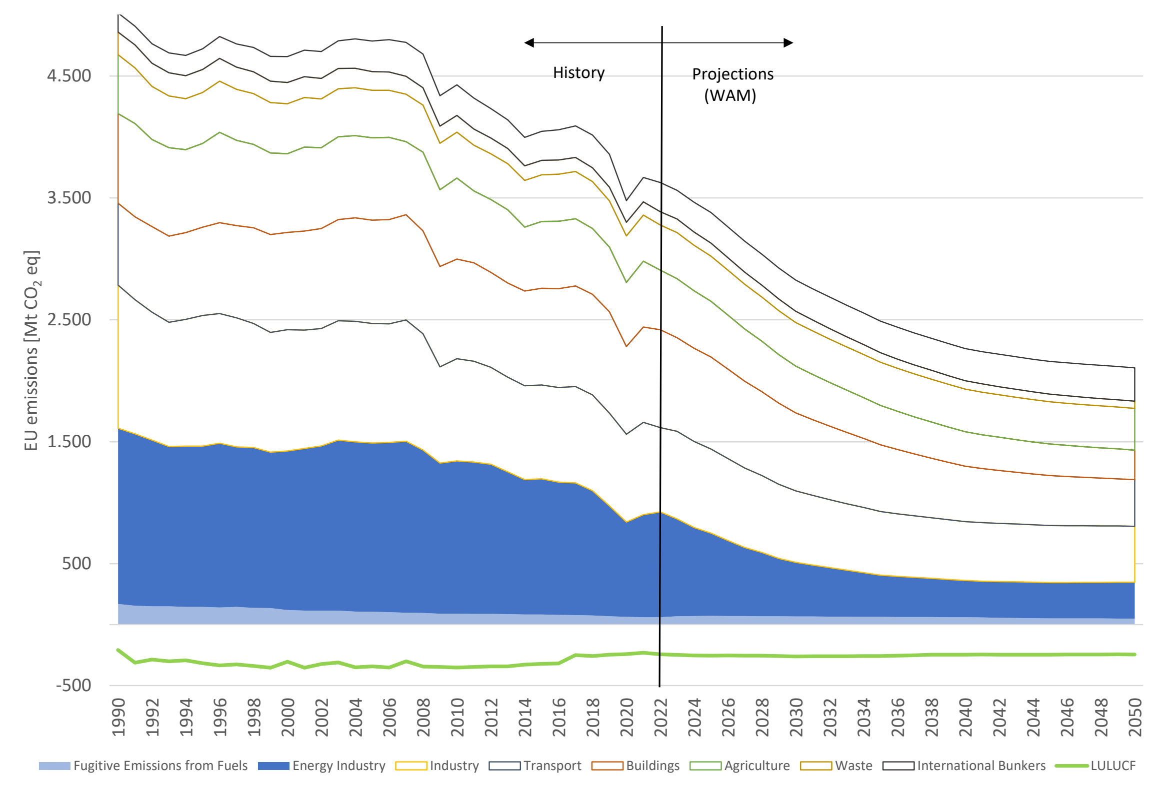
[2] Emissions are only estimated based on activity rates and emission factors. Some activities, i.e. extraction and production, have decreased, others have increased: most notably transportation of natural gas. Due to better materials and new measurements, the factors have also been adjusted downwards so that the reported emissions have also decreased.

Between 2030 and 2040, the dynamics of emission trends are again driven by a decline in emissions from the energy industry. Fugitive emissions also decrease but at a slower pace, increasing its share in energy sector emissions to approx. 15% between 2035 and 2040. Further decreases in emissions after 2040 only occurs for fugitive emissions, while emissions for the energy industry remain unchanged. Member States do not provide projections for petroleum refining separately; rather, these are included within the projections for the energy industry sector. Qualitatively, trends for emissions from this sector are directly driven by changes in the respective demand sectors. The accompanying paper on the transport sector (Seibert et al. 2024) describes trends and necessary policies in detail.

**Figure 1: Historical and projected GHG emissions by sector (in Mt $CO_2$ equivalent)**




Note: WAM = implementation of additional measures that are already being implemented or are planned; WAM projections are not goal attainment scenarios, i.e. projections for emission reductions to meet the EU climate targets. Energy sector emission trends are marked in dark and light blue and include those from energy industry (CRF cat. 1.A.1), and fugitive emissions from fuels (CRF cat. 1.B.).

Source: EEA (2023b)

## Historical and future trends in national projections

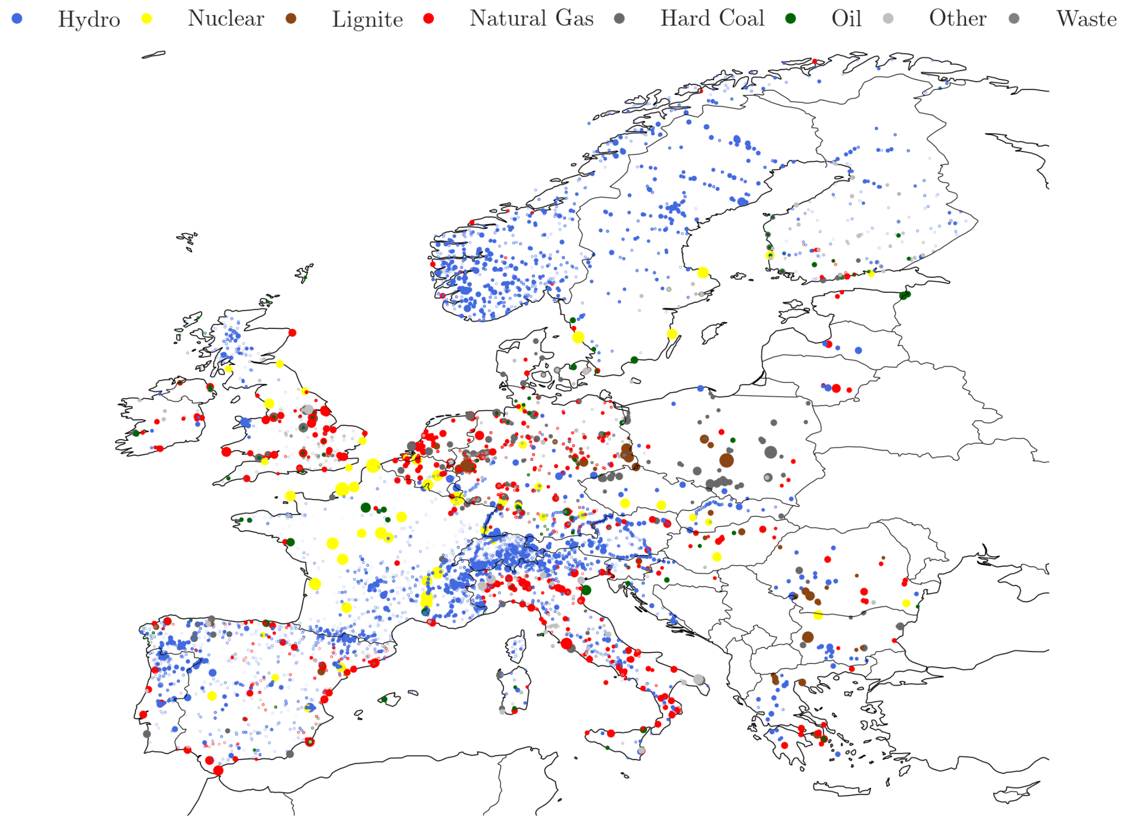
### 2.2.1 Historical trends

Figure 2 shows the distribution of large-scale power-generation units in the EU-27, Switzerland, Norway, and United Kingdom. It highlights the diversity in generation technologies and primary energy sources employed across these countries. Historically, the choice of primary energy source was influenced by domestically available natural resources and trade partnerships.

- Hydropower is prevalent in mountainous regions of countries like France, Switzerland, Germany, Austria, Italy, Portugal, Spain, and Norway.

- Lignite-fired generation dominates in Germany, Poland, Czechia, Greece, Bulgaria, and Romania, where generation is carried out by mine-mouth power plants, ensuring that energy carriers with low energy content are not transported over long distances.
- Hard coal-fired generation has a multifaceted heritage. Similarly to lignite, hard coal-fired power plants were initially constructed in close proximity to hard coal deposits. For instance, in the United Kingdom they were situated near the English and Welsh coal fields, while in Germany they clustered around the coal-rich Ruhr area and Silesia in Poland. During the 1970s, hard coal transitioned into an internationally traded commodity, leading to increased competition between domestic coal production and global markets. In many European regions, local coal production now struggled to compete with international counterparts, prompting a strategic shift in the location of coal-fired power plants. These plants are strategically positioned along coastlines and major rivers to facilitate easy access to international markets. Countries with historical ties to their own hard coal deposits, such as Germany, still maintain hard-coal-fired generation capacities. Additionally, nations with convenient access to international seaborne commodity trade, including Portugal, the Netherlands, and Italy, also feature such capacities. Meanwhile, countries like Poland and Romania continue to rely on domestic coal production. In the pursuit of climate targets, an increasing number of countries have taken steps to phase out coal power plants. This involves a significant reduction in coal-fired capacity in the years ahead. As part of this transition, some coal-fired power plants are being converted into biomass-fired facilities. Notable examples include those in Denmark (Renewable Energy World 2019), the Netherlands (Bioenergy International 2021), and the United Kingdom (Electric Insights 2021).
- Natural gas-fired generation has a transition story. Traditionally, these units were situated in countries with domestic gas production, like the UK and the Netherlands, or in nations that secured long-term supply through strategic pipeline connections. Examples of the latter include Spain, Italy, Germany, and the former Eastern bloc countries. However, the advent of liquefied natural gas technology has reduced dependence on pipeline infrastructure for international gas trade. As a result, countries with access to international seaborne trade – such as Greece, Italy, Spain, the Baltic states, and Poland – are now investing in gas-fired capacities or diversifying their energy supplies.
- Nuclear-based electricity generation is particularly prominent in the French electricity system, accounting for 70-80% of total electricity generation. But it is also present in electricity systems in Spain, Bulgaria, Romania, Hungary, Slovakia, Czechia, Finland, Sweden, the Netherlands, Belgium, the United Kingdom, and Switzerland. Germany phased out nuclear power in April 2023.

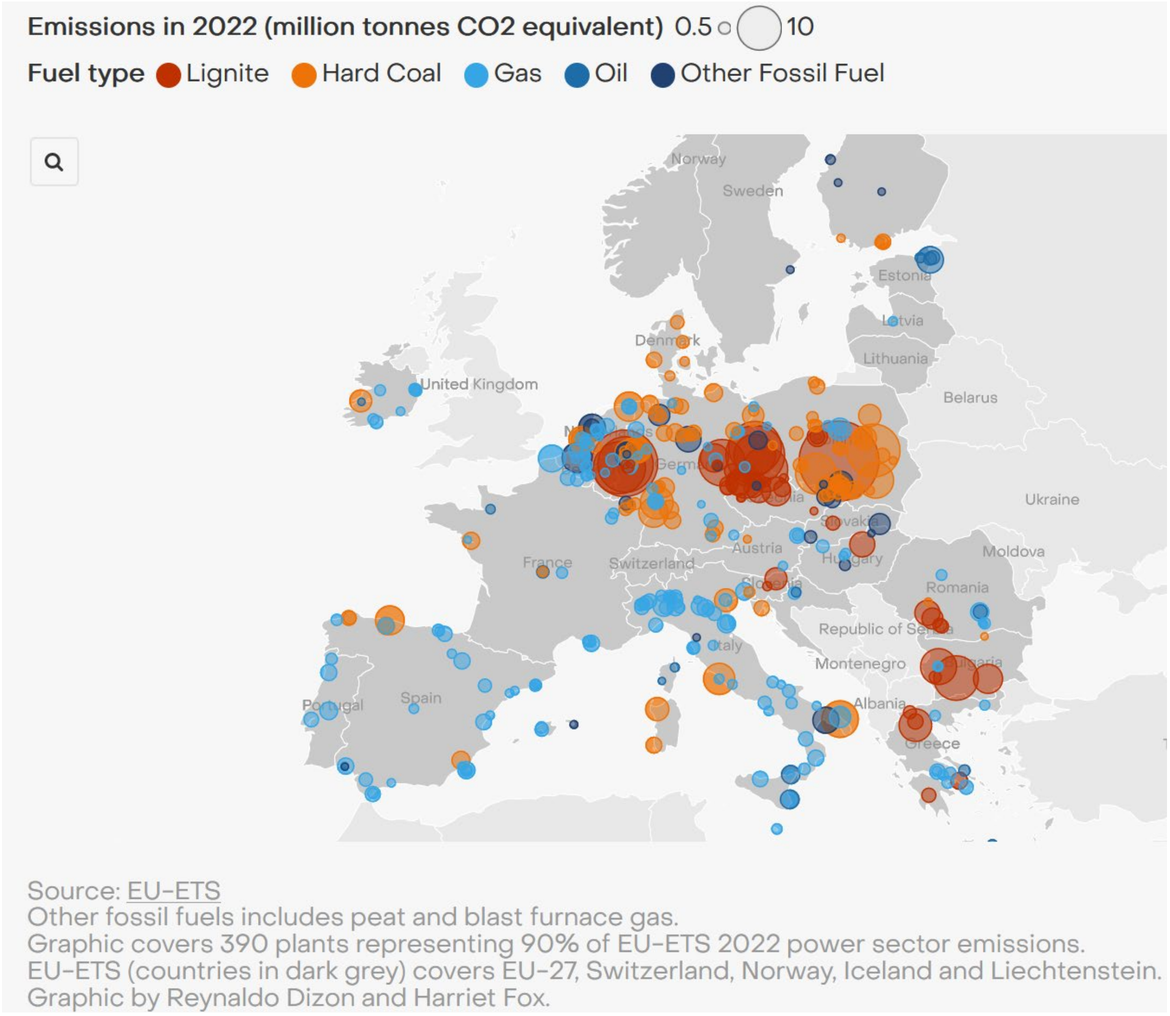
**Figure 2: Distribution of large-scale power generation units in the EU 27, UK, Switzerland and Norway in 2019**




Source: Gotzens et al. (2019)

Corresponding to the respective generation fleets of the Member States, Figure 3 shows the location and magnitude of emissions of individual fossil-fuelled power plants. With their large-scale lignite- and hard-coal-fired generation units, Germany, Poland, and Czechia stand out, hosting several sites with emissions exceeding 10 Mt $CO_2e$ in 2022. The map also highlights the concentration of gas-fired generation in Mediterranean countries like Spain, Italy, and Greece, and in gas trading hubs like the Netherlands and Belgium. Installations with large emissions from other fossil fuels are mainly integrated steelworks in which waste gases are used for electricity and heat generation.

**Figure 3: $CO_2$ emissions from power plants covered by the EU ETS in 2022**

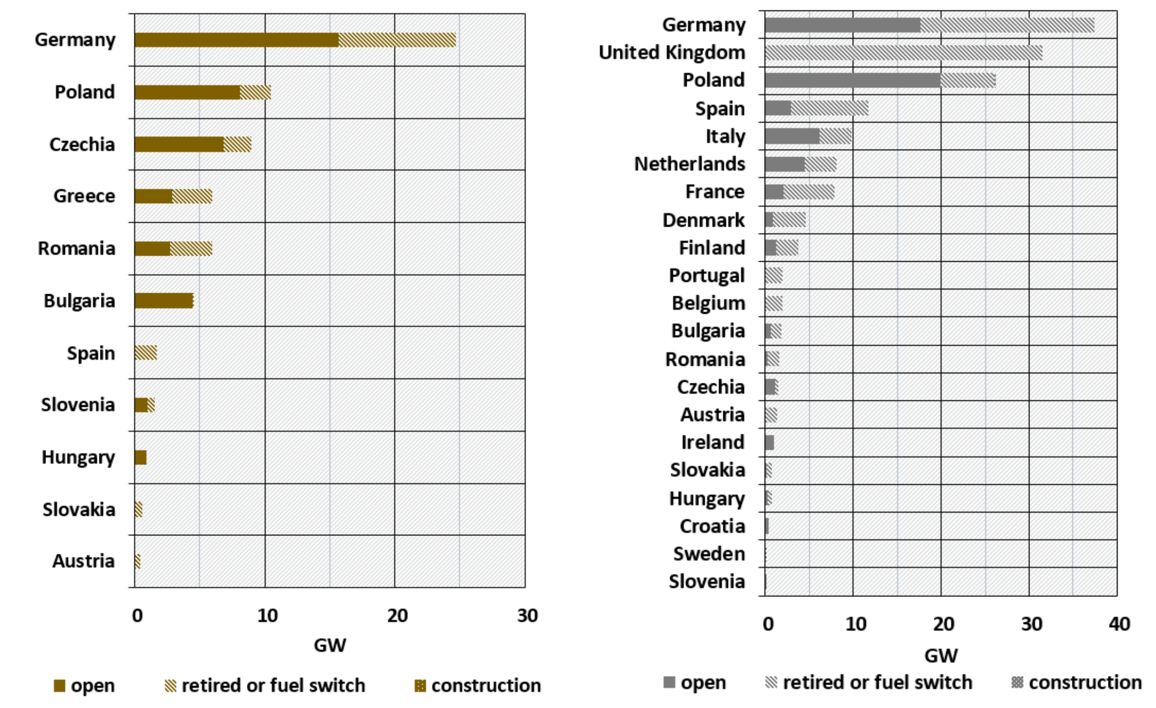



Note: Biomass and some waste generation are not included.

Source: Ember (2023)

In 2022, Germany gave rise to 30% of total EU 27 energy sector emissions, with emissions exceeding 250 Mt $CO_2e$. Poland contributed 175 Mt $CO_2e$, corresponding to almost 20% of the total, while Italy contributed approx. 100 Mt $CO_2e$, corresponding to approx. 10% of the total (EEA 2023a). With coal-fired generation being the main driver behind high emissions in the energy sectors of Member States, the role of coal is crucial in terms of decarbonising their energy sectors. Figure 4 shows the current installed capacity of lignite-fired (left panel) and hard coal-fired (right panel) generation. It also shows the capacity that has already been retired and that is under construction in the individual countries. Poland is the only country that expanded coal-fired generation with an industrial 100 megawatt (MW) unit still in 2024. While large reductions in hard-coal fired generation units have been achieved in various countries, most notably in the United Kingdom, Germany, and to a smaller extent Spain, Poland and France, lignite-fired capacities are showing little change in countries with large capacities such as Germany, Poland, and Czechia and Bulgaria.

**Figure 4: EU-27+UK: Gross capacities of coal power plants installed since 1950 including retired plants and plants under construction, differentiated by country and for lignite (left panel) and hard coal (right panel)**



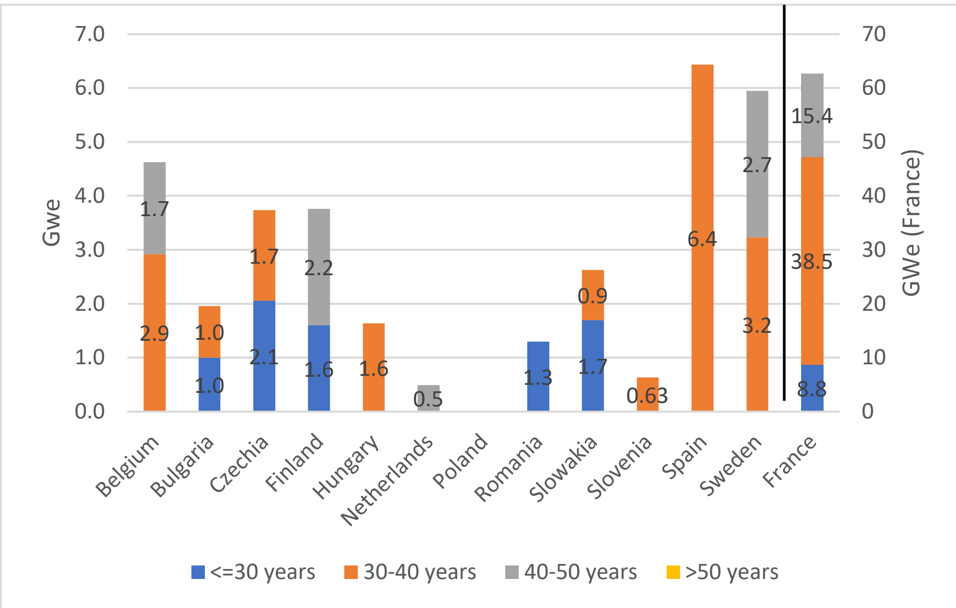

Note: Power plants reported as open in this dataset include units that are operational and units that are in different types of stand-by, not participating in the regular electricity market but available to balance unexpected and long-lasting electricity shortages.

Source: Authors' own illustration based on data from (Europe Beyond Coal 2024)

Nuclear power generation accounted for 21.6% of gross electricity generation in the EU-27, in 2022, producing 609 terawatt hours (TWh) (Eurostat 2023). By the end of 2023, the EU-27 had a total net installed nuclear-based electricity generation capacity of 95.8 GWe. However, as shown in Figure 5, capacity is very much concentrated in a few Member States. France stands out with an installed capacity of 62.7 GWe. In other Member States, installed capacity is much lower, with Spain and Sweden both having around 6 GWe, Belgium around 5 GWe, and Czechia and Finland both around 4 GWe. As of the end of 2023, Denmark, Estonia, Ireland, Germany, Greece, Croatia, Italy, Cyprus, Latvia, Lithuania, Luxembourg, Malta, Austria, Poland, and Portugal do not have any nuclear capacities installed.

The existing nuclear fleet generation fleet is quite old. As highlighted in Figure 5, more than 20% of the fleet has already been in operation for 40 to 50 years, and more than 80% of the fleet has been in operation for more than 30 years. By 2040, only 23 GWe will not have already passed their typical technological lifetime of 50 years. By 2050, this is true for only 12.6 GWe of the 96 GWe installed by the end of 2023.

**Figure 5: Net installed nuclear electricity generation capacity by EU Member State and years of operation**




Source: Authors' own diagram based on IAEA (2024) and Loreck et al. (2023)

### 2.2.2 Future trends

In terms of absolute reductions, Germany has played a key role, accounting for over 25% of the overall EU reductions in the energy supply sector between 2005 and 2022. Spain and Italy have also made significant contributions, with shares in the reduction exceeding 10%.

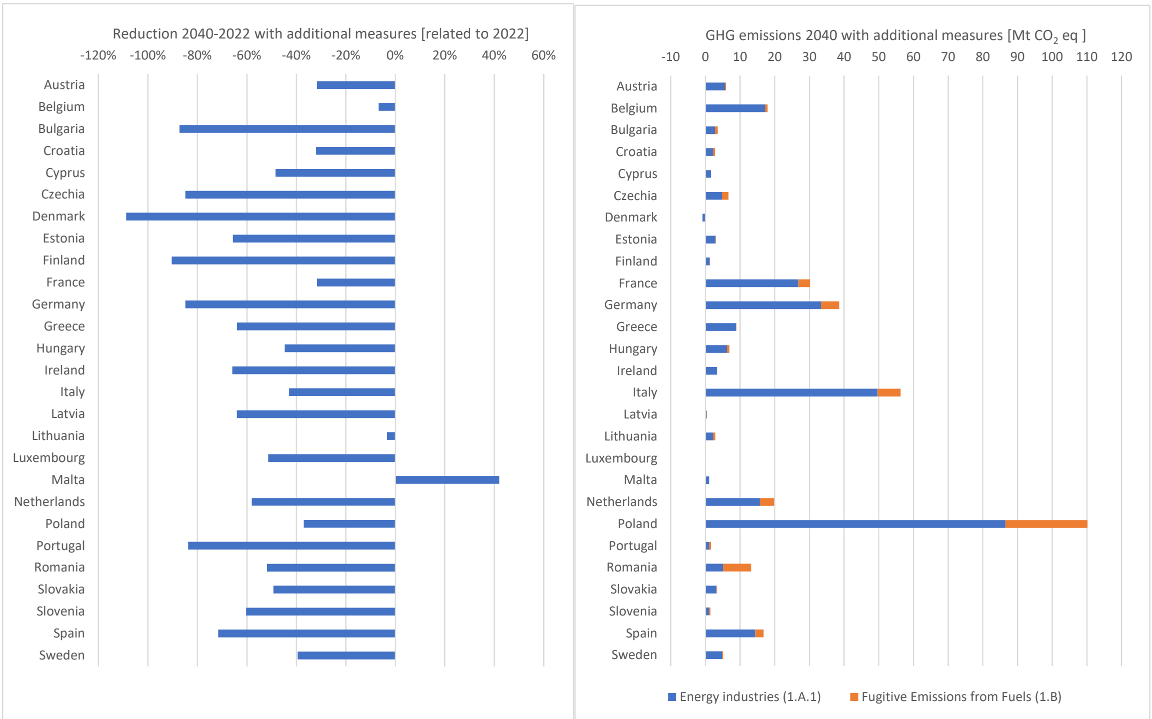
In 2019, Member States submitted their first National Energy and Climate Plans (NECPs). Subsequently, in 2023, they conducted a draft revision of their first NECPs, and in 2024 final updated NECPs have to be submitted. These revisions aim to align with the tightened energy and climate targets and objectives outlined in key European policies, including the European Green Deal, the European Climate Law, the 'Fit for 55' legislative package, and the 2022 REPowerEU Plan. Notably, these updated plans account for the amplified challenges faced by the Energy Union, including the implications of the Russian Federation's invasion of Ukraine. Furthermore, they reflect the European Union's international commitments as stipulated in the Paris Agreement (EC 2023c).

In parallel, Member States report national GHG projections to the European Commission under Article 18 of the Governance Regulation. Based on these projections submitted in the year 2023, in the time period between 2022 and 2030, Germany makes by far the largest contribution to total emission reductions in the energy sector, exceeding 40%. Italy and Spain each contribute almost 10% of the reduction, while Czechia and the Netherlands make reduction contributions of more than 5%. Only in the 2030 to 2040 period do coal-based electricity systems in Poland, Czechia, Bulgaria and Germany plan to reduce or even phase out coal-fired generation (see Table 2). Correspondingly, the largest contributors to absolute emission reductions in the energy sector are Poland (32%), Germany (26%), Bulgaria (10%), and Czechia (9%) (see Figure 6). With no firm plan for a coal phase-out before 2050, the Polish energy sector remains by far the largest emitter among the Member States, accounting for 30%, or 110 Mt $CO_2e$ of the total. Italy, Germany, and France are the next largest contributors with 56 Mt $CO_2$ (16%), 39 Mt $CO_2$ (11%), and 32 Mt $CO_2$ (8%), respectively. When examining the relative reduction efforts of individual Member States (see Figure 6), a divergence in ambition levels up to 2040 and beyond becomes clear. In the 2020 to 2040 period, only 8 Member States reduce their energy sector emissions by more than 60%, and only 6 do so by more than 80%. A 90% reduction or more is only achieved by Finland and Demark, with the Danish energy sector becoming net negative in terms of GHG emissions by 2030 and returning to levels below 1 Mt $CO_2$e by 2040.

In most Member States, the emissions that remain in 2040 are mostly brought about by the energy industry. There can be two reasons for higher shares of fugitive emissions in this context:

- The country still has a domestic coal production or at least a coal mining legacy and coal-bed methane emissions. In particular, this is the case for Poland, Germany, and Czechia.
- Methane is still produced domestically or widely used in the energy system and fugitive emissions from the production, transportation and distribution infrastructure contribute significantly to a Member State's total emissions from the energy sector. Production is the trigger for Romania, which plans to stabilise gas production until 2030 (EC 2023n), and presumably, beyond. Transportation and distribution for domestic consumption and/or functioning as a hub in the EU gas infrastructure can be reasons for higher levels in Netherlands, Germany, France, Italy and Spain.

**Figure 6: Member States' projections of energy sector emission: relative change 2022 to 2040 and absolute level in 2040**




Note: Data shown for national 'with additional measures' (WAM) projections. Energy sector projections include those from the energy industry (CRF cat. 1.A.1), and fugitive emissions from fuels (CRF cat. 1.B.)

Source: EEA (2023b)

## 2.3 Relationship to other sectors

Through increased interaction with other sectors, regulations in other sectors have a strong influence on the development of electricity demand, and demand for network-bound heat supply and thus on the transformation that can be achieved in the energy supply sector. This is particularly true for electrification in the transport sector for compliance with fleet targets, electrification and expansion of district heating in building and industrial heat supply for compliance with RE heat targets, and the production of hydrogen and derivatives via electrolysis, which is addressed by a variety of instruments. There is also strong interrelation with the curricular economy and $CO_2$ transportation and storage infrastructure via waste incineration. Infrastructural aspects such as the expansion of the European electricity grid are addressed within the framework of Trans-European Networks for Energy (TEN-E).

## 2.4 Key challenges in this sector

### 2.4.1 Unprecedented RES-E expansion

RES-E is the basis for the envisioned decarbonisation of the energy sector (EC 2024f). Renewables have been gathering momentum in some Member States. In 2022, the total installed capacity in the EU was 255 GW of solar PV, 152 GW of onshore wind, 18 GW of offshore wind; renewables-based electricity generation amounted to 1151 TWh, corresponding to a 41% share in the total electricity generation in the EU (European Environment Agency 2023). Yet, a huge increase in annual deployment rates is necessary to get on track for achieving climate neutrality by 2050. Wind-based generation and PV-based generation have large-scale future growth potentials (ESABCC 2023). The goal is to achieve the range of 1600 to 2100 GW in combined solar PV and wind capacity installed and 3300 to 4400 TWh of RES-E generation by 2040, which corresponds to a share in gross electricity generation that is more than 85% (see section 4.2.3 for details on RES-E deployment projections). This will require increasing solar PV and wind deployment rates by 50-80%, even after they more than doubled in the 2021-2023 period compared to 2014-2020.

The RED will remain a central element and driver of the expansion of renewable energies in the energy sector in the future. Legally-binding targets for installed renewables capacities (as currently set out in the EU Solar Strategy, and the Offshore Wind strategy) or RES-E electricity generation will help to create a clear framework for future investments. Legally-binding targets for RES-E are central to providing security for future RES-E investments. While there is a consensus on the need to vastly increase wind and solar PV capacities, it might still be difficult to agree on a RES-E generation target on the EU level. Shaped by national interests, individual Member States lobby for an expansion of the scope of technologies eligible under the RES targets; it is argued that other technologies, most notably nuclear and bioenergy, should be allowed to contribute to meeting these targets.

The electricity market design needs to co-evolve and adhere to future system design. With new large-scale electricity demand from, for example, hydrogen production, heat pumps and e-mobility, the role of flexibility becomes increasingly important and there is a need for a radical change in the nature of installed generation technologies (small, decentralised units vs. large-scale generation units on central grid nodes). The unified proposal for the reformed Energy Market Directive (EC 2023e) sets the framework for organising the backup capacities, RES-E installations and flexibility options needed in this future design.

### 2.4.2 Quick phase-out of coal-fired generation

In 2022, coal-fired generation still accounted for 450 TWh (16%) of electricity generation and 435 $MtCO_2e$, corresponding to a 56% share of emissions in electricity and heat generation in the EU-27, and a 47% share of total EU-27 GHG emissions from the energy sector[3]. While

[3] Own calculations based on Brown und Jones(2024) and EEA(2023a).

many Member States have firm plans to phase out coal long before 2040, not all of these plans are enshrined in law or backed by shut-down dates for individual units. Poland – a country with one of the largest coal-fired generation fleets in the EU-27 – does not have any firm plans to phase-out coal before 2049 (see Table 2).

The EU ETS is the key climate policy mechanism for phasing out coal. With the emissions cap falling to zero by around 2039, coal – one of the most emission-intensive energy carriers – will be phased out earlier. $CO_2$ prices in the EU ETS will affect emission-intensive coal-fired generation to a greater degree than less emission-intensive gas-fired units long before that time. The specific level required for a fuel-switch also depends on the relative fuel prices.

Phasing-out lignite and emission-intensive regional resources like oil shale requires support for the economic transition of the respective regions. To this end, the EU has introduced the Just Transition Mechanism which provides targeted guidance and financial support (EC 2023a). However, additional support might be necessary as was the case in Germany with the additional payments agreed in the Commission on Growth Structural Change and Employment (BMWi 2019) and enshrined in the Federal Act to Reduce and End Coal-Fired Power Generation (KVBG) (BMWi 2019).

### 2.4.3 Transition of natural gas-fired generation to climate-neutral energy carriers

In 2022, natural gas-fired generation accounted for 535 TWh (19%) of electricity generation and 245 Mt $CO_2$e, a share of 32% of emissions for electricity and heat generation in the EU-27, and a share of 27% of EU-27 total GHG emissions from the energy sector. In contrast to coal-fired generation, there are no structured plans supported on EU level to reduce and phase-out gas-fired capacities. However, these power plants and Combined Heat and Power (CHP) units need to transition to climate-neutral gaseous energy carriers, such as hydrogen, biomethane or green Power-to-X (PtX) products like ammonia, methanol, or e-methane.

Only with alternative dispatchable units available and given that their respective support scheme is sensitive to $CO_2$ pricing will the EU ETS be the driver of phasing out natural gas. However, as long as natural gas remains the price-setting fuel in the Central European electricity market, increasing EU ETS prices alone will not push natural gas out of the market.

The agreed energy market reform allows a support scheme for new investment in the form of two-way contracts for difference and equivalent schemes for wind energy, solar energy, geothermal energy, hydropower without reservoir, and nuclear energy.

At the same time, the EU Taxonomy (Europäisches Parlament; Rat der Europäischen Union 2020), the respective Delegated Regulation (EU 2023c) and the Guidelines on State Aid for climate, environmental protection and energy (EC 2022b) set very strict conditions under which capacities starting out as natural gas-fired units and later on shifting to Carbon Capture, Transport and Storage (CCTS), or to low-carbon or renewable gas can receive financial support on the EU or Member State levels.

### 2.4.4 Small and unclear role for nuclear power generation

In 2022, nuclear power generation accounted for 609 TWh (22%) of electricity generation, down from 928 TWh in 2004. The EU nuclear power plant fleet is old, and without lifetime expansion beyond the typical technology lifetime of 50 years, the available generation capacity will decline to 23 GW by 2040 (see box 1). This is in stark contrast to capacities of 71-88 GWe reported in the EC Impact Assessment for 2040. Lifetime expansion with increasing associated risks and the construction of new installations with a capacity of at least 15 GWe would be required to achieve these capacity levels.

The EU Taxonomy (Europäisches Parlament; Rat der Europäischen Union 2020) sets conditions for public financial support for the construction of new units and the refurbishment of existing nuclear power generation.

SMR research programs with a total of 150 million Euro (EUR) of funding available are earmarked in the EU budgets to further develop these technologies up to 2025. Despite available public funding, companies pursuing the development of these technologies have been reducing their ambitions or closing their programs altogether (Pistner et al. 2024).

Much of the nuclear supply chain is dominated by Russia and Kazakhstan. In 2023, 44.5% of uranium delivered to EU utilities still came from Russia (23,5 %) or Kazakhstan (21 %), while no uranium originated in the EU; likewise less than 30% of conversion services and approx. 50% of enrichment services were provided in the EU (ESA 2024). Nuclear fuel does not count towards fuel import dependence in the EU impact assessment. This should be changed to account for strong dependencies in the supply chains.

### 2.4.5 Rapid ramp-up of hydrogen production capacities and transport and storage infrastructure

In 2023, 0.5 GW of electrolysis-based hydrogen production capacity was installed in Europe (IEA 2023). These production capacities need to quickly ramp up tin order o supply the aspired consumption levels of 800-1100 TWh in 2040 – even more so if imports do not play a significant role, as is foreseen in the ECImpact Assessment (IA) (EC 2024f).

On the demand side, RED III (EU/2023/2413) (EU 2023d) is the most significant driver, setting the target for penetration levels of hydrogen and other renewable fuels of non-biogenic origin (RFNBOs) for the industry and the transportation sector, and defining eligibility criteria.

Carbon Contracts for Differences (CCfDs) can become another important pull factor for hydrogen demand as they provide long-term financial support for energy-intensive industries willing to transition towards cleaner production (Bundesminesterium für Wirtschaft und Klimaschutz 2024).

On the supply side, the European Hydrogen Bank works to solve the chicken-and-egg problem by organising auctions for renewable hydrogen production in the EU.

Hydrogen infrastructure and its integration with other infrastructures are regulated by the Hydrogen and Decarbonised Gas Market Package which consists of an update of the Regulation on ‘the internal markets for renewable gas, natural gas and hydrogen' (EU 2024/1789)and an update of the Directive on ‘common rules for the internal markets for renewable gas, natural gas and hydrogen’ (EU 2024/1788).

### 2.4.6 Rapid expansion of non-fossil fuel-based flexibility option

The energy transition from fossil fuel-based dispatchable plants to intermittent non-dispatchable renewables requires a fundamental change in the way in which supply and demand are matched. In the new system, non-fossil fuel flexibility options such as pump-storage, batteries, demand side management, and the European transmission grid as a spatial flexibility play a key role. In the European Union currently hosts 44 GW of pump-storage (in 2022) (Quaranta et al. 2022), 21 GW of battery (in 2024) (EASE 2024), and 0.5 GW of electrolyser capacity (IEA 2023). Only a very small amount of demand-side flexibility is currently used.

Future scenarios see a huge expansion of flexibility options. For electrolysers and batteries, a significant increase to 350 GW and 200 GW respectively is foreseen by 2040 in the EC (2024f) Impact Assessment. Pumped storage has a limited potential and is expected to increase to approx. 80 GW by 2050 (EC 2024f). The future role of demand-side flexibility heavily depends on the regulatory framework governing how new consumption applications such as electric vehicles and heat pumps will be integrated into the electricity system. EU Directive 2024/1711 and Regulation 2024/1747 came into force in 2024, defining measures for non-fossil flexibility on EU level for the first time.

### 2.4.7 Targeted and cost-effective contribution of $CO_2$ capture, transport and storage and waste incineration and direct air capture

In order to address hard-to-abate emissions for waste incineration, CCS is a viable option. Bio-CCS should not be supported uniformly; rather, tailored approaches need to take into account the multitude of challenges around nature-based solutions (see Meyer-Ohlendorf et al. (2023). Moreover, the use of direct air capture (DAC) makes it possible to compensate hard-to-abate emissions from other sectors, in particular agriculture. While the first two have high technology readiness levels (IEA, 2020), DAC needs further financial support in order to reduce costs and bring it closer to commercialisation. The most promising technologies are at Technology Readiness Level (TRL)-7. However, the advancement to TRL-11 in the new International Energy Agency (IEA) scale for disruptive technologies looks unlikely since the scale-up from small pilots to an industrial scale requires time and large investments. Moreover, validation on a large scale is still missing or has not yet been planned (Bisotti et al. 2024).

Carbon capture and storage plays a major role in the EC Impact Assessment with a total of 90-340 Mt $CO_2$ to be captured, transported and stored by 2040 (EC 2024f). In order to ramp up the development, the EC has proposed **The Industrial Carbon Management Strategy (EC 2024d).** Among other things, it echoes the target $CO_2$ capture level of 50 Mt $CO_2$ per year by 2030, which was previously defined in the Net Zero Industry Act (NZIA) (EC 2023o), and proposes action for preparing a regulatory framework, market design and infrastructure planning mechanism, establishing a matching platform for linking $CO_2$ transport and storage providers with emitters, developing an investment atlas of potential $CO_2$ storage sites, and establishing rules for the accounting of all industrial carbon management activities.

The EC Impact Assessment also includes carbon capture for fossil fuels in the power sector summing up to 30-40 Mt $CO_2$ captured in 2040, and accounting for 10%-30% of total $CO_2$ captured from all sources (EC 2024f). However, these emissions could be avoided by switching to climate-neutral fuels. The inclusion of carbon capture for fossil fuel-fired generation as an option can create lock-in for fossil fuel infrastructure, comes with the problem of additional emissions from methane leakages in the supply chain, and provides the wrong incentives for the layout and dimensioning for future common $CO_2$ transport infrastructure.

EU ETS can work both as a driver of emission reductions and as a source of financial incentive for $CO_2$ storage. Waste incineration is to be included in the EU ETS from 2028 (Art. 30 4c, EU 2024a). This regulation also includes provisions on the further assessment of whether landfills, with their methane and nitrous oxide emissions, should also be included to avoid adverse incentives. Direct air carbon capture and storage (DACCS) could be included in the EU ETS using provisions for ‘harmonised rules for projects that reduce emissions’ in the EU ETS regulation (Art. 24a, EU 2024a), thereby generating a stream of income for these projects.

### 2.4.8 Sizing down refineries and switching to Fischer-Tropsch-based refining

In 2021, EU petroleum refining accounted for 93 Mt $CO_2e$, corresponding to 25% below 2005 levels. These reductions were driven by a decrease in primary refining capacity of 19% since 2009, and low utilisation rates, especially during the Covid pandemic in 2020 (Cooper 2022). In the future, the remaining demand for fuels and hydrocarbon by-products such as liquefied petroleum gas and naphtha can be met by switching to Fischer-Tropsch-based refining taking renewable hydrogen and climate-neutral $CO_2$ sources as inputs.

Regulation that will further drive down fuel demand and hence reduce required refining capacities in the EU include incentives for the further direct electrification of road transport and indirect electrification of shipping and aviation with synthetic fuels (see accompanying paper on the transport sector Seibert et al. (2024)).

The decarbonisation of the remaining refineries is driven by the RED III Directive. This includes minimum requirements of an at least 29% share of renewable energy in the final consumption of all energy used in transport, or a minimum 14.5% reduction in greenhouse gas emissions compared to those that would have been created by fossil fuel use; a 5.5% share of advanced biofuels and RFNBOs in the final consumption of all energy supplied to transport, with a 1% RFNBO minimum share; and an indicative goal of at least 1.2% of energy used in maritime transport to come from RFNBOs in 2030 (NOW 2024). The decarbonisation of the remaining refineries is also driven by regulations on sustainable aviation fuels in the ReFuelEU Aviation Regulation (EU 2023b), and by maritime fuel standards defined by the FuelEU Maritime Regulation (EU 2023a). Hydrogen demand from refineries, which comprises a major share of current hydrogen consumption in the EU, will need to comply with the industry targets set out by RED III, making sure that 42% of hydrogen use in 2030 and 60% in 2035 originates from RFNBOs.

# 3 Sector contributions to the 2040 climate target

## 3.1 Current relevant EU legislation

### 3.1.1 Renewable energy deployment in electricity generation

The Renewable Energy Directive (EU 2018) is the central regulation for fostering renewables expansion, both on the supply and on the demand side. The directive defines the overarching European target for renewable energies. The revised Renewable Energy Directive (REDIII, EU/2023/2413) (EU 2023d) now mandates a minimum 42.5% share of renewable energy in total EU energy consumption by 2030, with 45% as an aspirational goal. This corresponds to nearly double the existing share of renewable energy within the EU (EC 2024g). According to the EC (2023i) assessment of the updated NECPs submitted by late 2023, the share of renewable energy in final energy consumption on the EU level could amount to between 38.6% and 39.3% in 2030. This is significantly higher than the 32% set in RED II yet lower than the binding target of 42.5% with the collective endeavour to achieve a target of 45% laid down in the 2023 RED III. Very few Member States have submitted a contribution that is in line with their expected national contribution under the Governance Regulation and the RED III.

Although all Member States are encouraged to increase their share of renewables in electricity generation to contribute to reducing GHG emissions and import dependency on fossil fuels (EC 2022c; EU 2018), there are no firm target levels for 2030 or beyond on the EU level enshrined in the RED. Table 1 details the renewable energy shares in electricity generation in 2030 according to Draft updated NECPs 2023. It shows a wide range of 100% as a maximum in, for example, Lithuania, and 30% and 49% as minimums in Slovakia and Belgium. While 100% is also reported for Estonia, its planned phase-out of shale oil as late as 2035 seems to contradict this (see section 4.1.2). Compared to the RES-E share of 85-90% for 2040, stated in the decarbonisation scenarios (see section 4.2.3) and taking into account the clear increase in electricity demand (see section 4.2.2), there is still a long way to go for most of the EU Member

States – particularly for those countries with high shares of domestic fossil fuel production and no firm pre-2050 phase-out plans like Poland (see section 4.1.2).

**Table 1: Overview of renewable energy shares in electricity generation of individual Member States in 2030**

| EU Member State | Renewable energy share in electricity generation in 2030 according to Draft updated NECP 2023 | EU Member State | Renewable energy share in electricity generation in 2030 according to Draft updated NECP 2023 |
|---|---|---|---|
| **Austria** | - | **Italy** | 65% |
| **Belgium** | 49% | **Latvia** | - |
| **Bulgaria** | - | **Lithuania** | 100% |
| **Croatia** | 74% | **Luxembourg** | 37% |
| **Cyprus** | - | **Malta** | |
| **Czechia** | - | **Netherlands** | 86% |
| **Denmark** | - | **Poland** | - |
| **Estonia** | 100% | **Portugal** | 85% |
| **Finland** | 57% | **Romania** | 56% |
| **France** | 58% | **Slovakia** | 30% |
| **Germany** | 80% | **Slovenia** | 52% |
| **Greece** | 80% | **Spain** | 81% |
| **Hungary** | - | **Sweden** | 88% |
| **Ireland** | 70% | | |

Source: Draft updated NECP 2023 of the respective Member State EC (2023d)

The Renewable Energy Directive also contains rules to ensure the use of renewable energies in the transport sector and in the heating and cooling sector and for reaching the respective target for 2030. It also contains common principles and rules for support schemes for renewable energy, the right to produce and consume renewable energy and sustainability criteria for biomass. Moreover, the directive contains provisions to remove barriers, promote investment and reduce the cost of renewable energy technologies.

The RED is supported by the following accompanying regulations and action plans:

- **Permitting**: According to Council Regulation (EU) 2022/2577 (EU 2022b), amended by Council Regulation (EU) 2024/223 (EU 2024b), the planning, construction and operation of RES-E units, and their connection to the grid, the related grid itself and storage assets are now presumed to be in the "overriding public interest and serving public health and safety when balancing legal interests in the individual case". Provisions in this regulation reduce the complexity of permitting, create clearer rules for balancing nature conservation concerns with RES-E deployment and thus aim to reduce permitting costs and times.
- **Onshore wind energy**: The European Wind Power Action Plan (EC 2023k) acknowledges the large gap between current expansion levels of 16 GW in 2022, on the one hand, and the required expansion by 37 GW per year in order to achieve the EU 2030 targets of 510 GW, on the other hand. The action plan defines six main pillars of

concerted action by the European Commission, Member States and the industry and sets out measures that should be urgently taken for each of them.

- **Offshore wind energy**: The Communication on achieving the EU's offshore wind ambitions (EC 2023j) highlights that the annual installed capacity needs to increase ten-fold compared to 2022 in order to achieve the new indicative target of 111 GW of offshore renewables by 2030 (76 GW offshore wind) and 317 GW (260 GW offshore wind) by 2050 (EC 2023k). It identifies 6 focus areas and describes actions taken to address them.
- **Solar energy**: The EU Solar Energy Strategy (EC 2022e) puts forward a target of over 320 GW of solar PV capacity by 2025, and almost 600 GW by 2030. It includes initiatives that will introduce a legally-binding EU solar rooftop obligation that is compulsory for all new public and commercial buildings with a useful floor area larger than 250 $m^2$ by 2026, for all existing public and commercial buildings with a useful floor area larger than 250 $m^2$ by 2027, and for all new residential buildings by 2029. Moreover, the Commission aims to make permitting procedures shorter (e.g. limiting the length of permits for rooftop solar installations, including large ones, to a maximum of 3 months) and making these simpler by means of a legislative proposal recommendation and guidance (European Parliament 2024).

### 3.1.2 Phase-out of fossil-fuel-based generation

The future of coal in the electricity sector differs between the coal-using European countries; however, most have phase-out plans with different dates (see Table 2). There are four countries that have already ceased using coal. These are Belgium (coal phase-out in 2016), Austria (2020), Sweden (2020) and Portugal (2021). Hungary and Ireland plan to phase out coal by 2025 and 2027 respectively. Denmark's coal power plants have individual closure dates, the last one occurring in 2028. Finland plans to phase out coal by 2029 according to legislation. Croatia wants to phase it out by 2033 at the latest. In January 2022, Slovenia announced that it would phase out coal by 2033. Slovakia plans to phase out coal by 2030 and Bulgaria announced in October 2021 that it will phase out coal by 2038-2040. At the other end of the scale is Poland, which does not have any official plans to phase out coal at all to date.

**Table 2: Overview of coal phase-out plans of EU Member States**

| EU Member State | Planned coal phase-out in the electricity sector |
|---|---|
| **Bulgaria** | 2038-2040 – Dates mentioned in the National Resiliency and Recovery Plan submitted to the EC in 2021; investments in upgrades are needed to keep operating existing plants to comply with IED regulation. |
| **Croatia** | 2033 – Announced as the phase-out date by the Croatian Prime Minister at COP26 |
| **Czechia** | 2033 – Government announced this intention in January 2022, but plans have not yet been enshrined in law. |
| **Denmark** | 2028 – All coal-fired power plants have individual closing dates, the last one occurring in 2028. |
| **Estonia*** | 2035 – (*concerns oil shale, the relevant fossil fuel) According to the Coalition Agreement |
| **Finland** | 2029 – As per the coal phase-out law that bans the use of coal in power generation |
| **France** | 2027 – President Macron announced in September 2023 that France would extend the life of its two remaining coal plants beyond the originally planned coal phase-out of 2022. |
| **Germany** | 2038 – According to current law; the current Coalition Agreement aims for 2030 as the phase-out date. |

| | |
|---|---|
| **Greece** | 2028 – One remaining lignite-fired power plant, which was originally planned to close in 2025 but was extended to 2028 to address electricity price increase observed in 2022. |
| **Hungary** | 2027 – Last coal-fired power plant to close once new gas-fired plant is operational; date could be postponed to 2029. |
| **Italy** | 2025 – According to a non-binding energy strategy of 2017 and confirmed in 2019. Due to delays in the expansion of Sardinia's connection to the mainland, the coal-fired power plant there will continue to operate until 2027. |
| **Ireland** | 2025 – Announced in 2018 when Ireland joined the Powering Past Coal Alliance. |
| **Netherlands** | 2029 – Operation of the last coal power plants must cease at the end of 2029 according to current law. |
| **Poland** | No phase-out plans, government has announced the plan to keep using coal until 2049. |
| **Romania** | 2030 – According to a law passed in June 2022. |
| **Spain** | 2025 – According to the Spanish NECP. |
| **Slovenia** | 2033 – As per government announcement made in 2022. |
| **Slovakia** | 2024 – All coal-fired power plants have a final year to cease coal-fired electricity and heat generation. |

Note: Austria, Belgium, Cyprus, Latvia, Lithuania, Luxembourg, Malta, Portugal, and Sweden do not have coal in the electricity and heat generation mixes.
Source: Authors' own compilation based on Beyond Fossil Fuels (2024)

In this regard, the ECstates that all Member States have started to phase out solid fossil fuels for energy generation, but only a few plan to become coal-free before 2030 (EC 2023b). Some Member States are even reversing previous commitments in the Territorial Just Transition Plans approved by the Commission in 2022.

The key climate policy in place driving the phase-out of coal is the EU ETS. This mechanism covers the energy-intensive industries and the energy sector, sets a cap on emissions and allows for emission allowance trading between participants. The cap on emissions is reduced based on a linear reduction factor of 2.2% up to 2023 and is further tightened to 4.3% from 2024 to 2027 and to 4.4% from 2028 (2003/87/EG 2003). As a result, the cap will fall to zero by around 2039. Questions are arising with respect to market functioning and market behaviour leading up to and beyond 2039, which must be addressed in the near-term (see, for example, Pahle et al. (2023)).

But even without the cap falling to zero or close, with marginal cost pricing in the primary European electricity market and the EU ETS covering emissions from large-scale electricity and heat generators, the profitability of coal-fired units is already under strong pressure as soon as the $CO_2$ prices reflect that emission-intensive coal-fired generation is more expensive than less emission-intensive gas-fired units. The concrete level required for a fuel-switch also depends on the relative fuel prices. With natural gas prices quickly declining after the peak induced by the Russian war of aggression against Ukraine and the subsequent energy crisis, fuel switch prices are also decreasing. The fuel-switch price that results from the EC IA assumption is about 100 EUR(2023)/European Allowance (EUA)[4] for 2030; it decreases further after 2030 (EC 2024f). However, natural gas prices are assumed to amount to approx. 60 EUR (2023)/megawatt hour (MWh) lower heating value (LHV) in 2025, and 56 (2023)/MWh

[4] Fuel prices are reported in Figure 4 (EC, 2024) for coal and gas in EUR2015/boe. Applying respective conversion factors and a deflator of 1.26/1; 0.925 LHV/HHV, emisison factors of 0.336t$CO_2$/ Megawatt Thermal (MWhth) for coal and 0.201 t$CO_2$/MWhth for natural gas and efficiency of 60% for natural gas and 42% for coal.

LHV in 2030. With current fuel prices, the fuel switch would already occur at about 60 EUR (2023)/EUA.

Lignite and oil shale, which are similarly emission-intensive, are regional domestic resources in the respective Member States. Therefore, the phase-out in these regions also entails closing the respective mining and associated industry, and hence transforming substantial parts of the economic basis in these regions. To support this transition, the EU has introduced the Just Transition Mechanism that provides targeted guidance and financial support (EC 2023a). Such activity is also back by the Guidelines on State Aid for climate, environmental protection and energy, (EU 2022a). Until end of 2023, these allowed state aid for investment into natural gas-fired generation in order to speed up coal phase-out, for Member States with real gross domestic product (GDP) per capita at market prices in EUR at or below 35% of the Union average in 2019. Regardless of GDP levels and with no time limit, they allow support for closure of profitable solid fuel plants and mines, and support of unprofitable ones at exceptional cost to mitigate the social and regional consequences of the closure.

### 3.1.3 Gas-fired generation units with targeted switch climate-neutral energy careers

In contrast to coal-fired generation, there are no structured plans supported on the EU-level to reduced and phase-out gas-fired capacities. However, these power plants and CHP units need to transition to climate neutral gaseous energy carriers, like hydrogen, biomethane or green PtX-products like ammonia, methanol, or e-methane. In the EC IA of 2024, the use of gaseous energy carriers decreases by 54-68% in the period 2020 to 2040 (EC 2024f). Further reductions are projected up to 2050. The remaining consumption includes synthetic gases and assumes an increase in available biomethane that is fed into the gas networks.

With alternative dispatchable units available, the EU ETS can also be a driving force in phasing-out natural gas. However, as long as natural gas remains the price-setting fuel in the central European electricity market, increasing EU ETS prices alone will not push natural gas out of the market.

With some adaptation and, in some cases at additional cost, a unit can start as a natural gas-based installation and switch to climate-neutral energy sources, later on. However, the EU strictly regulates financial support in such cases:

Under very strict rules for which compliance has to be verified by an independent third party, the EU Taxonomy (EU 2020; 2023c), REGULATION (EU) 2020/852, and the respective Delegated Regulation (EU) 2023/2486) allows investments into fossil gas-fired capacities: The units must ensure lifecycle GHG emission levels of below 100g $CO_2$e/kilowatt Hour (kWh), which can only be achieved with the co-firing of low carbon or renewable gases or with the use of carbon capture, transport and storage. In both cases, the technology must also comply with EU Taxonomy criteria. Units for which construction permission has been granted before 2031 as back-up capacity or as CHP units must convert to renewable or low-carbon gas before 2036. The new unit cannot substantially extend capacity compared to the old one and has to replace coal or oil-fired generation. Member States that replace coal-fired units must report a coal phase-out plan in their NECP.

According to the Guidelines on State Aid for climate, environmental protection and energy (EC 2022b), new investments in natural gas-based generation have to be tested to ensure there are no lock-in effects. Possible exemptions are a switch to CCS/Carbon Capture and Utilisation (CCU) or a shift to renewable or low-carbon gas or the closure of the plant consistent with the EU 2030 climate targets and 2050 climate neutrality targets.

### 3.1.4 Nuclear power generation units – life-time expansions and new plans for a domestic energy source?

There is a strong political push for new nuclear capacities including SMRs (Ursula von der Leyen 2024) and activity by the EU COM (EC 2024f) geared at facilitating financing of new capacity, building new industrial supply chains. However, there is also new financial support for the lifetime expansions of existing units in compliance with the EU Taxonomy (Council of the European Union 2023; EC 2024a). This push is driven by the large gap between the capacity decrease of the old EU nuclear fleet, on the one hand, and the envisioned capacities and role for nuclear of some Member States, on the other hand (see box 1). The push is also in stark contrast with the economic and technological potential of this technology. While today's technology lines are often labelled as 'novel,' many of these concepts were already researched and developed during the initial phases of nuclear technology in the 1940s and 1950s (Pistner et al. 2024). These included fast reactors, high-temperature reactors, and molten salt reactors. Despite this early promise, globally, light-water reactors became dominant while other technologies, such as sodium-cooled fast reactors (SFRs), faced challenges in widespread adoption. SFRs ended up in what is often referred to as the 'valley of death' for innovation and economics. Although the initial inventions were made, subsequent innovations and widespread implementation did not follow suit. The path dependency established by the prevalence of light-water reactors suggests that this technology will continue to dominate in the short and medium term. SFRs may find a niche application within this context; however, pursuing SFRs involves significant time and effort. Planning, licensing, constructing, and operating experimental and demonstration reactors typically require one to two decades per project, if not longer based on historical experience. Furthermore, the knowledge gained with these facilities must inform the technical design of eventual prototype reactors. Considering the urgency of achieving emission reduction in the energy sector by 2040, it is unlikely that any SMRs will make a significant contribution. The required decarbonisation level for the energy system by 2040 may limit the need to include this technology in portfolios for 2050.

When comparing the security of energy supply and the import dependence of different energy systems scenarios, nuclear power is considered as a domestic energy source. However, uranium is not mined in the EU-27 at all; in fact, only 32% of uranium imports in the EU in 2020 came from mines not owned by totalitarian regimes (Herold et al. 2022). Moreover, large parts of the complex nuclear supply chain rely on imports from other counties in which the processing facilities are located. Importantly, many of the European reactors, including the French nuclear fleet, directly or indirectly rely on Russia as a supplier for parts in the nuclear fuel rods supply chain. Hence, taking nuclear power generation into account as a domestic energy source neglects the underlying supply chain and the strong concentration on few suppliers (Herold et al. 2022).

### 3.1.5 Rapid ramp-up of hydrogen production capacities and transport and storage infrastructure

**Hydrogen demand**

The RED III (EU/2023/2413) sets a number of targets and sub-targets for the consumption of hydrogen and RFNBOs (EU 2023d). In industry, Member States must ensure that 42% of hydrogen use in 2030 and 60% in 2035 originates from RFNBOs; in transportation: at least 1% of final energy consumption (FEC) must come from hydrogen and RFNBOs; and in maritime transport, an indicative level of at least 1.2% of energy used is to come from RFNBOs by 2030. Each Member State will also be required to report the level of RFNBOs it expects to import and export in its NECP report (Laprévote et al. 2023). By 2040, total consumption of hydrogen is projected to increase from about 100 TWh in 2030 to 800-1100 TWh (see section 4.2.6).

The RED III also provides detailed criteria for assessing when a fuel can be classified as an RFNBO and therefore count towards these goals. A central criterion is lifecycle GHG emissions savings of at least 70% compared to a fossil comparator of 94 $gCO_2e$/megajoules (MJ).[5] For electrolysis-based hydrogen and RFNBOs, there are additional criteria for ensuring that electricity comes from RES-E additional generation so that the electricity input can be evaluated with zero GHG emissions (EU 2023e; 2023f).

CCfDs are an important pull factor for hydrogen demand as they provide long-term financial support for energy-intensive industries willing to transition towards cleaner production. In the German system, the winners of the respective auctions will be compensated by climate protection agreements for a period of 15 years to cover for their additional costs (operating expenses or expenditure and capital expenditures) to convert their production (BMWK 2024).

**Hydrogen supply**

In 2023, 0.5 GW of electrolysis-based hydrogen production capacity was installed in Europe (IEA 2023). Until 2030, announced capacities add up to 130 GWe. This would exceed target capacity for 2030 in the EU REPower Plan (EC 2022a), and even more so, target capacity in the ECIA for 2030 (EC 2024f) see section 4.2.6). According to the EC, as of 2023, Denmark, Germany, the Netherlands, Spain and Portugal alone plan to build a total of up to 40 GW by 2030 (EC 2023b). In none of the assessed scenarios, and in particular, in none of the EC (2024f) IA scenarios, there is a role for hydrogen from other sources than electrolysis.

In order to drive hydrogen production and to overcome the chicken-and-egg-problem, the EU has set up the European Hydrogen Bank. In 2023, it was European to stimulate renewable hydrogen production and use. The bank has launched an 800 million EUR pilot auction on a fixed premium for renewable hydrogen production within the EU at the end of 2023. In mid-2024, the results of the first auction were published. They exhibit high participation with a total of 132 bids, contracting a total production of about 50 TWh over the course of 10 years. They are showing very low bid prices of 15EUR/MWh hydrogen ($H_2$) and below due to cost sharing between support from the auction and purchasing companies (McWilliams und Kneebone 2024). Similar tenders for renewable hydrogen imports from outside the European Union are also planned. Joint auctions of the European Hydrogen Bank and H2Global are being discussed (IEA 2023).

**Hydrogen-based electricity generation**

According to the IEA, about 2 GW of hydrogen or ammonia-fired generation capacity is planned to come online in Europe by 2030 (IEA 2023). Neither the EC IA of 2024, nor the other scenarios assessed in section 4.2 provide details on the use of hydrogen or PtX-products in power generation. The EC IA of 2024 only lists stored energy in hydrogen and PtX as a flexibility option and states ranges of between 70 TWh for S1 to 10 TWh for S3 for hydrogen and 10 TWh for S1 to 50 TWh for S3 for e-methane (EC 2024f).

**Hydrogen infrastructure**

The Hydrogen and Decarbonised Gas Market Package[6] establishes an extensive set of regulations. It includes rules and conditions for natural gas infrastructure to be reused for hydrogen and introduces a European Network of Network Operators for Hydrogen to ensure sound management of the EU hydrogen network and facilitate the trade and supply of hydrogen across EU borders. It sets rules for hydrogen transmission network tariffs and how they will be applied

[5] Note that the EU Taxonomy refers to two different thresholds: one for hydrogen, requiring emissions savings of 73.4%, and one for hydrogen-based synthetic fuels of 70% relative to the same fossil fuel comparator of 94 g $CO_2$ e/MJ and using the RED III methodology of the EU (2023d).

[6] Regulation (EU) 2024/1789 and Directive (EU) 2024/1788.

to different users of the system. Particular support can be granted to system development and workforce transition in coal- and carbon-intensive regions. National network development plans will develop joint scenarios for electricity, gas and hydrogen. They will be aligned with the respective NECPs, and an EU-wide Ten Year Network Development Plan (EC 2023h)), which is also one of the outcomes of the EU strategy on energy system integration (EC 2020a). Hydrogen and gas network operators will have to include information on infrastructure that can be decommissioned or repurposed, and there will be specific hydrogen network development plans to ensure that the construction of the hydrogen system is based on a realistic demand projection. Moreover, the regulation allows flow restrictions if hydrogen blending exceeds 2%.

**TEN-E** works towards fostering links in the energy infrastructure of EU countries (EC 2023g). The regulation identifies three hydrogen and electrolysers corridors with several key energy infrastructure projects that are critical for completing the European internal energy market and contribute towards energy security and climate change mitigation goals (projects of common interest (PCIs)) and key energy infrastructure projects promoted by the Union in cooperation with third countries (projects of mutual interest (PMIs)). Among other things, projects on the list are eligible for an accelerated and streamlined permit granting procedure, including a binding three-and-a-half-year time limit for this procedure, and are able to apply for financial assistance under the Connecting Europe Facility (CEF). Similarly, **IPCEI** represents projects which make a significant contribution to economic growth, jobs, the green and digital transition and competitiveness for the Union industry and economy. However, they do not necessarily have to be related to infrastructure, and, importantly, are financed nationally – they do not receive support from the EU. To date, three IPCEI in the hydrogen value chain have been launched, with a total value of public and private investment of over 65 billion EUR (EC 2024c).

### 3.1.6 The role of non-fossil fuel flexibility options

The main EU legislation regulating flexibility options is the EU electricity market reform enshrined in **EU Directive 2024/1711** and **Regulation 2024/1747.** On the consumer side, the Directive enshrines the right to have multiple suppliers which might be particularly useful for heat pumps and electric vehicles, and defines active customers as non-fossil fuel flexibility options. The regulation details and implements measures to enhance flexibility within the energy system, ensuring efficient integration of renewable energy and better management of supply and demand fluctuation. It does the following in particular:

- emphasises the importance of well-functioning and efficient short-term markets for integrating renewable energy and flexibility sources into the electricity market (section 13);
- lowers the minimum bid size to allow for the participation of small-scale flexibility service providers (section 16);
- details provisions for a peak-shaving product to enable additional demand response during regional or Union-wide electricity price crises (section 17);
- suggests that regulatory authorities periodically assess the need for flexibility in the electricity system at the national level, considering sources like flexible electricity generation, interconnectors, demand response, energy storage, and production of renewable fuels (section 46); and
- details rules for non-fossil fuel flexibility support schemes, including payments for available capacity, to achieve the indicative national objective for non-fossil fuel flexibility (section 46).

The recent EU Grids Action Plan aims to address the main challenges in expanding, digitalising and better using EU electricity transmission and distribution grids (EC 2023l). Actions include accelerating the implementation of PCIs and stimulating faster permitting for grids deployment (EC 2023l). In 2018, the EU already set a electricity interconnection target for 2030 of at least 15% (EC 2018).

### 3.1.7 Bioenergy, waste incineration, direct air capture and $CO_2$ storage

The **EU ETS** can work both as a driver of emission reductions and as a source of financial incentive for $CO_2$ storage. Waste incineration is to be included in the EU ETS from 2028 (Art. 30 4c, 2003/87/EG 2003). This regulation also includes provisions on the further assessment of whether landfills, with their methane and nitrous oxide emissions, should also be included to avoid adverse incentives. Since the revision of the EU ETS regulation in 2023, $CO_2$ emissions for bioenergy can only apply a zero-emission rating if the bioenergy complies with sustainability criteria under RED III (EU 2023d), including LCA-based emission reductions of at least 70% compared to the fossil comparator. BECCS and DACCS could be included in the EU ETS using provisions for 'harmonised rules for projects that reduce emissions' in the EU ETS regulation (Art. 12, 2003/87/EG 2003), thereby generating a stream of income for these projects. The revised regulation also clarifies the generation rules on the definition of long-term $CO_2$ storage in the context of CCU. Only emissions that are not released at the end of the lifetime of a product can be deduced from the total amount of emissions; the release is not limited to the installation, but also includes subsequent uses (Art. 24a, 2003/87/EG 2003). This is particularly relevant in the emissions accounting of CCU as the obligation to surrender the respective emissions certificates remains with the capture plant as long as the $CO_2$ is incorporated in non-permanent products (e.g. fuels). However, the monitoring and reporting guidelines need to specify the definition of long-term storage, and the regulation provides the possibility for a legislative proposal to review treatment of CCU in mid-2026.

The **Directive on the geological storage of $CO_2$ (CCS Directive)** (EU 2009) establishes a legal framework for geological storage of $CO_2$ in geological formations in the EU. Emissions captured, transported and stored according to this Directive will be regarded as not emitted. It also contains provisions on the capture and transport components of CCS. Operators are included in EU ETS, which ensures that in case of leakage, they have to surrender emission allowances for any resulting emissions.

The European Commission has proposed a strategy to enhance **industrial carbon management** (EC 2024d). Echoing the target of at least 50 Mt $CO_2$ captured per year by 2030 set in the NZIA (EC 2023o), the main actions include:

- preparing a regulatory framework, market design and infrastructure planning mechanism;
- establishing a matching platform for linking $CO_2$ transport and storage providers with emitters;
- developing an investment atlas of potential $CO_2$ storage sites; and
- establishing rules for the accounting of all industrial carbon management activities.

The strategy does not include the creation of **any new funding opportunities** for carbon management technologies; rather, there is continued support via existing vehicles such as the Innovation Fund (EC), CEF (EC), and Horizon Europe (EC). The Commission also plans to assess the need for public funding for investment in industrial carbon management up to 2040 and 2050. National funding is regulated by the Guidelines on State Aid for climate, environmental protection and energy (EC 2022b) and can be granted if it complies with either the rule on aid for the reduction and removal of greenhouse gas (section 4.1.), or aid for the security of electricity supply (section 4.8.), or aid for energy infrastructure (section 4.9.) (Levina et al. 2023).

## 3.2 Possible range of emissions and central energy sector elements in 2040 – and glancing towards 2050

Table 3 shows the current levels of key indicators governing the GHG emissions and the level of transformation of the energy supply sector. It also provides ranges of estimates from different scenario projections for 2040 and 2050. It summarises the information that is provided in detail in the subsequent sections.

**Table 3: Harmonised table with min/max EU-wide contribution to 2040 climate target**

| Parameter | Unit | 2021/2022/2023 | 2040 | | 2050 | |
|---|---|---|---|---|---|---|
| **Net GHG emissions incl. CDR** | Mt $CO_2$ eq | 924 (2022) | 1-191 | 0 - 250 | -58 | -208 - 0 |
| **Gross GHG emissions (net of fossil-fuel and bio-based carbon capture)** | Mt $CO_2$eq | 924 (2022) | 122-203 | | | |
| **Total electricity demand** | TWh | 2826 (2022) | 4560-5210 | 2230 - 6850 | 6400-6920 | 2880 - 8310 |
| **Fossil fuel-based electricity generation** | TWh | 1050 (2021) | 160-370 | 30 - 240 | | |
| **Fossil fuel-based electricity generation with Carbon Capture** | TWh | 0 | 60 - 90 | | | |
| **RES-E generation share** | % | 41% (2022) | 81%-90% | 54% - 93% | 87%-89% | 68% - 94% |
| **Nuclear generation share** | % | 22% (2022) | 9%-12% | 3% - 23% | 8% | |
| **Nuclear capacities** | GWe | 96 (2023) | 71-88 | 27-255 | 71 | |
| **RES-E capacities** | GWe | 641 (2023) | 1760-2110 | 1630 - 2300 | | |
| **Gas-fired capacities** | GWe | 170[1] (2020) | 140-155 | | | |
| **Other fossil-fuelled capacities** | GWe | 160 (2020) | 20 | | | |
| **Electrolyser capacity** | GWe | 0.5 (2023) | 190 - 300 | | | |
| **Production for $H_2$ from electrolysis** | TWh | | 700 - 1160 | | | |

[1]This also includes manufactured gases, which typically are produced as by-products of coking, steelmaking and refining.

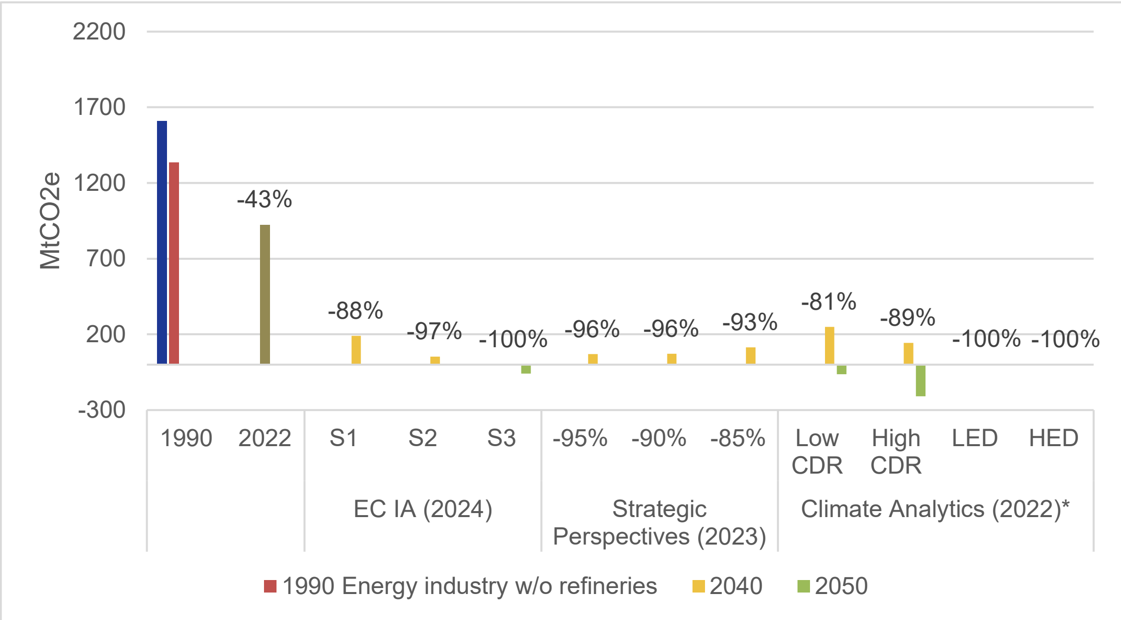
Source: Authors' own compilation based on EC (2024f) IA, EEA, ESABCC (2023), Kalcher (2023), Climate Analytics (2022), Eurostat (2023), (EC 2021c), and own calculations

### 3.2.1 Total GHG net emissions from the energy supply sector and GHG balance in the EC 2024 Impact Assessment

Ten scenarios envision net GHG emissions (including fossil fuel-based, bio-based and direct air Carbon Capture) from the energy supply sector between 0 Mt $CO_2$eq (Climate Analytics, Low Energy demand (LED) and High Energy Demand (HED), 2022) and 250 Mt $CO_2$eq (Climate Analytics, low CDR, 2022) in 2040. To achieve these projections, the EU would have to cut emissions by between 81% and 100% compared to 1990 levels (see Figure 7).

Measures contributing to emission reductions shared by the scenarios include the rapid phase-out of fossil fuels, and the rapid expansion of RES-E capacities. They diverge in the role of carbon dioxide removal (CDR) technologies, measures to reduce energy demand, and the role of nuclear energy.

**Figure 7: Net GHG emissions from the energy supply sector in 1990, 2022, 2040 and 2050 from different scenarios**




Note: *Values refer to power sector emissions for CA (2022), percent reduction for these scenarios is relative to 1990 energy industry w/o refineries emissions; LED: Low energy demand; HED: high energy demand.

Source: Nissen et al. (2023), EC (2024f) IA, Strategic Perspectives (2023), and Climate Analytics (2022)

Table 4 summarises information on the GHG emission balance for the energy supply sector, and for other CDR relevant emission sources and sinks. Emissions in the range of 186-233 Mt $CO_2$eq are projected to be generated in the ECIA scenarios for the energy supply sector (EC 2024f). A significant portion of these emissions is to be captured (26-41 Mt $CO_2$eq from fossil-fuel based power generation, and 4-34 Mt $CO_2$eq from bio-based power generation). Assuming that these emissions are directed towards long-term storage, leaves the sector with a net emission balance of 112-122 Mt $CO_2$eq in 2040. However, there are two sources of uncertainty about whether using this as the balance for the energy supply sector is correct:

- **The role of DACC**: In the ECIA, DACC is attributed to the energy sector, and emissions captured are counted towards the balance of the sector (EC 2024f). However, the attribution of emission reductions achieved via DACCS is not yet clear. It could be the energy sector if DACC is treated like ‘other energy industries’ but could also count towards, for example, the industry sector or become an own category.

- **The role of e-fuels**: E-fuels require a climate-neutral carbon source. Both biomass and DACC could provide this. While the ECIA indicates the portions of fossil-fuel-based, bio-based and DAC-based carbon directed towards e-fuels, the specific numbers are not available, nor is the information on how bio-based carbon directed towards e-fuels is split between sources from the energy sector and the industry sector (EC 2024f).

**Table 4: Details on the GHG balance in the EC (2024) Impact Assessment for 2040**

| [Mt $CO_2$eq] | 2040 | | |
|---|---|---|---|
| | **S1** | **S2** | **S3** |
| **Total GHG emissions of the energy supply sector** | 233 | 187 | 186 |
| **of which** | | | |
| **fossil CCS** | 26 | 41 | 32 |
| **biomass** | 4 | 34 | 32 |
| **Energy supply sector level GHG balance** | 203 | 112 | 122 |
| | | | |
| **DACC** | 12 | 59 | 121 |
| **Capture from industrial processes** | 44 | 127 | 159 |
| | | | |
| **Underground storage (all sectors)** | 42 | 147 | 243 |
| **E-fuels** | 44 | 75 | 101 |

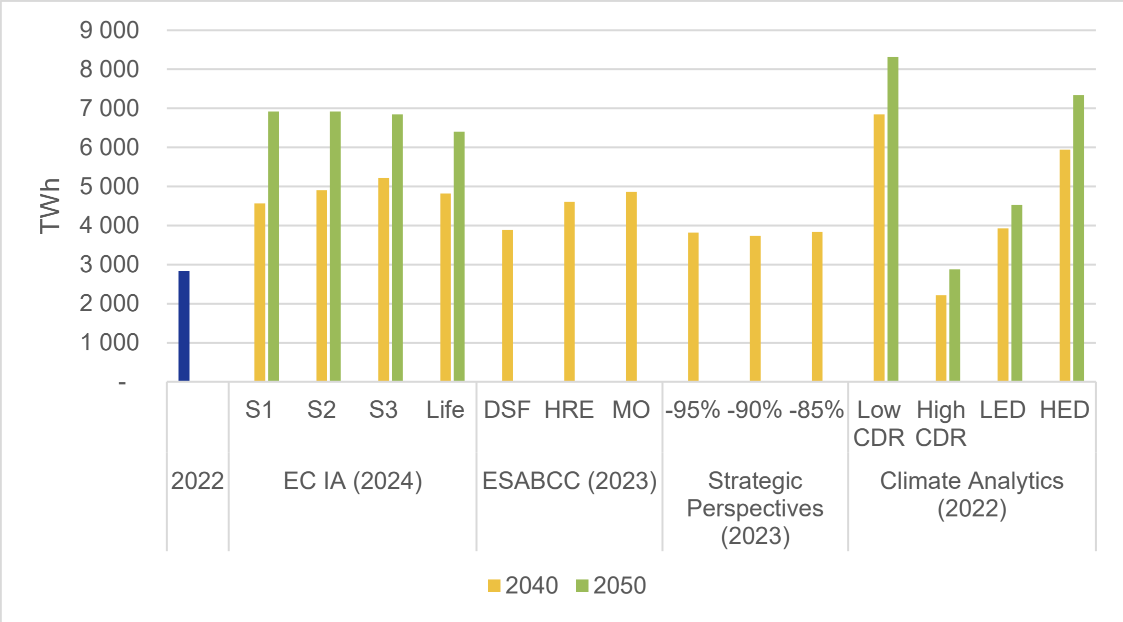
Source: Authors' own compilation based on (EC 2024f)

For more information about generated emissions in scenarios published in the Impact Assessment 2024 see Gores and Graichen (2024).

### 3.2.2 Total electricity demand

With new large-scale electricity demand from hydrogen and derivatives production, heat pumps, power-to-heat applications and e-mobility, total electricity demand is projected to substantially increase from 2022 levels of 2830 TWh. In 2040, gross electricity generation is projected to range between 3700 TWh (-90% scenario, Strategic Perspectives, 2023) and 6850 TWh (low CDR scenario, Climate Analytics, 2022). The EC IA scenarios are in the medium range of the assessed scenarios, with 4560 TWh (S1) to 5210 TWh (S3) (EC 2024f). While the level of electrification is the driver of electricity demand in the European Scientific Advisory Board on Climate Change (ESABCC) scenarios (2023), from 2030 onwards the demand for $H_2$, RFNBOs and DAC drives the difference in the EC IA scenarios, with a demand of 1000-1500TWh (21-28% of total generation) in S1-S3 (2024f, p. 289). For 2050, total generation is projected to increase to 7000 TWh and above in the scenarios.

**Figure 8: Gross electricity generation in 2022, 2040 and 2050 from different scenarios**



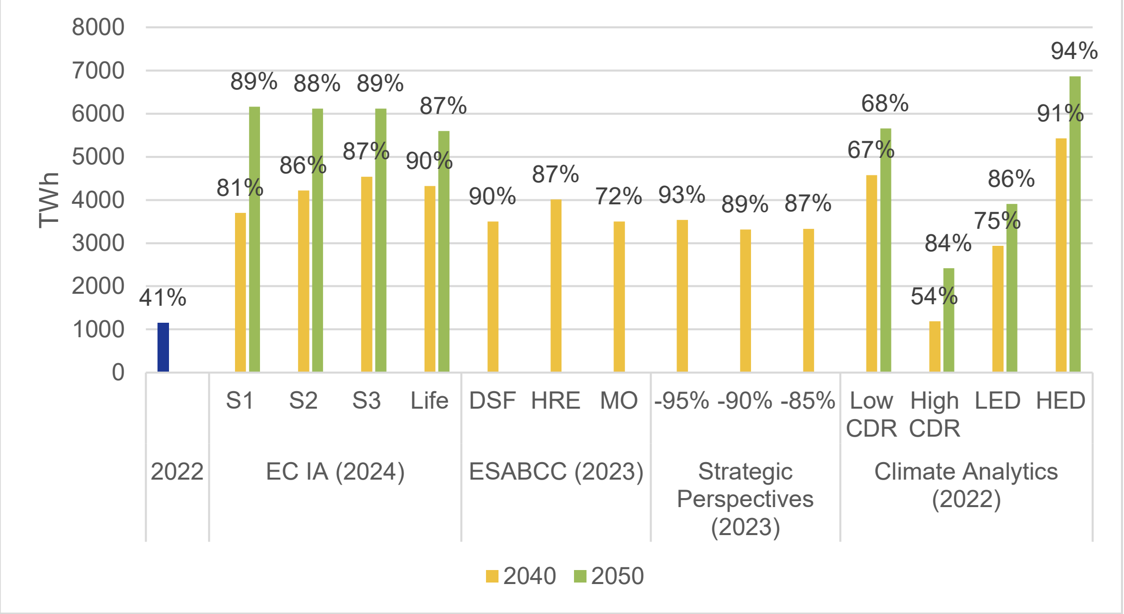

Note: DSF: demand side focus; HRE: high renewable energy; MO: mixed options; LED: Low energy demand; HED: high energy demand

Source: EEA, EC (2024f) IA, Strategic Perspectives (2023), and Climate Analytics (2022)

### 3.2.3 RES-based generation, shares and capacities

RES-E is the basis for the envisioned decarbonisation of the energy sector. Electricity generation from RES-E is projected to increase more than threefold, from 1150 TWh in 2022 to values between well above 3000 TWh and 4500 TWh, for 2040. Only the high CDR scenario that focuses on CDR and therefore allows high levels of emission overshoots before 2050, suggest that RES-E generation can remain at current levels (Climate Analytics 2022). The share of RES-E generation in total electricity generation is between 85-90% in most scenarios. The nuclear and CDR-heavy mixed options scenario (ESABCC 2023) and three of the four CA scenarios (2022) remain below this level, while the high energy demand scenarios (CA, 2022) and the -95% scenario (Kalcher 2023) exceed a 90% RES-E share. Between 2040 and 2050, RES-E generation and shares increase to levels of 5500-6100TWh and 87-94% respectively.

**Figure 9: RES-E based generation in 2022, 2040 and 2050 from different scenarios, and shares in gross electricity generation**



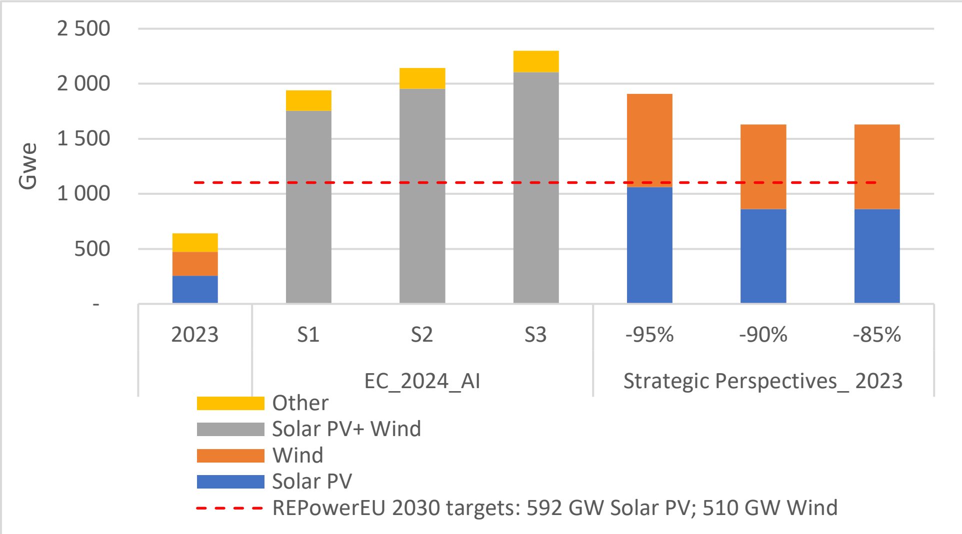

Note: DSF: demand side focus; HRE: high renewable energy; MO: mixed options; LED: Low energy demand; HED: high energy demand; biomass-based RES-E generation is excluded in the ESABCC scenarios.

Source: EEA, EC (2024f) IA, Strategic Perspectives (2023), and Climate Analytics (2022)

In order to achieve the strong increase in RES-E generation, installed capacity has to vastly increase. In 2023, the EU-27 had a total of 641 GWe of RES-E capacity installed, with 255 GWe from solar PV, 219 GWe from wind (92% of which comes from onshore installations) and the remainder from hydropower (24%) and bioenergy (5%) (IRENA 2024). According to ECsolar PV capacity is to increase to about 600 GWe and wind capacity to about 510 GWe by 2030 (EC 2022d). This means that in the next seven years, the installed capacity more than doubles. The observed maximum additions for wind (20 GWe) and solar PV (51 GWe) will need to be exceeded to achieve these targets. This highlights the need to accelerate RES-E expansion and to overcome barriers.

For 2040, only two of the studies examined provide details on installed RES-E capacities. In ECIA projects total capacity of wind and solar PV increase to 1750-2100 GWe (EC 2024f). Higher installation is driven by higher electricity demand for $H_2$, RFNBOs and DAC. Strategic Perspectives (2023) projects required RES-E capacities of 1600-1900 GWe. Low electricity demand leads to lower required capacities. Not much momentum is foreseen for installation of other types of renewables. Favourable locations for hydropower are already developed in the EU-27, and bioenergy is not regarded as an electricity source that can be massively expanded due to limited sustainable bioenergy resources.

**Figure 10: Installed RES-E capacities in 2023 and 2040 from different scenarios, and tentative REPowerEU 2030 target level**

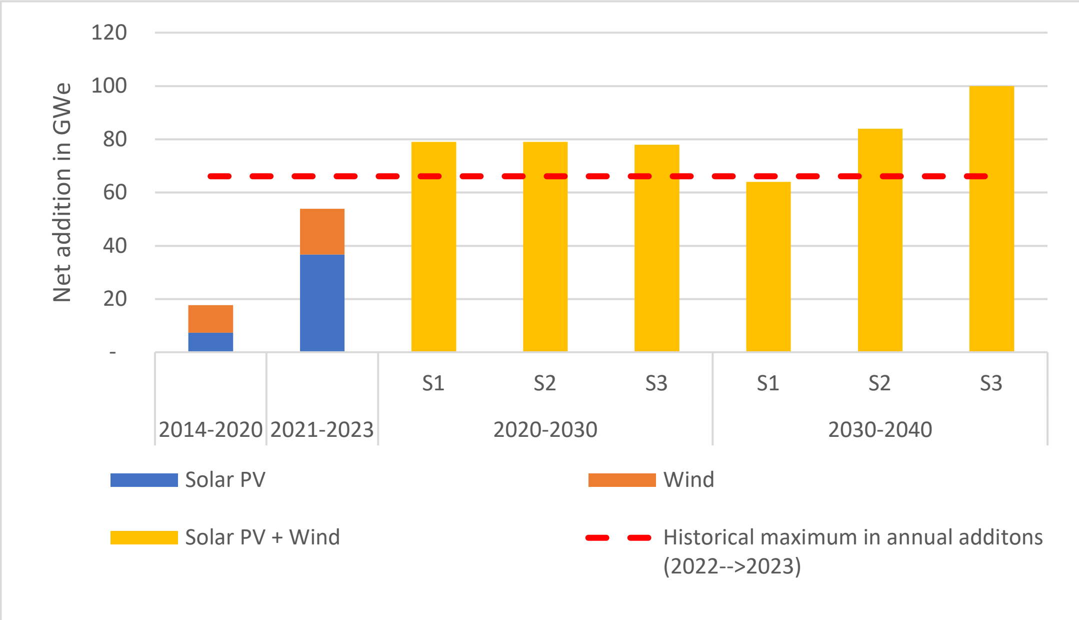



Source: IRENA (2024), EC (2024f) IA, Energy Perspectives (2023), and EC (2022d)

In terms of required installation rates for solar PV and wind, the recent boost in addition rates needs to be expanded and reach unprecedented levels of 80-90 GWe net deployment in the period 2020-2040. Figure 11 illustrates average deployment rates for the period 2014-2020 and 2021-2023. While during the former period additions were at a low of on average 18 GWe per year, during the latter period on average 54 GWe were added annually. This is still about 30% less than required for the entire period 2020-2030 - and about 40% for the period 2030-2040 - to be in line with the EC IA projections (EC 2024f) . However, with net additions of more than 66 GWe from 2022 to 2023, the trend clearly goes into the right direction.

Importantly, the EC-IA does not specify additions for solar PV and wind separately, even though additions of solar PV have must lower administrative burden and lead times than onshore or even offshore wind, which requires long term planning with individual grid connections (EC 2024f) .

**Figure 11: Average annual deployment of wind and solar PV: historical deployment and scenarios from the EC IA**




Source: Oeko-Institut based on (IRENA 2024) and EC (2024f)

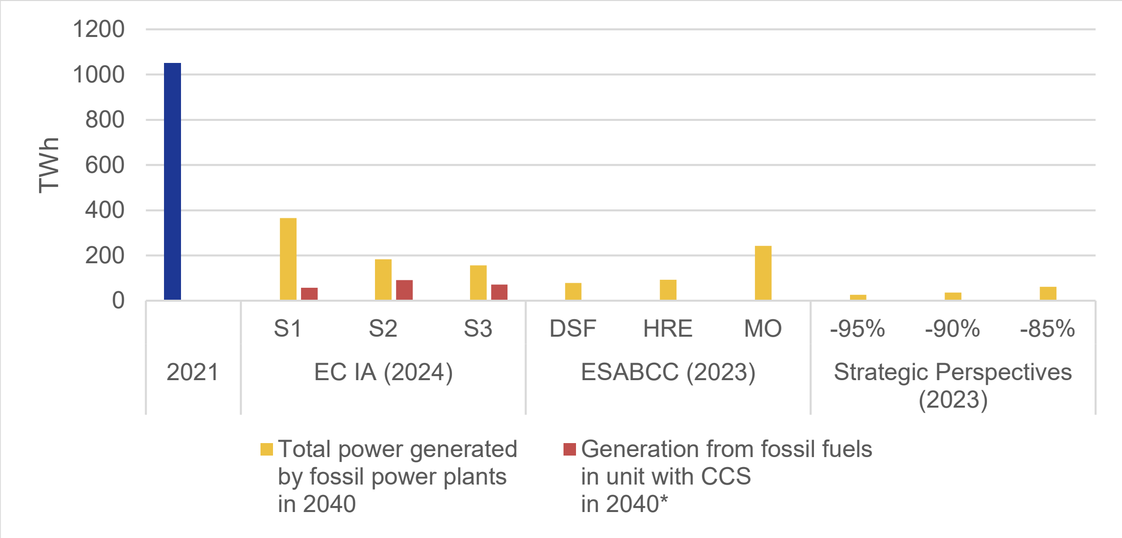
### 3.2.4 Installed fossil fuel generation capacity, generation and shares

Fossil fuel-based generation is reduced from about 1000 TWh in 2021 to 25-365 TWh (-95% scenario, Strategic Perspectives, 2023, and S1, EC (2024f) IA), in 2040. These figures include both unabated fossil fuel-based generation and CCS-based. Correspondingly, the share of fossil fuels in power generation decreases from 36% in 2021 to 1-8% in 2040, with a share of 5% and 8% reported in the Mixed Options and the S1 scenarios respectively. In the EC (2024f) IA scenarios, fossil-fired generation is projected to consist almost solely of gas-fired power plants, with and without CCS. Our calculations based on the data provided in the EC (2024f, Table 6, and Figure 19) IA suggest that in the EC scenarios 60-90TWh[7] are generated in units equipped with carbon capture, meaning that the rest of 90-310 TWh comes from unabated fossil fuel-based generation, which run as peakers (EC 2024f, p. 289). Seven of the scenarios still contain coal-fired generation, namely the Mixed Options scenario (about 50 TWh, ESABCC 2023), the Strategic Perspectives scenarios (14-33TWh of coal-fired CHPs) and the EC (2024f) IA scenarios, however for the latter type of generation is not specified[8].

[7] Carbon capture from fossil fuel in power generation is stated to come from gas-fired units EC (2024f), p. 289. Assuming that these units are CHP units with a typical electrical efficiency of 40% and an 20% energy penalty for the carbon capture unit, gives an emission factor of 0.62 $tCO_2$/MWh. This value is used to calculate back respective power generation based on reported volumes of carbon capture in the power generation, assuming a capture rate of 90% (EC (2024f), Table 6).

[8] However, the EC IA specifies that small amounts of coal and oil-fired capacities remains available in 2040 (2024f), p. 290. No further specification is given on electricity generation from this units.

**Figure 12: Fossil fuel-based electricity generation in 2021 and 2040, and generation from units equipped with carbon capture from different scenarios**




Note: * Generation from units with CCS is not reported in the IA of EC (2024f). Values are calculated based on the reported $CO_2$ emissions captured from fossil fuel-based power generation, assuming that natural gas is the main fuel with emission factor 0.201 $tCO_2/MWhth$, average electric efficiency of 40%, and capture rate 90%. DSF: demand side focus; HRE: high renewable energy; MO: mixed options.

Source: IA of EC (2024f), ESABCC (2023), and Energy Perspectives (2023)

Only the EC IA of 2024 provide an estimate of installed fossil-fuel fired capacities for 2040, where fossil-fuel capacity will decrease from 324 GW in 2020 (EC 2021c) to 155-170 GW in 2040 (EC 2024f, p. 291), with 90% of it being gas-fired units, and the remainder being oil- and coal-fired capacities. Carbon capture for power generation increases to 10-20 GW by 2040 and 30 GW in 2050 in the EC IA scenarios (2024f). For the Strategic Perspectives scenarios installed capacity can be calculated based on the information on fossil fuel-fired generation, which only occur in CHP plants here. It is an order of magnitude lower, with 8-20GWe [9] and with no carbon capture (Kalcher 2023).

The EC-IA and all other assessed scenarios remain silent on any potential conversion of capacities from fossil fuel based to $CO_2$-free fuels, such as coal-fired to biomass-fired, gas-fired to biomethane-fired [10] or gas-fired to hydrogen-based (EC 2024f).

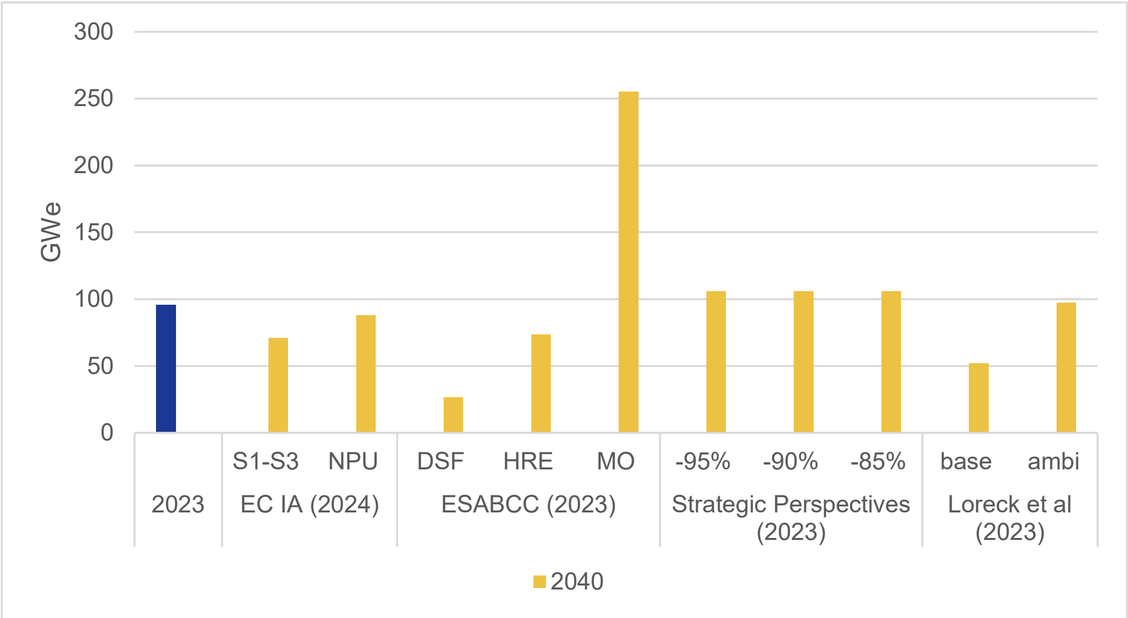
### 3.2.5 Nuclear capacity and generation

Starting with an installed nuclear capacity of 96 GWe, by the end of 2023, scenarios of future EU-27 energy sector development report either a moderate capacity decline (71-88 GWe) or a moderate increase to 106 GWe, by 2040 (see Figure 12). There is no endogenous driver of nuclear capacity in the EC IA scenarios; rather, the capacities included in the NECPs and respective update are taken as the basis (EC 2024f). The DSF scenario assumes a strong decrease to about 27 GWe, which would be in line with a shutdown of existing capacities after a technical lifetime of 50 years and no new installations (see box 1). An assessment combining ambitious lifetime expansion for existing capacities with the realisation of ambitious plans for the construction of new nuclear reactors suggests that a total of about 100 GWe could be achievable by 2040 under such favourable circumstances (Loreck et al. 2023). Hence,

[9] Assuming a low average capacity utilisation of 20%.
[10] Note that biomethane has a limited potential as it has to be possible to feed the biomethane into the gas network. If this is not possible, the use of biogas instead saves additional energy input and can therefore be assumed to be the standard approach.

scenarios reporting nuclear power generation capacities exceeding 100 GWe, like the MO scenario which has an installed nuclear capacity of 255 GWe in 2040, cannot be substantiated against real world conditions (ESABCC 2023).

**Figure 13: Installed nuclear electricity generation capacities in 2023, and 2040 from different scenarios and projections**

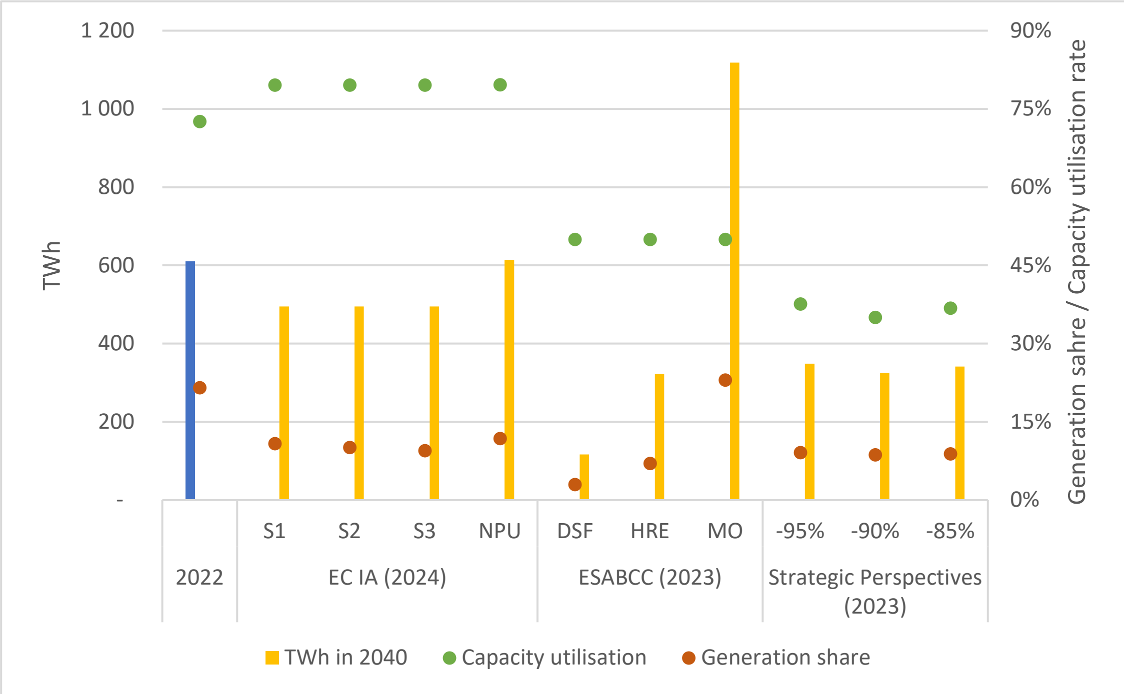



Note: NPU: Nuclear policy update (after March 2023); DSF: demand side focus; HRE: high renewable energy; MO: mixed options; ambi: ambitious expansions; base: baseline. Values for ESABCC are calculated by on reported electricity generation, assuming a utilisation rate of 50%.

Source. IAEA (2024), EC (2024f) IA, ESABCC (2023), Strategic Perspectives (2023), and Loreck et al. (2023)

By 2040, nuclear power generation decreases from current levels of 609 TWh to 495 TWh in the ECIA scenarios(EC 2024f) and 325-349TWh in the Strategic Perspectives scenarios (2023) and the high renewable energy pathway of the ESABCC (2023) (see Figure 13). Correspondingly, the share of nuclear in gross electricity generation decreases from 22% to 7-11%. Even in the most optimistic scenario, the share is 1% above current levels. Nuclear generation declines to 120TWh (3%) in the ESABCC scenario with a demand side focus (2023). With updated plans on nuclear expansions, generation increases just above current levels in the ECIA (EC 2024f). In the ECIA scenarios, capacity utilisation is projected to increase to 80%, suggesting a based-load use of nuclear which does not seem compatible with high share of renewables and strong demand for flexibility (EC 2024f). However, utilisation rates below 40%, as is the case in the Strategic Perspectives scenarios (2023), will strongly increase levelised cost of electricity both for existing units that require investment for allow for lifetime expansions but even more so for new installations. Such low utilisation rates also need to be taken into account in the design of the units in order to comply with the technical constraints on capacity utilisation.

**Figure 14: Electricity generation, share in total generation and capacity utilisation factors in 2022, and 2040 from different scenarios**




Note: NPU: Nuclear policy update (after March 2023); DSF: demand side focus; HRE: high renewable energy; MO: mixed options;. Values for ESABCC (2023) are calculated based on reported electricity generation, assuming a utilisation rate of 50%.

Source: Eurostat (2023), EC (2024f) IA, ESABCC (2023), and Strategic Perspectives (2023)

**Box 1: Nuclear generation capacity**

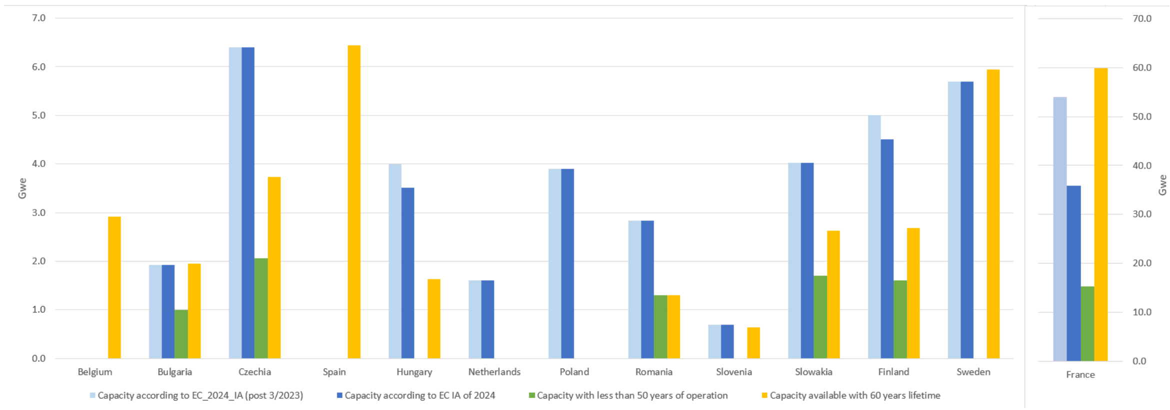
Without lifetime extension beyond the typical technological lifetime of 50 years, the nuclear generation fleet in the EU-27 would shrink to 23.0 GWe by 2040, and 12.6 GWe by 2050. This is in stark contrast to the capacities projected for the year 2040 in different scenarios of the ESABCC or the EC Impact Assessment, which range between 27 GWe and 255 GWe, with central estimates around 71-74 GWe (ESABCC 2023; EC 2024f). 71 GWe, as projected in the EC Impact Assessment, would be a reduction compared to the installed capacity in 2015 of 110 GW, but these numbers do no take into account decisions of June 2023 in France. If these are considered, French nuclear capacity could actually increase to 54-71 GWe which would translate to an estimated nuclear capacity of between 82 GWe and 101 GWe in 2040 on EU level.

The EC Impact Assessment (EC 2024f) provides details on the underlying assumptions considered in projections, referring to the EU 2020 Reference scenario (EC 2021a; 2021c), which includes individual countries' NECPs submitted in 2019. Moreover, the assessment incorporated updates announced by different Member States by March 2023 (EC 2024f). Figure 14 below compares the installed nuclear capacity in 2040 that corresponds to the Impact Assessment estimate of 71 GWe on Member State level; it includes the installed capacities in each Member State that have not reached the end of the installation's typical technological lifetime of 50 years by 2040. Without lifetime extension beyond 50 years, Belgium, Spain, Hungary, Netherlands, Slovenia and Sweden would phase out nuclear by 2040 or before. Extending the lifetimes of nuclear installations by 10 years would provide Bulgaria, France, Slovenia and

Sweden with the installed capacities assumed in the EC Impact Assessment (EC 2024f).[11].However, lifetime expansions significantly increase the risk of nuclear accidents with catastrophic risks.

Such an assessment is provided to highlight the minimum need for additional investments assumed in the Impact Assessment. On Member State level, it is planned that the respective capacities are to be achieved through a combination of lifetime extensions and additional investments in new reactor capacities. As a minimum, a total of 14.9 GWe in new capacities is needed, which are distributed among Czechia, Hungary, the Netherlands, Romania, Slovakia, and Finland. Poland does not yet have any nuclear capacities installed; hence the planned new capacities are accompanied by setting up the entire regulatory, technological and security infrastructure necessary to safely operate nuclear power plants. Typical lead times for new nuclear capacities are more than 10 years (Sovacool et al. 2020) . The main EC assessment does not take into account the change in plans and regulation related to nuclear power that occurred after March 2023. Importantly, updates in France, Hungary, and Finland would increase the total installed capacity in the EU-27 to 88 GWe, with France bringing about 17 GWe of the 18 GWe increase (EC 2024f).

**Figure 15: Net nuclear electricity generation capacity in 2040 available under different lifetime assumptions and comparison to levels reported by EC Impact Assessment, by EU Member State**




Note: EC (2024f) only provide details on installed capacity on the EU-27 aggregate level. For data on country level it refers to the EU2020 Reference scenario (EC 2021a; 2021c) and provides additional information in the text. However, the information is sometimes contradictory and not sufficient to reconstruct the EU-27 figures. Values presented in this graph are adjusted to align with the net total installed capacity of 71 GW for the EU-27.

Source: Authors' own diagram based on IAEA (2024), EC (2024f), and own calculations.

### 3.2.6 Hydrogen production capacity, imports and total demand

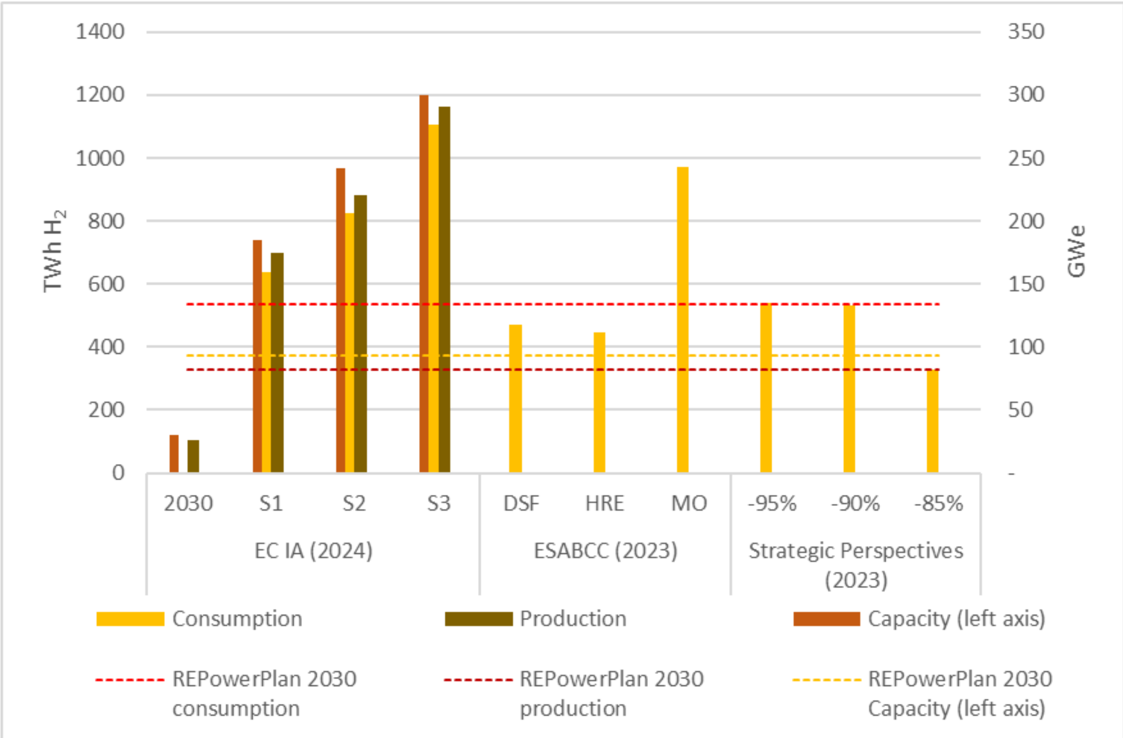
Green hydrogen is broadly used as an energy vector to substitute grey hydrogen, but also beyond traditional applications (like the chemical sector and refineries) it contributes to decarbonise the hard-to-abate sectors and to support the operation of the power sector with high shares of variables renewable energies providing seasonal storage (EC 2024f). The EC-IA projects hydrogen production to increase to 700 – 1160TWh by 2040 (EC 2024f). 33 – 53 % of this production is consumed for efuels production, which is the main driver of additional electricity demand and additional hydrogen production in the different scenarios. Other studies foresee substantially lower hydrogen consumption, with the most ambitious Strategic Perspectives

[11] According to INRAG (2021), authorities in Bulgaria, Slovakia, Slovenia have already granted 60 years of lifetime for the remaining reactors. In Czechia, reactors do not have an expiration date for their operation license, but it is planned that the reactors will run for 60 years.

scenarios (Kalcher 2023) at 540 TWh and two of the three ESABCC (2023) scenarios at about 460 TWh. Only in the nuclear and CCS-heavy mixed options scenario is 970 TWh reached. The EU REPowerPlan (EC 2022d) included estimates for consumption for 2030. A total of 530 TWh should be consumed, with 330 TWh coming from domestic production and the rest from imports. Production levels in the ECIA for 2030 are three times lower, at about 100 TWh (EC 2024f). The same holds for installed capacity, which amounts to 30 GWe in the ECIA and 93 GWe in REPowerPlan (EC 2022d; 2023f; 2024f). [12] While the ECIA does not provide details on $H_2$ consumption levels and required imports for 2030, in 2040 imports of hydrogen are below 20 TWh (EC 2024f). [13]

ECIA highlights hydrogen as an important electricity storage option, with 10-70 TWh of hydrogen from electrolysis stored in 2040, and 40-50 TWh in 2050 (EC 2024f)).

**Figure 16: Installed electrolyser capacity, hydrogen production and hydrogen consumption in 2030 and 2040, in different scenarios, and target levels from REPowerEU for 2030**




Note: DSF: demand side focus; HRE: high renewable energy; MO: mixed options.

Source: EC (2024f) IA, ESABCC (2023), Energy Perspectives (2023), and EC (2022d)

[12] The plan provided details on target values in Table 4, and in the text. However, in the table, there is typo, saying installed capacity should be 65 MW hydrogen, we assume 65 GW, as stated in the text. We assume 70% efficiency to convert to electricity input capacity (GWe), as this unit is more commonly reported EU (2023d).

[13] A very thin block is visible in Figure 15 for 2040 in the EC IA of 2024 EC (2024f).

# 4 How to achieve the necessary contributions: Discussion of possible policies, measures and options

This paper examines the steps needed to transform the energy supply sector towards climate neutrality, and where the sector needs to be by 2040, both in terms of emissions and the central sector elements, but also in terms of the necessary regulatory framework.

With regards to the central sector elements, the transformation is essentially based on four pillars:

- expansion of renewable energies, and efficient use of renewable energies;
- phasing out of the use of domestically available (peat, oil shale, lignite and hard coal) and imported (hard coal and natural gas) fossil fuels in electricity and combined electricity and heat generation;
- provision of climate-neutral flexibility options, and campaigning grid expansion
- provision of climate-neutral electricity-based energy carriers and negative emission technologies

In order to achieve the large expansion of RES-E capacity required (see section 4.2.3 for details on projections for RES-E deployment), provisions to remove barriers, promote investment and reduce the cost of renewable energy technologies are needed. These include reducing lead times for RES-E installation and grid connections via faster approval processes. Clear targets for installed renewables capacities or RES-E electricity generation on Member State level could help to create a clear framework for future investments. The continuation of the Renewable Energy Directive (RED) remains a central element and driver of the expansion of renewable energies in the energy sector in the future (EU 2023d). Reducing energy demand in general, and electricity demand in particular, contributes to increasing RES-E share. This can be achieved via efficiency measures or sufficiency approaches. These are mentioned in accompanying sectoral documents on buildings (Hesse, Tilman, Sibylle Braungardt 2024) , industry (Kögel et al. 2024) and transport (Seibert et al. 2024).

While the EU ETS is the clear driver of phasing out coal-fired generation, the situation is less clear in the case of natural gas. With alternative dispatchable units available, the EU ETS can also be a driving force in phasing-out natural gas. However, as long as natural gas remains the price-setting fuel in the Central European electricity market, increasing EU ETS prices alone will not push natural gas out of the market. Only with alternative dispatchable units available and given that their respective support scheme is sensitive to $CO_2$ pricing, the EU ETS will also be the driving force in phasing-out natural gas. Hence, sufficient climate-neutral, dispatchable generation and other flexibility options need to be in place. Moreover, the interplay between necessary support schemes for such generation units and the respective electricity market design has to maintain a clear cost advantage towards a clean dispatch compared to natural gas-based generation.

With new large-scale electricity demand from, for example, hydrogen production, heat pumps and e-mobility, an increasing role for flexibility and a radical change in the nature of installed generation technologies (small, decentralised units vs. large-scale generation units on central grid nodes) the electricity market design also needs to co-evolve and adhere to future system design.

The achievement of the 2040 climate target necessitates substantial expansion of and upgrades to the European Union's power grids and energy storage systems. The transition to a different energy mix will demand significant investments over the next 10-15 years. Its success hinges on establishing an appropriate regulatory framework, on integrated infrastructure planning, and on providing incentives for resilient supply chains (EC 2024f).

Carbon capture plays a major role in the EC IA of 2024 (EC 2024f). However, there needs to be a comprehensive debate and assessment of sustainable levels of annual $CO_2$ storage, among others, taking into account total available storage volumes and future definitions and levels of hard-to-abate emissions. The ECIA also includes carbon capture for fossil fuels in the power sector summing up to 30 - 40 $MtCO_2$ captured in 2040, and accounting for 10 % - 30 % of total $CO_2$ captured from all sources (EC 2024f). However, these emissions could be avoided by switching to climate-neutral fuels. The ECIA includes carbon capture for fossil fuel-fired generation as an option, but doing so creates lock-in for fossil fuel infrastructure, comes with the problem of additional emissions from methane leakages in the supply chain, and provides the wrong incentives for the layout and dimensioning for future common $CO_2$ transport infrastructure (EC 2024f) .

In the short term, the role of industrial carbon removal is constrained and needs to overcome high investment and operational costs, tackle regulatory challenges, addressing the complexity of infrastructure projects, and public acceptance (EC 2024f). The EU ETS might be used as a vehicle for providing financial incentives for industrial carbon sinks. However, BECCS should not be supported uniformly; rather, tailored approaches need to take into account the multitude of challenges around nature-based solutions. A first but important step towards increasing sustainability in the use of bioenergy could be changing its emission factor in the EU ETS. The current zero emission factor for bioenergy creates an incentive for the use of biomass for installations under the EU ETS. This thwarts the achievement of targets set for natural sinks for the LULUCF sector and has adverse effects on biodiversity and natural conservation. For further discussion of the role of carbon removals in the EU 2040 climate target and framework, see Meyer-Ohlendorf et al. (2023) .

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