Implementing the EU 2040 Climate Target: Building blocks and measures

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Opinions expressed in this report represent the views of the authors and do not necessarily represent the position of the BMWK.

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Abbreviations

BECCS	Bioenergy Carbon Capture and Storage
BEVs	Battery-electric vehicles
BF-BOF	Blast-Furnace Basic-Oxygen-Furnace

CBAM	Carbon boarder adjustment mechanism
CCS	Carbon Capture and Storage
CAP	Common Agricultural Policy
CAPEX	Capital expenditures
CBA	Cost–benefit analysis
CCU	Carbon Capture and Utilisation
CDR	Carbon Dioxide Removal
CO_2e	Carbon dioxide equivalents
CPR	Construction Products Regulation
CEAP	Circular Economy Action Plan
DACCS	Direct Air Carbon Capture and Storage
E-AF	Electric arc-furnaces
EC	European Commission
ECL	European Climate Law
EEA	European Environment Agency
EED	Energy Efficiency Directive
EJ	Exajoules
ENTSO-E	European Network of Transmission System Operators for Electricity
ENTSO-G	European Network of Transmission System Operators for Gas
EP	European Parliament
EPBD	Energy Performance of Buildings Directive
ESABCC	European Scientific Advisory Board on Climate Change
ETCS	European Train Control System
EU	European Union
EU ETS	European Emissions Trading System
GAE	Gross Available Energy
GHG	Greenhouse gas
HGVs	Heavy goods vehicles
IA	Impact Assessment
ICAO	International Civil Aviation Organization
ICE	Internal combustion engine
ICMS	Industrial Carbon Management Strategy
IED	Industrial Emissions Directive
IMO	International Maritime Organization
LRF	Linear Reduction Factor
Mt	Million tons
NECPs	National Energy and Climate Plans
NZIA	Net Zero Industry Act
PCI	Project of Common Interest

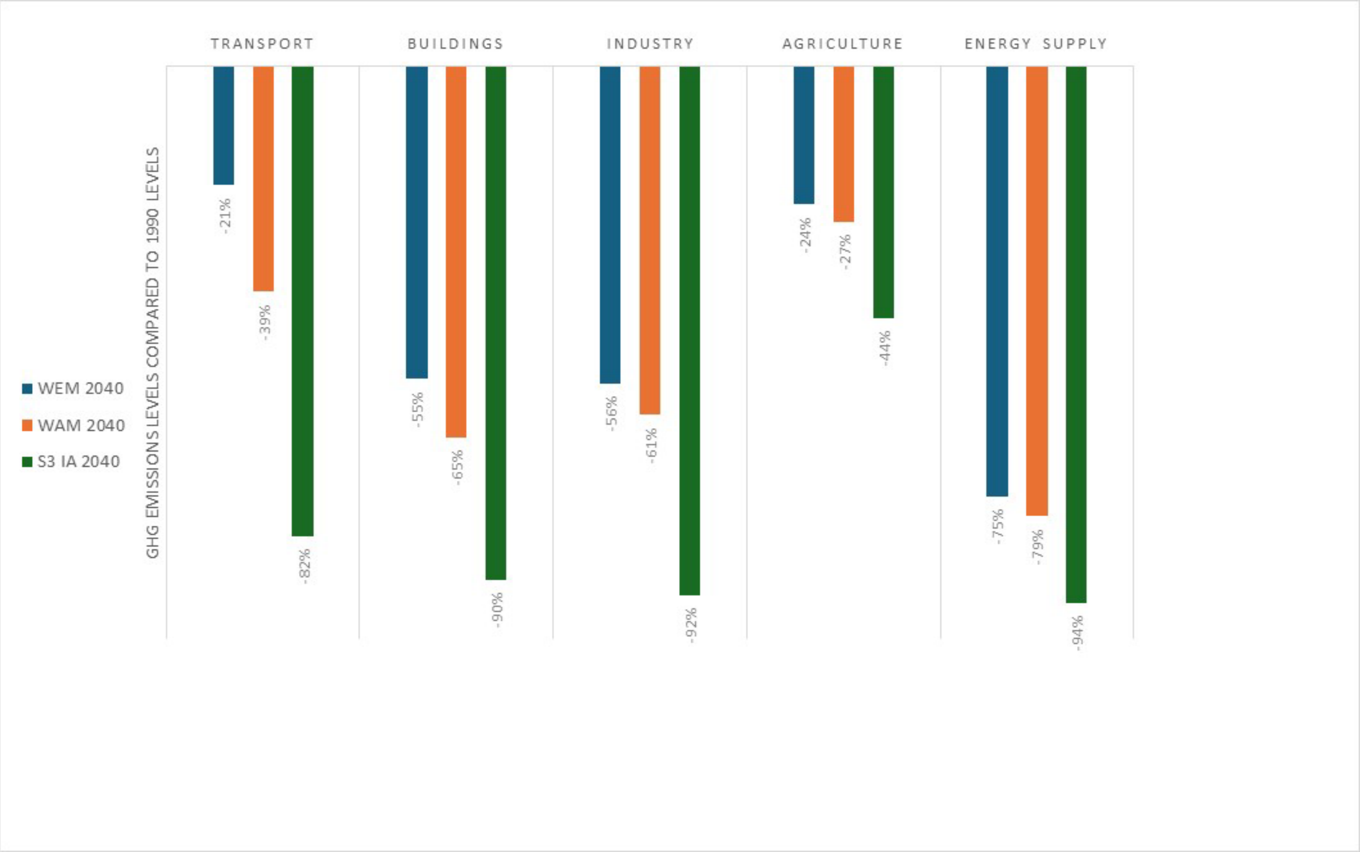
RED	Renewable Energy Directive
RFNBOs	Renewable fuels of non-biological origin
RRF	Recovery and Resilience Facility
SAFs	Sustainable Aviation Fuels
STEP	Strategic Technologies for Europe Platform
TEN-E	Trans-European Networks for Energy
TYNDPs	Ten-Year Network Development Plans
VAT	Value Added Tax
WAM	Projections with additional measures
ZEVs	Zero-emission vehicles

Executive summary

The European Climate Law (ECL) requires the EU to adopt a climate target for 2040. **The European Commission recommends an EU climate target for 2040 of 90% reduction in *net* GHG emissions by 2040** (compared to 1990)**.** Achieving emission reductions on this scale is indispensable if the EU is to stay on a realistic path towards climate neutrality by 2050 and net negative emissions thereafter.

To achieve emission reductions on this scale, the EU must meet its 2030 climate target and scale up its current reduction efforts significantly. With existing measures, as published by the European Environment Agency (EEA) in 2024, the **EU is projected to only reduce net emissions by 54% in 2040, and 62% if additional measures are implemented**[1]. The EEA projects that the EU is currently set to miss its climate neutrality target for 2050 and its 55% reduction target for 2030. Even with additional measures, net emissions are projected to fall by only 66% in 2050, and by 49% in 2030. With existing measures, emissions are projected to decrease by 43% in 2030 and 57% in 2050. Considering these projections for the EU as a whole, no economic sector is currently on track to achieve the required emission reductions – as shown in the following graphic.

Figure 1 Sectoral emission reduction pathways until 2040



Note: Transport here does not include international transport activities, although they are in the scope of the target. “Energy supply” means energy supply activities and Fugitive Emissions from fuels (Inventory categories 1.A.1 and 1.B), the

[1] Considering the target scope of the European Climate Law, including intra-EEA aviation and 50 % extra-EEA MRV navigation.

matching to IA categories relies on assumptions. 2040 emissions from S3 scenario of the IA are gross emissions, after fossil CCS. Source: (European Commission, 2024a) EEA (2023a)

Importantly, however, greenhouse gas (GHG) emissions in the EU fell by an unprecedented 8% in 2023. This marks the largest year-on-year emission reduction in several decades, except for the COVID-impacted year of 2020, and brings estimated 2023 emissions to 37% below 1990 levels. **Reductions in 2023 were more than five times the average rate since 2005 and surpasses the annual rate required to meet the 2030 climate targets.** They are major step towards meeting the EU's climate target for 2030.

Energy supply

Member States' projections indicate a continuation of declining emissions in the energy supply sector until 2030 and beyond. With existing *and* additional measures, projections assume a 68% reduction of emission from the energy supply sector by 2030. **For 2040, projections indicate reductions of 79%,** leaving the energy sector at an annual emission level of 360 Mt CO_2e. Although substantial, these reductions fall short of the sector's necessary contribution to achieving the EU's 90% net reduction target. According to the Impact Assessment by the European Commission (IA), emissions from the energy supply sector are projected to decrease by 86-88% (excluding fossil-, bio- and DACCS), or 88-100% net of these emissions and attributing negative emissions to the energy supply sector. Other scenarios anticipate even steeper reductions, with some forecasting gross reductions of up to 100% by 2040.

To bring about reductions on this scale, rapid and large-scale expansion of renewable energy is indispensable. According to the IA, **renewables are expected to cover 81% to 87% of total electricity supply by 2040,** up from around 40% in 2021. To achieve this growth, the annual rate of **installing new renewable power generation must increase by a factor of 4 to 5** compared to the period 2011 to 2020. Positively, deployment rate has accelerated after 2020, reaching a high of 66 GWe in 2022. Still, these rates need to be increased by 50-80% to achieve required installation levels in 2040 and 2050.

Phasing out of the use of fossil fuels in electricity and combined electricity and heat generation is another essential building block. The IA projects that installed fossil-fuel-fired capacities will decline from 324 GW in 2020 to 155-170 GW by 2040. The uptake of renewable energy for power and heat supply, driven by technology improvements, subsidies and supported by carbon prices in the ETS are the main drivers to implement phasing out these capacities. The overall ETS cap ensures that emissions are reduced in energy industries and the industry sector, but the **current phase-out rate of fossil-based generation, especially for the heat supply as well as the consumption of fossil fuels in the industry sector, is still too slow.** Nuclear power is unlikely to reliably contribute to decarbonizing the energy supply sector because of high and uncompetitive construction costs, lead times of 15 years or more to build new capacity and frequent delays in nuclear projects.

EU legislation decarbonizing the energy supply sector is largely already in place. Emissions of large combustion units are covered by the ETS 1, units below the ETS 1 threshold will be covered by the ETS 2. In 2022, 86% of GHG emissions from the energy supply sector were subject to the ETS 1 (EEA 2023). With its current linear reduction factors (LRF), no new emission allowances will be issued after 2039 in ETS 1 and after 2043 in ETS 2. **If fully implemented, the ETS 1 and 2 will have reduced emissions within their scope by 95% in 2040 (compared to 2005).** In turn, it is essential for target achievement that the EU maintains the current ETS and its emission cap.

However, the ETS alone does not automatically guarantee reductions at required scale. Gross ETS emissions 2040 still account for 200 Mt in the recommended S2.5 scenario in the 2040 IA of the Commission. To mitigate the risks of non-compliance and exceeding the ETS cap, **additional complementary measures** are necessary. These notably include legally binding renewable energy targets beyond 2030 and new designs for electricity markets that support climate-neutral generation capacities and flexibility.

Industry

According to S3 of the Commission's IA, in 2040 **industry emissions will decrease by 92% compared to levels in 1990**. However, industrial emissions are projected to **decrease by only 61% in 2040, even if additional measures are implemented**. Achieving a 92% reduction in emissions by 2040 depends largely on the timely availability of green electricity, green hydrogen and CCS in sufficient quantities. They also depend on significant improvements in material circularity, substitution and efficiency.

The **ETS is the main driver for these emission cuts, but additional measures are needed**. Regulatory frameworks, such as the proposed Ecodesign for Sustainable Products Regulation and the revision of the Construction Products Regulation, are crucial for unlocking emission reduction potentials and promoting material efficiency in industries. Further consideration of recycling quota, as outlined in the Circular Economy Action Plan, would support the improvement of the recycling rate.

Carbon contracts for difference help mitigate price uncertainty and investment risks by establishing an agreement between a government and a stakeholder on a fixed carbon price for a specified period. Moreover, EU funding, e.g. from the Innovation Fund, must be made more accessible and less risk averse. Currently, most grants of the Innovation Fund are given to large companies, while start-ups and SMEs struggle with the complex application process.

Transport

To contribute to an EU 2040 climate target of net reductions of 90%, the IA projects that emissions from domestic transport fall by 82%, while emissions from international *and* domestic transport decrease by 73% in 2040. **However, the sector is seriously off track to achieve such reductions.** Domestic transport is projected to reduce emissions in 2040 only by 21%, if existing measures are implemented and by 39%, if additional measures are implemented.

To achieve reductions of 73% in transport and 82% domestic transport, it is indispensable that (1) road transport is largely electrified, (2) road transport is shifted to cleaner modes, and to moderate transport volumes and (3) GHG intensity of the fuel mix is reduced, and energy efficiency is increased.

- **Electrification of road transport:** The IA projects that the share of battery-electric vehicles of the entire fleet will rise to 57-58% by 2040. Despite significant growth in recent years, battery-electric vehicles (BEVs) represented only 1.7% of the European car fleet in 2023. Achieving the required levels of electrification necessitates a significant increase in the current rate of BEV uptake. Only carbon prices that are unacceptably high both socially and politically have the theoretical potential to electrify road transport at this pace. For this reason, the ETS 2 alone cannot deliver the required electrification rates. It is therefore essential that the new fleet emission standards are maintained.

- **Reducing and shifting road transport:** Given the unrealistically rapid pace of electrification in most scenarios and the long lifespan of cars, vans and trucks, it is evident that the electrification of road transport alone cannot achieve the required emission reductions. Reducing transport volumes and shifting road transport to cleaner transport modes is another vital pillar of decarbonizing road transport.

  Accordingly, all IA scenarios indicate a modal shift towards rail in both passenger and freight transport, but – problematically – recent trends are moving in the opposite direction. To reverse this negative trend, investments in railroads must increase considerably. In urban areas, avoiding and shifting road transport through measures such as new urban planning concepts, promotion of cycling and walking, car-free zones, and more attractive public transport, are essential tools to contribute to the necessary cuts in emissions from road transport.

- **Reduced GHG intensity of fuel mix:** According to the IA, emissions from aviation, navigation and – to a lesser extent – road transport are mainly reduced by the uptake of fuels with lower GHG intensity, such as e-fuels and biofuels. These fuels are an important component of reducing emissions in these sectors, but they have very significant limitations – ranging from problematic zero rating of emissions from burning biofuels to the limited availability of green hydrogen and sustainable biomass. Because of these limitations, moderating demand in these transport modes is a critical component of achieving the necessary emission cuts. In addition to increasing costs of air travel through taxes and other levies, reducing airport capacities through reformed noise protection rules or reduced landing and starting slots are exemplary tools to cut emissions at required scales. To reduce short distance flights, attractive railway systems are essential.

Buildings

According to the IA, emissions from the buildings sector are projected to decrease by 92% by 2040. The IA assumes that these reductions are primarily driven by the widespread deployment of heat pumps and the renovation of building envelopes. However, achieving these reductions presents a very significant challenge due to several factors, including limited funding, the lack of skilled labor in the construction sector, the need to provide more affordable housing and the necessity to refurbish old buildings and construct new ones cost-effectively amidst rising construction costs. According to the EEA, the sector is projected to reduce its emissions by 2040 by only 55% with existing measures, and by 65% with additional measures.

The IA assumes that **direct CO_2 emissions from buildings decrease rapidly in this decade, from about 450 MtCO_2 in 2015 to 190 MtCO_2 in 2030, i.e., by 57%.** It should be noted that these steep declines in emissions from the buildings sector assume that gas consumption will fall by 64% from 2015 to 2030. Such reductions in gas consumption in such a short period are, however, unprecedented.

EU legislation essential for reducing emissions from the building sector – such as the EPBD, EED, and RED – has recently been reformed. **While these reforms are steps in the right direction, they are clearly insufficient to reduce emissions from the building sector in the range of 92% by 2040.** To achieve emission cuts substantially higher than projected with existing and planned measures, it is crucial to

- establish stringent minimum energy performance standards (MEPS) and the corresponding renovation obligations also for residential buildings,

- raise the annual increase in renewable energy of 1.1% in 2026 to 2030 to an annual increase of 3.4% for the period 2030 to 2050 and to amend RED targets accordingly,
- end installing new fossil fuel boilers as soon as possible – possibly through phasing out stand-alone fossil boilers by amending the Ecodesign Directive,
- and establish a comprehensive approach to the buildings sector transformation on a district and municipal level. It is important that Member States fully implement the provisions as specified in Art. 25 of the EED.

In addition to these measures, it is **important to broaden the discussion on how to use existing buildings more effectively and on moderating projected growth in the floor area**. There are many examples where existing buildings have been put to other uses, e.g. through converting empty office buildings in residential buildings, but these examples have not been scaled up.

Agriculture

The IA projects GHG emissions **from agriculture to be 30% lower than in the scenario S 3 and 46% lower than in the LIFE scenario** (compared to levels in 2015). A key feature of the agricultural sector is that emissions from livestock farming consistently account for around two-thirds of all emissions and that technical measures – such as feed additives – have only a limited potential for reducing these emissions. This feature makes the reduction of livestock the key building block for reducing agricultural emissions at the required scale. Without reducing livestock, attaining necessary emission cuts becomes unrealistic. Reduction of livestock is also instrumental for freeing land for other purposes, notably for achieving the EU's biodiversity goals and enhancing natural sinks. Moreover, significantly reduced meat and milk consumption mitigates inflation and food insecurity. Around 90% of soy and two-thirds of all cereals consumed in the EU are used to feed animals – a practice that drives up food prices and undermines food security.

Reducing livestock numbers requires a combination of measures, not one single measure. This combination of measures includes quotas for livestock per hectare, milk quota, tradable production rights for animals, or buy-out schemes to cap the total number of animals. Stricter animal welfare regulations – such as limits on stocking densities for hens, pigs, and calves – can also contribute to reducing livestock. Additionally, regulations on stables, fertilizers, and manure are also instrumental for reducing livestock. Reforming the CAP provisions that currently allocate 82% of agricultural subsidies to meat and dairy production is a priority. Legally binding targets for emissions from agriculture is another important option. An ETS 3 regulating agricultural emissions is less likely to help significantly reduce livestock numbers in the EU.

It is important to emphasize that these measures will reduce livestock numbers in the EU but will not address meat and dairy imports from third countries. **To tackle these imports, implementing taxes on meat and dairy is a crucial option.** It is also worth noting that even under the LIFE scenario, significant numbers of livestock would remain in the EU after 2040.

The big building blocks: green electricity, sustainable biomass, green hydrogen, and carbon dioxide removals

To achieve emission reductions at the scale described above, the IA assume that (1) green electricity, (2) sustainable biomass, (3) green hydrogen, and (4) carbon dioxide removals will be available in large volumes and on time. The IA also assumes significantly reduced energy consumption. These are the “**big building blocks” that are indispensable for achieving the necessary emission cuts**.

- **Availability of green electricity:** According to all scenarios, achieving the 2040 target depends on the availability of green electricity – in sufficient volumes and on time. The IA assumes that demand for electricity will rise from 2,905 TWh in 2021 to about 5,210 TWh in Scenario 3 by 2040. Availability of these amounts of green electricity will depend on the rapid expansion of renewable energy, as presented above.
- **Availability of sustainable biomass:** Biomass is another big building block for achieving net reductions of 90%. Primarily driven by increased demand for advanced liquid biofuels and biomethane, the use of biomass and waste is projected to increase by 30% in the IAs scenarios S2 and S3, representing approximately 20% of the gross available energy (GAE) in 2040. In total, the IA expects that biomass produces 9 Exajoules (EJ) of energy. Other scenarios assume even higher demands, possibly bringing total biomass demand to 17–19 EJ or even 25 EJ by 2050.

  However, it is very uncertain whether these additional amounts of biomass and land required to grow it will be available. For context, growing 8 EJ of biomass is equivalent to 62% of the EU’s total agricultural production. Such a large increase in land use is implausible, especially if the production of meat and dairy in the EU is not reduced significantly. Furthermore, scaling up biomass production to this extent would make it even more challenging to reverse ecosystem decline and meet the EU’s nature restoration targets. Aggravating the challenge, climate change is expected to reduce the capacity of ecosystems to produce biomass and to remove CO_2.
- **Availability of green hydrogen:** Availability of green hydrogen is another big building block on the path towards net reductions of 90% by 2040. The IA assumes that hydrogen consumption rapidly scales up, achieving 55-95 Mtoe by 2040 in the S1-S2-S3 scenarios. However, the current growth in green hydrogen production is far too slow.
- **Availability of carbon removals:** To deliver a reduction of EU net GHG emissions of 90% by 2040, the IA assumes that carbon removals reach up to 400 Mt CO_2. Although the IA projects a relatively modest net contributions of LULUCF removals, it still assumes that the LULUCF sector will remove more carbon than the 310 Mt CO_2 required by the 2030 target. This is a challenging target because the LULUCF removals are declining, and climate change is very likely to accelerate this decline. Achieving industrial removals between 50 Mt (S2) and 75 Mt (S3) is also ambitious. For comparison, 5 Mt is the EU's aspiration for 2030.
- **Reduced energy consumption:** The IA projects that GAE decreases by around 30%, with only small differences across all scenarios. However, if current trends persist, the EU will not meet its 2030 energy efficiency targets. To achieve these targets, the average annual reduction in primary energy consumption must be more than doubled compared to the rate since 2005, while the reduction in final energy consumption must be four times faster.

Putting these building blocks in place by 2040 is a significant challenge. There is a significant risk that they will not be implemented in time and to a sufficient degree. The IA demonstrates that demand-side measures outlined in its LIFE variant can help mitigate these risks. The LIFE variant reduces demand in sustainable biomass, green electricity, green hydrogen and carbon removals. It also requires less investments.

1 Introduction

The EU will adopt a climate target for 2040 in the coming years. This is a legal obligation set out in the European Climate Law (ECL). The climate target is a critical milestone on the EU's path towards climate neutrality by 2050 and net negative emissions thereafter.

On 6 February 2024, the Commission published its **communication on the EU's climate target for 2040**. In this communication, the **Commission recommends a 90% reduction** in *net* GHG emissions by 2040, and an emission budget of 14-16 Gt until 2040. According to the Impact Assessment (IA) accompanying the communication, *gross* GHG emissions in the EU are projected to reduce between 75% (S1) and 85% (S3) in 2040 and around 92% in 2050 compared to 1990. The communication and the accompanying IA are intended to "launch a broad political debate with stakeholders and citizens" (European Commission, 2024a). The Communication takes account of the European Scientific Advisory Board on Climate Change (ESABCC) scientific advice on EU-wide 2040 climate target and a greenhouse gas budget for the period from 2030 to 2050. The ESABCC recommends a EU's GHG emissions budget of 11 to 14 Gt CO_2e between 2030 and 2050 and emission reductions of 90 - 95% by 2040, relative to 1990.

The communication is not a legal proposal to introduce a 2040 climate target in the European Climate Law. **It will be the responsibility of the new Commission to propose an amendment to the ECL enacting the 2040 target.** It is expected that the new Commission will propose necessary amendments to the ECL in the first quarter of 2025. It is also for the next Commission to make legislative proposals for the implementation of the 2040 target. According to the Commission, preparations will begin for a post-2030 policy framework once a legally binding target for 2040 is adopted (European Commission, 2024d).

Against this backdrop, **this report discusses the implementation of the EU's new 2040 climate target.** It aims to identify building blocks and measures particularly relevant for cutting the EUs emissions by net 90% in 2040. In its first chapter, the paper provides an overview of the big building blocks for the implementation, such as the availability of green electricity, sustainable biomass, CCS, carbon removals, and funding. Chapter 2 discusses what sectoral measure are particularly important for the implementation of the 2040 target. To this end, the report analyses key building blocks and key measures required to achieve the necessary emission cuts in transport, buildings, industry, agriculture, and energy production.

Given the very large scope of the issues relevant for achieving the EU's new 2040 climate target, the **report focusses on the key building blocks and measures**, i.e. measures that are indispensable for achieving said climate target. The report aims to contribute to the emerging debate on the EU's climate target for 2040. It does not include a fixed list of political priorities. The report builds on several sectoral papers, published in the context of a project funded by the German Federal Ministry for Economic Affairs and Climate Action.[2] The report takes account of papers on carbon removals, the post-2030 EU climate architecture and the design of the EU 2040 climate target, which were also written in the context of this project (Meyer-Ohlendorf, Kocher, Gores, et al., 2023a; Meyer-Ohlendorf, Kocher, Graichen, et al., 2023b, 2023a), but does not reiterate their findings.

[2] EU 2040 climate target: level of ambition and implications, https://www.ecologic.eu/19177

2 Building blocks for the 2040 target

In its communication of 6 February 2024, the Commission proposes net reductions of 90% by 2040 compared to 1990. Such reductions lie in between the IA's core scenarios 2 and 3. **Scenario 3 builds on**

- the achievement of the 2030 target of 55%,
- the continuation of the Fit-for-55 energy trends, and mitigation of non- CO_2 emissions according to the current framework, as all scenarios in the IA do,
- reductions of GHG emissions in the land sector, including non-CO_2 emissions in the agriculture sector and carbon removals in the LULUCF-sector,
- and high amounts of carbon removals, as well as higher production and consumption of e-fuels.

Despite some differences, all IA's core scenarios have one thing in common: emission reductions are **primarily achieved through innovation, technology, investment, and infrastructure changes.** [3] According to the IA, industry emissions are reduced via electrification, implementation of new manufacturing technologies, innovation in processes, use of alternative materials or sources such as RFNBOs and cleaner supply chains. In the residential and service sectors, emissions decrease through widespread adoption of heat pumps and building envelope renovations. Transport emissions decline due to large-scale deployment of electric vehicles and a shift from fossil fuels to e-fuels and advanced biofuels in road, maritime, and aviation sectors. In agriculture, GHG emissions are mitigated through advancements in breeding, reduction of enteric emissions, and improved manure and fertilizer management.

For a **path that is largely built on innovation and technology, it is indispensable** that

- green electricity,
- sustainable biomass,
- green hydrogen,
- carbon dioxide capture and removals and
- funding,

among others, are available in sufficient quantities in good time. **As another precondition, it is equally essential that the EU achieves its energy and climate 2030 targets.** This section briefly discusses the extent to which these building blocks are likely to be implemented on time. Given the complexity of the issues, this chapter only provides broad overviews.

2.1 Meeting the 2030 target

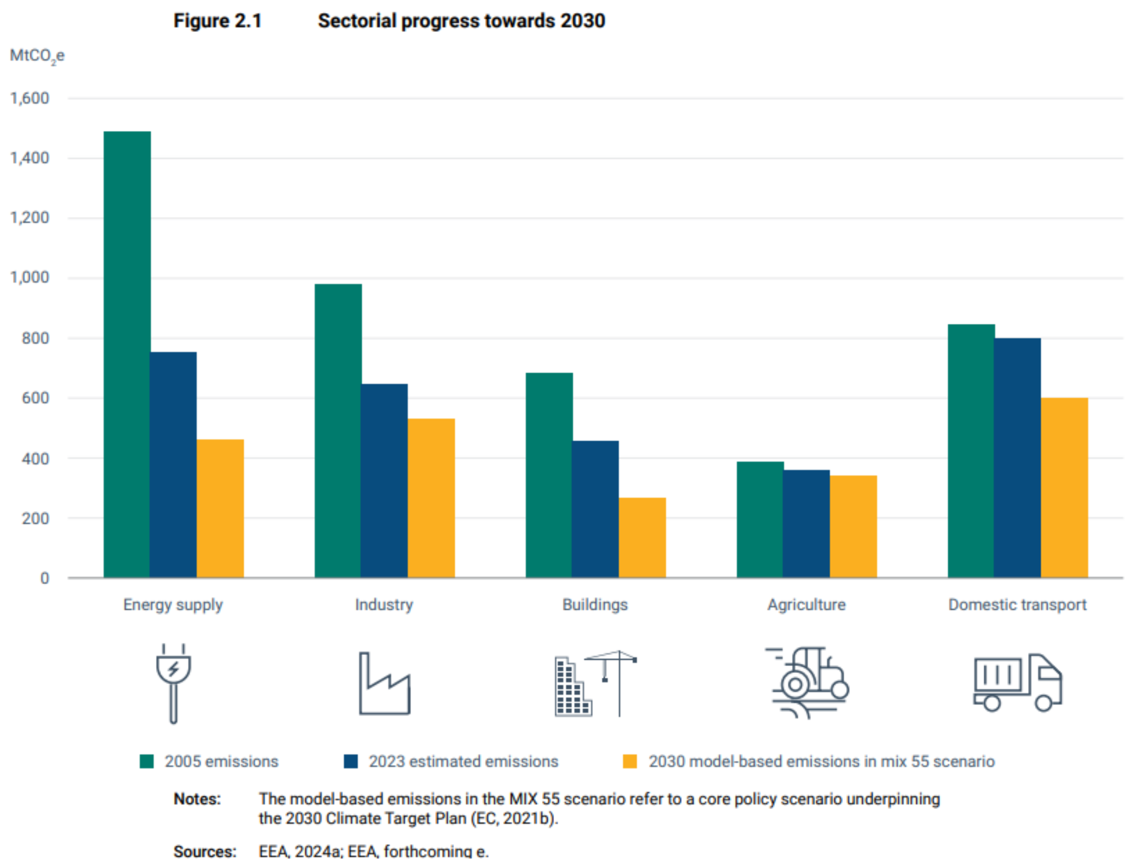
The 2040 communication states that delivering the **2040 target "will depend on the *full* implementation of the 2030 climate and energy framework**" (emphasis added) (European Commission, 2024b, p. 10). In other words, achieving the 2040 target of net 90% as proposed

[3] The IA also takes account of the so-called Life variant. This variant looks at the sensitivity of the analysis to key societal trends related to more sustainable lifestyles. However, "LIFE" is not attached to a specific target option and is not used to compare the different target options. It illustrates how demand-side driven actions "can complement the supply-side technology deployment analysed in the core scenarios".

by the Commission becomes much more difficult if the EU fails to reduce its emissions by net 55% as required by its 2030 climate target.

According to the EEA's 2023 Trends and Projections Report, the EU is projected to reduce its emissions by **43% by 2030 with existing measures**. Even with **additional** measures, the EEA projects that the EU will only achieve **emission cuts of 49% by 2030**. To deliver on the 2030 targets, the **pace of annual absolute GHG emission reductions must more than double** compared to the annual progress seen since 2005. The annual reduction rate must accelerate, particularly in the sectors covered by the Effort Sharing Regulation.

Figure 2 Sectorial progress towards 2030



EEA, 2023

For the time after 2030, the EEA projects in 2024 that existing policies and measures will deliver net emission reductions in the scope of the Climate Law of 54% in 2040 and 57% in 2050 (compared to 1990). Considering currently adopted and planned measures, Member States' aggregated emissions are projected to fall by 62% below 1990 levels in 2040, and 66% in 2050.[4] **As a result, the EU will need to step up its efforts significantly to achieve net reductions of 90% by 2040 and climate neutrality by 2050**. The current gap is very large, particularly in transport and agriculture, and must be closed as soon as possible.

Very positively, however, GHG emissions in the EU fell by an unprecedented 8% in 2023. This marks the largest year-on-year emission reduction in several decades, except for the COVID-impacted year of 2020, bringing estimated 2023 emissions to 37% below 1990 levels. **Reductions in 2023 were more than five times the average rate since 2005 and surpasses**

[4] These numbers refer to the ECL target scope including part of international transport emissions.

the annual rate required to meet the 2030 climate targets. They are major step towards meeting the EU's climate target for 2030.

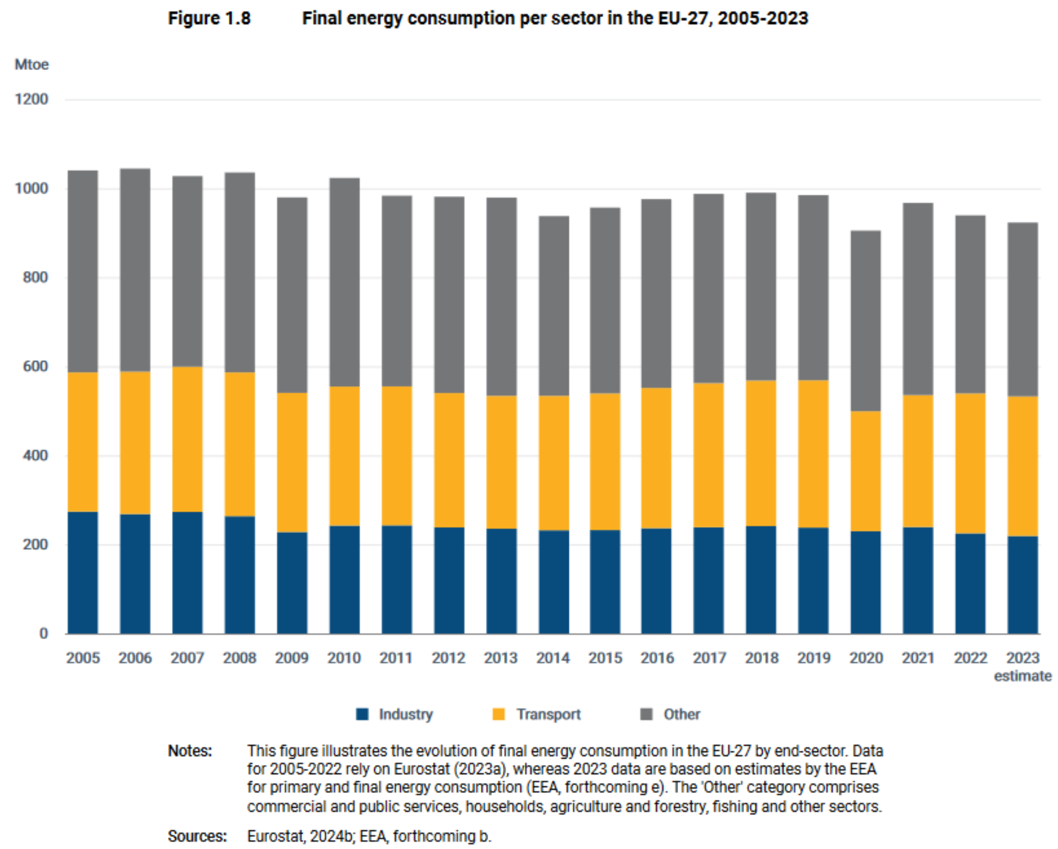
In addition, it should be noted that the IA proposes an **emission budget** for the EU in S 3 of 16 Gt from 2030 to 2050. This proposal is 2 Gt above the range recommended by ESABCC (11-14) or at the upper end of what ESABCC considers as a feasible GHG budget (13-16 Gt) for a 50% probability contribution to 1,5°C ESABCC, 2023).

2.2 Reduced energy consumption

Reduced energy consumption is a crucial building block for achieving the required emission cuts. The IA projects that 'continued energy efficiency improvements will reduce the need for energy'. Accordingly, **gross available energy (GAE) is expected to decrease by around 30%**, from 1450 Mtoe (or 61 EJ) in 2021 to approximately 1020 Mtoe (43 EJ) in 2040, with small differences across scenarios S1, S2, and S3. The LIFE variant suggests a further reduction in GAE by 24 Mtoe (1 EJ). The IA also projects that GAE will stabilize after 2040, as energy savings will be offset by the additional energy required for renewable hydrogen and direct air capture. Similarly, the ESABCC finds that total final energy use will decrease by 20-40% from current levels by 2040 across all pathways. The transport sector is expected to see the largest reduction in energy consumption (30-60%), followed by the industrial sector (20-45%) and the residential and tertiary sectors (15-35%) (ESABCC, 2023a).

However, despite recent advancements and an overall reduction in energy consumption since 2005, **progress has been too slow**. According to the EEA, final energy consumption in 2023 was only 11% lower than in 2005 (EEA, 2023b). If current trends persist, the EU will not meet its 2030 energy efficiency targets. To achieve these targets, the average annual reduction in primary energy consumption must more than double compared to the rate since 2005, while the reduction in final energy consumption needs to be more than three times faster (EEA, 2023b). For comparison, the following graphic illustrates changes in energy consumption in Member States since 2015.

Figure 3 Final energy consumption in EU 27 per sector



EEA, 2023

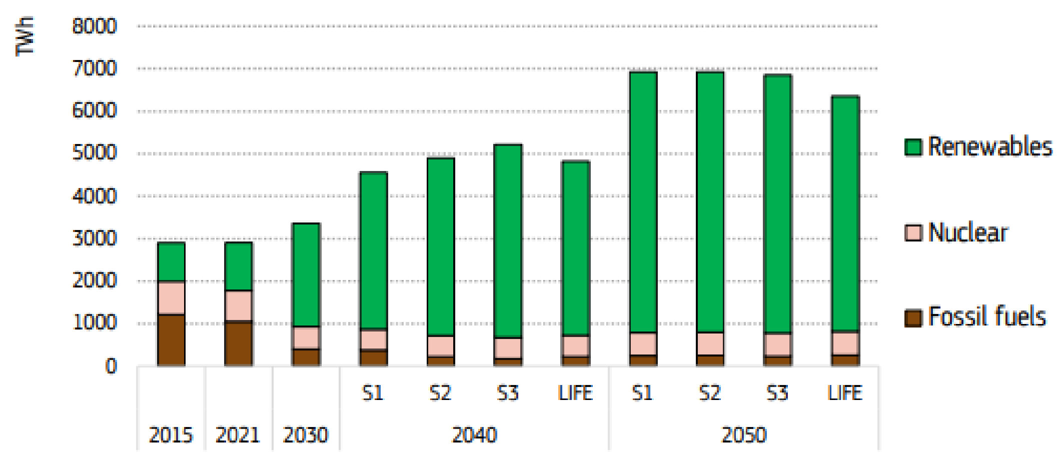
2.3 Availability of green electricity

According to all scenarios, **achieving the 2040 target depends on the availability of green electricity** – in sufficient volumes and in time. The electrification of transport, buildings, and industry as well as the production of RFNBOs (Renewable Fuels of Non-Biological origin) and DACC (Direct Air Carbon Capture) require large amounts of green electricity and are essential building blocks for achieving net reductions of 90%.

The IA projects that **electricity demand will increase drastically** in the coming decades. It assumes that electricity generation will rise from 2,905 TWh in 2021 to about 4,565 TWh in Scenario 1 (S1), 4,900 TWh in Scenario 2 (S2), and 5,210 TWh in Scenario 3 (S3) by 2040. Electricity consumption in the EU's transport sector, for example, increases drastically, from less than 5 Mtoe in 2015 to 42-43 Mtoe in 2040 and 53-54 Mtoe in 2050 in the S1, S2 and S3 scenarios. This represents 15-16% of the EU's total final electricity consumption across all sectors in 2040. In addition, electricity demand from data processing in general and artificial intelligence in particular is projected to grow to approximately 35 GW by 2030, up from 10 GW today (Green et al., 2024).

Renewable energy is projected to supply most of the electricity in 2040. According to the IA, renewables are expected to cover 81% to 87% of total electricity supply by 2040, up from around 40% in 2021.[5] The IA also projects that net installed renewable capacity will increase dramatically by a factor of four to five between 2020 and 2040.

Figure 4 Electricity generation by energy carrier, 2015-2050

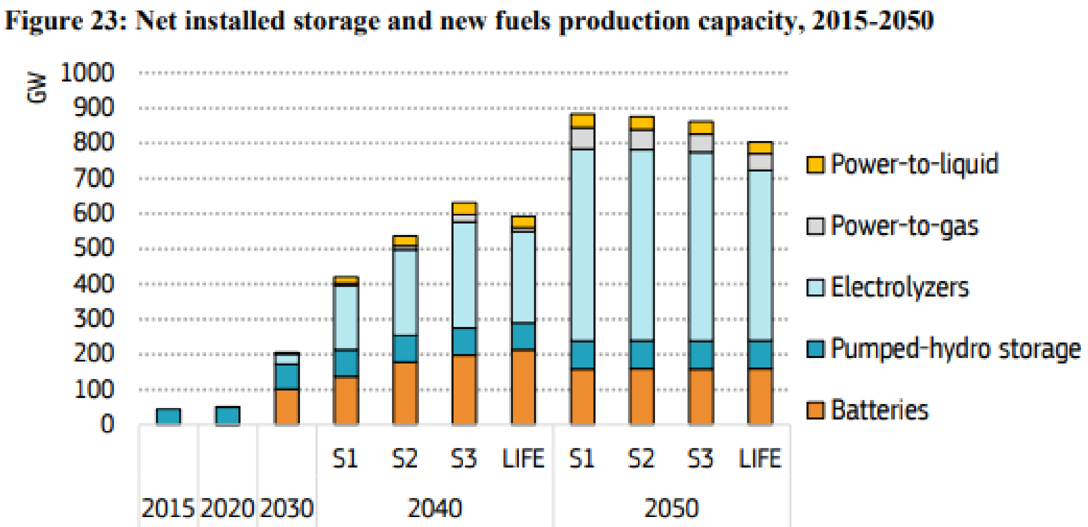


Source: (European Commission, 2024a)

In an energy system largely built on renewable energy, increased storage capacity is indispensable. The IA **expects storage input/output to increase up to tenfold between 2020 and 2040 across the S1-S2-S3 scenarios – from 50 GW to 350-530 GW**. Pumped-hydro storage power is projected to grow from 50 GW in 2020 to 75 GW in 2040, with a steep increase until 2030. Deployment of battery storage is projected to accelerate after 2030, from 100 GW to 135-200 GW in S1-S2-S3 in 2040. Electrolyzer capacity increases from 30 GW in 2030 to 185-300 GW in 2040 (European Commission, 2024a, p. 291).

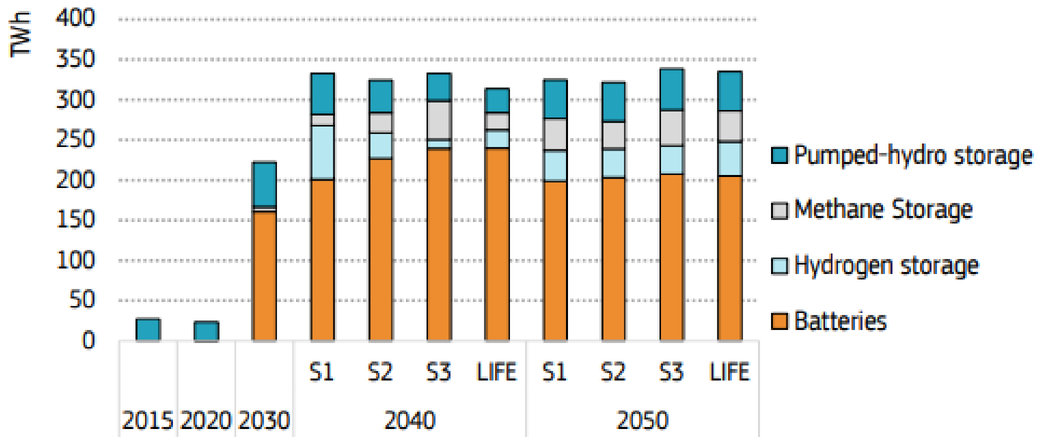
[5] The ESBACC confirms these findings. According to its advice, non-biomass renewables, including wind, solar and hydro power, provide 70-91% of electricity by 2040. In most scenarios, the share is higher than 85%. Nuclear power supplies between 3% and 23% of electricity in the filtered scenarios.

Figure 5 Net installed storage and new fuels production capacity, 2015-2050



Source: (European Commission, 2024a)

Figure 6 Stored energy by technology, 2015-2050



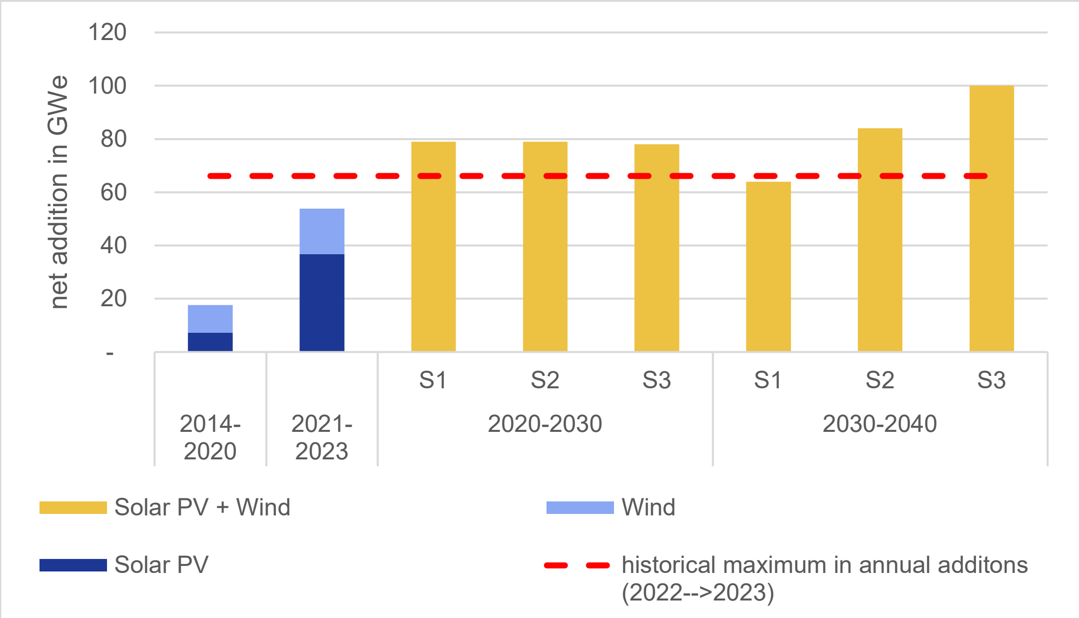
Source: (European Commission, 2024a)

To meet these demands, the **annual rate of installing new renewable power generation as well as storage capacity must increase drastically**. According to the IA, annual deployment rate for wind and PV in S3 would be nearly 80 GW between 2021 and 2030 and 100 GW between 2031 and 2040. However, between 2011 and 2020 only 20 GW of wind and PV were installed. In turn, the annual rate of installing new capacities needs to increase by a factor of 4 to 5 if compared to the period 2011 to 2020.[6] Positively, however, deployment rates has been

[6] It also noteworthy that the EU is not on track to meet its 2030 RES target. According to the EEA (2023), to reach the target level of 42.5% by 2030, the total share of RES will need to grow continuously by an average of 2.2 percentage points each year from 2022 to 2030. This is three times the growth rate during the period from 2005 to 2022.

at on average 54 GWe after 2020, and reached a historic high in 2022 to 2023 with a total net addition 66 GWe in wind and PV capacities, requiring an increase in the annual deployment rate of 50-80% to reach targeted installed capacity levels in 2040 and 2050 (see Figure 7). Achieving these deployment rates is a particular challenge for Member States with high shares of domestic fossil fuel production and no firm pre-2050 phase-out plans.

Figure 7 Average annual deployment of wind and solar PV: historical deployment and scenarios from the EC IA.



Source: Own illustration by Öko-Institut based on IRENA (2019) (European Commission, 2024c)

2.4 Availability of sustainable biomass

Biomass is another essential building block for achieving net reductions of 90%. Primarily driven by increased demand for advanced liquid biofuels and biomethane, the use of biomass and waste is projected to increase by 30% in scenarios S2 and S3, representing approximately 20% of the GAE share in 2040 (European Commission, 2024a). Overall, **the IA estimates that biomass generates 9 Exajoules (EJ) of energy.** The ESABCC indicates that the demand for bioenergy will increase by over 50% by 2040 in some scenarios, while other scenarios assume a more modest increase, or even no increase above today's levels (ESABCC, 2023a).

It is **uncertain whether it will be possible to generate biomass in the EU at this scale and within the short timeframe until 2040:**

- **Increased biomass demand in the EU – can available biomass meet bigger demand?** A report from Material Economics finds that demand in biomass in the EU will increase drastically over the coming decades. Pointing to different scenarios, the report projects that biomass demand would increase by 4-5 EJ for road transport, 5-6 EJ for biogas, 7 EJ for power generation, and more than 4 EJ for chemicals. In total, these claims would bring biomass use to 17–19 EJ by 2050 in conservative scenarios, more than 70% higher than today's 10 EJ. More ambitious scenarios bring total demand to 25 EJ, an increase of 150% (Material Economics, 2021). It should be noted, however, that other scenarios project lower biomass use (ESABCC, 2023a). It is a question of critical importance whether these increased amounts of biomass will become available. For comparison, 8 EJ is equivalent to 62% of the EU's total agricultural production.

- **Biomass production contributes to the decline of ecosystems**: In the EU, 80% of habitats are in poor shape (European Parliament, 2024). 81% of protected habitats, 39% of protected birds and 63% of other protected species are in a poor or bad conservation state (EEA, 2020). The new EU nature restoration law requires Member States to restore at least 30% of habitats in poor condition by 2030, 60% by 2040, and 90% by 2050. Biomass production has been a major driver for this decline. Increasing biomass production will make reversing ecosystem decline and meeting restoration targets less likely.[7]
- **Declining natural sinks also because of increased wood harvest**: Total net carbon removals from the LULUCF sector in Member States decreased in 2021 to 2030 Mt CO_2e, down from at least 300 Mt CO_2e/y in the period 1995–2016. Ageing forests with decreased carbon sequestration, natural disturbances such as wildfires and droughts and slower net forest area expansion have contributed to the decline in removals. Increased harvest of trees has been another major driver (Winkler et al., 2023). Natural sinks are projected to continue to decline until 2050 (Meyer-Ohlendorf, Kocher, Gores, et al., 2023b).
- **Additional biomass demand cannot be met by import:** Importing more biomass to the EU is not a viable solution because the required amounts of additional biomass are not available globally without increasing emissions elsewhere and destroying biodiversity in other regions.
- **The EU does not have the land to meet additional biomass demands:** With limits on waste biomass and imports, any significant increase in EU biomass supply would primarily need to come from the cultivation of new energy crops. This would entail a major transformation of EU landscapes: the 5 EJ of supply envisioned in some scenarios would require approximately 30 million hectares of land, equivalent to 20% of all current EU cropland, or the size of Italy (Material Economics, 2021). Increases of land use at this scale are only plausible if the EU's production of dairy and meat products decreases sharply. According to IA, for example, 13 million hectares from food production would become available for other purposes if 25% of population reduce meat consumption drastically (LIFE scenario).
- **Climate change undermines biomass production in Europe:** Aggravating the challenge, climate change will undermine forests' capacities to generate the additional biomass.

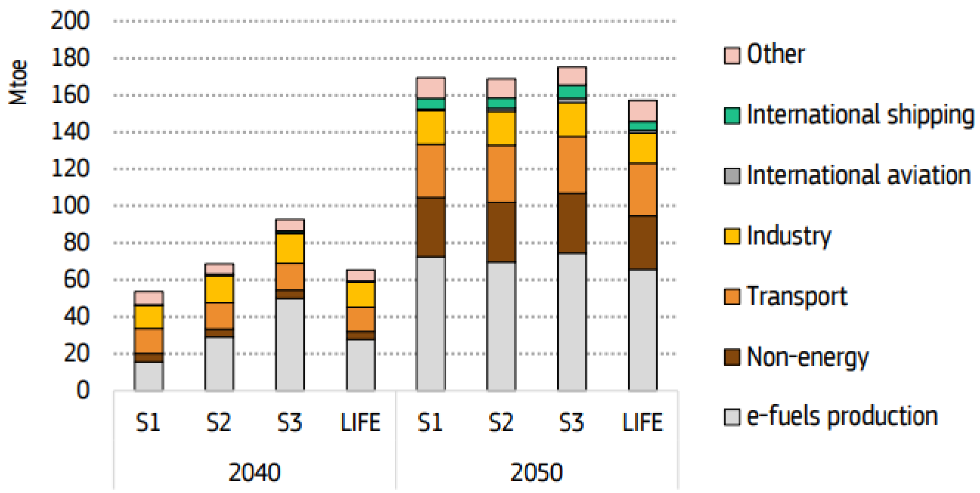
2.5 Availability of green hydrogen

Availability of green hydrogen is another big building block on the path towards net reductions of −90 % in 2040. **The IA assumes that hydrogen consumption scales up rapidly, reaching up to 95 Mtoe in 2040 in scenario S3. Hydrogen production in the S3 scenario is projected to be over 60% higher than in S1.** The production of e-fuels accounts for the "lion's share" of total hydrogen consumption in 2040. There is only a minor need for hydrogen to

[7] Overall use of solid biomass in 2020 was 239% what it was in 1990. Use in the energy sector (heat and power) increased more than 1,000%, while industrial use increased 185% and residential/commercial self-heating increased 167%. Forests are already overharvested and are unlikely to deliver biomass at this scale.

stabilize the electricity production system in these scenarios. The following table provides an overview of hydrogen consumption by sector.

Figure 8 Consumption of hydrogen by sector, 2040-2050



Source: (European Commission, 2024a)

Green hydrogen production is still in its very early stages. According to the Clean Hydrogen Monitor 2023 (Fonseca et al., 2023), hydrogen production capacity in Europe remained stable at around 11.5 Mtoe in 2022. Only a small fraction of this capacity is Power-to-hydrogen/water electrolytic capacity. In 2022, water electrolysis capacity represented just 0.3% of the total hydrogen production capacity in Europe, up from 0.1% in 2020. Conventional production methods based on fossil fuels accounted for 95.6% of the capacity and dominate the current hydrogen market. **In 2023, 0.5 GW of electrolysis-based hydrogen production capacity was installed in Europe** (IEA, 2023) **.**

Similar to the other building blocks, scaling-up of the production and use of green hydrogen on this scale poses significant challenges:

- **Green electricity:** It depends on the availability of green electricity (see above)
- **Hydrogen infrastructure:** The projected increase in hydrogen production requires significant infrastructure investments at rapid speed. However, these necessary investments are being delayed, and annual deployment rates need to increase drastically. To achieve the 140 GW of installed electrolysers needed to produce the 10 Mt of green hydrogen envisaged by REPowerEU, for example, Europe would need an annual growth rate of 150%. Currently, the growth rate is only 23%.
- **Hydrogen imports uncertain:** Given the limited availability of green electricity in Europe, hydrogen imports are critical, but they are also uncertain. They are particularly uncertain if hydrogen is sourced from unstable countries with high levels of corruption. It should also be noted that green hydrogen imports from these countries can also undermine their own decarbonization efforts and – hence – global mitigation efforts.

2.6 Availability of carbon capture and storage (CCS) and usage (CCU)

Carbon capture and storage (CCS) plays important roles in IA scenarios. While annual carbon capture remains below 100 $MtCO_2$ in Scenario 1 (S1), it increases to approximately 220 $MtCO_2$/year in Scenario 2 (S2) and around 350 $MtCO_2$/year in Scenario 3 (S3), where most emissions from the power sector and industrial processes are captured, and industrial carbon removal technologies are widely deployed. The captured carbon is either used to produce e-fuels (CCU) or stored, with storage injection rates reaching approximately 150 $MtCO_2$/year in S2 and 240 $MtCO_2$/year in S3 by 2040. The use of CO_2 in materials is expected to expand primarily in the decade from 2041 to 2050. The following table summarizes the IA's projections.

Table 1 Industrial carbon capture, storage and use

	2040			2050
Carbon Captured – MtCO2/year	**S1**	**S2**	**S3**	**S3***
By Source	**86**	**222**	**344**	**452**
Industrial Processes	37	123	137	136
Power (fossil fuels)	26	41	32	55
Power (biomass) and DACC**	16	54	153	232
Biogenic (upgrade of biogas into biomethane)	7	4	22	30
By Application (use and storage)	**86**	**222**	**344**	**452**
E-fuels	43	75	101	147
Synthetic materials	0	0	0	59
Underground storage	42	147	243	247

Note: *S1 and S2 values for 2050 are similar to S3 and represented in more details in Annex 8. **Includes carbon for storage (DACCS) and use.

Source: (European Commission, 2024a)

The 2023 **project announcements in Europe are expected to add approximately 73.5 million tons of CO_2 storage injection capacity annually** (Rossie, 2023). These projects are growing in scale, with the average storage capacity of 2023 projects being 40% larger than those announced in 2022. In total, 119 commercial-scale CCS projects were announced in Europe in 2023, marking a 61% increase compared to 2022 (Global CCS Institute, 2023). However, these projects are heavily concentrated in countries surrounding the North Sea, which is problematic, as the need for CO_2 storage extends far beyond this region. It is also important to note that the projects are at various stages of development, casting uncertainty over their full implementation.

2.7 Availability of carbon removals

Carbon removals are another big building block for reaching the proposed climate target of net 90%. To deliver a reduction of net GHG emissions of 90%, the IA assumes that the level of remaining EU GHG emissions in 2040 should be less than 850 $MtCO_2$-eq and carbon removals (from the atmosphere through land-based and industrial carbon removals) should reach up to 400 $MtCO_2$.

LULUCF net removals are projected to contribute most over 2030-2050 in scenarios S2 and S3 with net removals of around 320 $MtCO_2$-eq (see Table 7). The role of **industrial removals remains much more limited in the short run**. They become significant by 2040 to meet higher climate targets, with about 50 $MtCO_2$ in S2 and 75 $MtCO_2$ for S3, representing close to 25% of the total carbon capture.[8]

Table 2 Industrial removals and net LULUCF removals

	2040			2050
	S1	**S2**	**S3**	**S3****
Gross GHG emissions (MtCO2-eq)	**1273**	**943**	**748**	**411**
Total Removals (MtCO2-eq)	**-222**	**-365**	**-391**	**-447**
Industrial Removals (MtCO2)	-4	-49	-75	-114
LULUCF net removals (MtCO2-eq)	-218	-316	-317	-333

*Note: **S1 and S2 values for 2050 are similar to S3 and represented in more details in Annex 8.*

Source: (European Commission, 2024b)

While removals will play an important role in achieving net reductions of 90%, the heavy dependence on carbon removals outlined in the IA raises **many questions**:

- **Availability of natural removals in required quantities:** Although the IA projects a relatively modest net contribution of LULUCF removals, it still assumes that the LULUCF sector will remove more carbon than the 310 Mt required by the 2030 target. This is a challenging target. LULUCF removals declined by an average 13.9 Mt CO_2e per year between 2016-2021. This trend must be reversed to an annual increase of 6.3 Mt CO_2e per year to meet the EU's LULUCF net removals target (Velten et al., 2024). In addition, the outlook is grim. The effects of climate change, extreme weather events, and the limited ability of ecosystems to recover from them in a hotter climate make an increase of LULUCF removals less likely. The increasing demand for biomass puts further pressure on the sink.
- **Availability of industrial removals:** Achieving industrial removals between 50 Mt (S2) and 75 Mt (S3) is also ambitious. For comparison, 5 Mt is the EU's aspiration for 2030 (European Commission, 2021). Within the limits of the approaches' own sustainability requirements, increases of at least 625 kt CO_2e per year in capture and storage of CO_2 are required to meet the Commission's aspirational objective of 5 Mt CO_2e technical removal in 2030 (Velten et al., 2024).
- **Large uncertainties regarding carbon removals:** While the modelling shows a similar share of BECCS and DACCS by 2040 in S3 and beyond by 2050, their actual deployment depends on several conditions, including public acceptance, significant cost reductions, the timely implementation of large infrastructure projects, and the availability of sustainable biomass for BECCS and green electricity for DACCS.[9] It is uncertain whether these conditions will be met at the required scale and on time.
- **Scarcity of green electricity and sustainable biomass:** Depending on the scenario, the EU may require substantial amounts of green electricity for DACCS and a large supply of sustainable biomass for BECCS. Providing both poses a significant challenge,

[8] The ESBACC places the removal potential from the LULUCF sectors at between 100 and 400 Mt CO_2 and for BECCS and DACCS at between 50 and 200 Mt CO_2 in 2040.
[9] For the availability of biomass and green electricity see above

particularly in light of competing demands for these resources within the broader context of decarbonizing the EU's economies.

- **Equivalence problem of removals and reductions:** According to the Commission's 2040 communication, carbon removals "can either be achieved through the LULUCF sector as nature-based removals or technically as industrial carbon removals derived from carbon capture". The communication and IA imply that removals can replace reductions. They also suggest that all forms of removals are treated equally, regardless of whether they store CO_2 permanently or only temporarily. These assumptions are problematic. Removals and reductions are fundamentally different and cannot be treated equally (Meyer-Ohlendorf, Kocher, Gores, et al., 2023; Meyer-Ohlendorf, Kocher, Graichen, et al., 2023b, 2023a).

2.8 Funding and investment

Funding for the required investments is an additional and indispensable building block for achieving necessary emission cuts. The following table from the IA provides a detailed breakdown of investment needs.

Figure 9 Average annual energy system investment needs (billion EUR 2023)

	S1			S2			S3			ΔLIFE		
	2031-2040	2041-2050	2031-2050	2031-2040	2041-2050	2031-2050	2031-2040	2041-2050	2031-2050	2031-2040	2041-2050	2031-2050
Supply	236	377	306	289	328	308	341	281	311	-59	-14	-36
Power grid	79	88	84	88	81	85	96	75	85	-15	-2	-9
Power plants	97	187	142	128	157	142	151	133	142	-28	-6	-17
Other	59	102	81	72	90	81	94	73	83	-16	-6	-11
Demand excl. transport	332	377	354	355	357	356	372	338	355	-23	1	-11
Industry	38	31	35	46	24	35	48	22	35	-7	-3	-5
Residential	225	250	237	237	242	239	248	230	239	-12	4	-4
Services	49	78	63	53	73	63	57	67	62	-4	1	-2
Agriculture	19	19	19	19	19	19	20	18	19	0	0	0
Transport	866	875	870	861	885	873	856	882	869	-80	-85	-82
Total	1433	1629	1531	1505	1570	1537	1570	1501	1535	-162	-97	-129
Total excl. transport	567	754	661	644	685	664	713	619	666	-82	-12	-47
Memo:												
Real GDP (period average)	19444	22369	20906	19444	22369	20906	19444	22369	20906	19444	22369	20906

Note: "ΔLIFE" compares the cost of the LIFE scenario to the S3 scenario, which both meet the same overall net GHG reductions by 2040.

Source: (European Commission, 2024a)

However, estimating the necessary funding needs is challenging and subject to significant uncertainties. Regardless of these uncertainties, **trends in financing decarbonization are heading in the wrong direction.** According to ECNO, the climate investment gap for the EU to achieve its 2030 climate targets was €406 billion, or half of the annual investment required to meet the targets, in 2022 (Velten et al., 2024). Making matters considerably worse, subsidies for fossil fuel increased considerably in 2022 due to the energy crisis, reaching €190 billion.

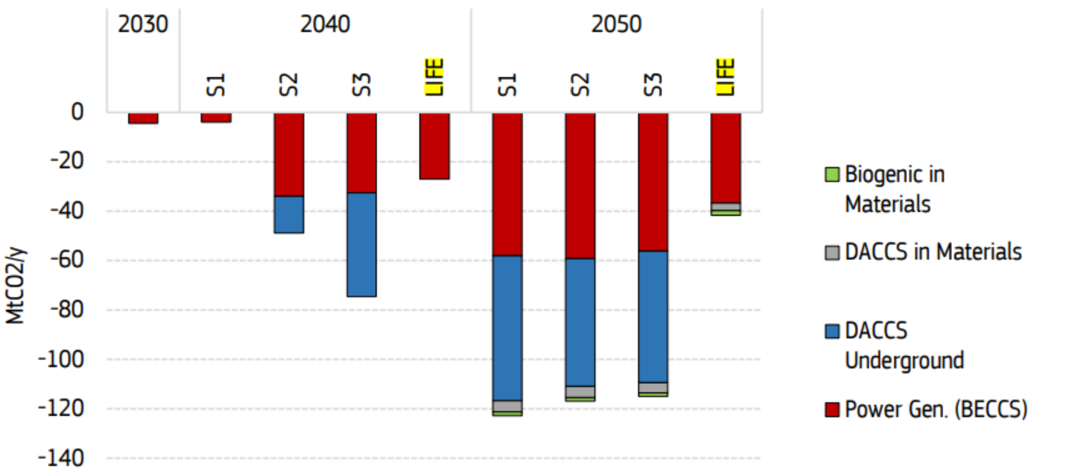
Given the complexity of issues relevant to funding the necessary investments for decarbonization, very many measures have been implemented to direct funding towards this goal. In addition to utilizing ETS revenues, reforms of EU multiannual financial framework, and financial market regulations, **ending fossil fuel subsidies is particularly important**. Although the 8th Environmental Action Programme urges Member States to phase out fossil fuel subsidies as soon as possible, these subsidies nearly tripled between 2021 and 2022 (OECD & IISD, 2024). Furthermore, ecological tax reform – another essential component of funding the decarbonization – is losing significance. The share of EU and Member States revenues from environmental taxation were decreasing in 2022. They only represented 4.9% of total EU and Member State tax revenues in 2022, compared to 5.43% in 2021 and 6.04% in 2013 (Eurostat, 2024a).

2.9 Demand side measures complementary but indispensable

Timely implementation of the above-mentioned supply-side building blocks is a major challenge. There is a considerable risk that they will not be available in sufficient quantities in good time. The IA demonstrates that **demand-side measures outlined in the LIFE variant** – such as shifts to a more sharing economy, more circular use of materials, and more sustainable mobility – can **help mitigate these risks** to some extent:

- **Reduced electricity and hydrogen needs:** Thanks to circular economy measures and more sustainable consumption patterns, LIFE allows for savings of almost 390 TWh of total electricity production by 2040. The circular economy measures and behavioral changes in the LIFE variant also significantly reduce the amount of required power generation capacity by around 200 GW in 2040. LIFE also reduces the demand for renewable hydrogen by around 15 Mtoe. Confirming these findings, the ESABCC states the Demand-side focus and High renewable energy pathways produce less than half the amount of hydrogen in 2050 than the mixed options pathway.
- **Reduced use of fossil fuels:** By 2040, fossil fuel supply for energy use will decrease by more than 70% compared to today. The measures outlined in LIFE further reduce fossil fuel use by an additional 10 Mtoe.
- **Lower investment needs:** According to the IA, LIFE demonstrates that demand-side actions, can reduce the need for investment across the entire period. In aggregate, average annual investment needs (excluding transport) from 2031 to 2050 are almost €50 billion, or 7.1%, lower with LIFE than under S3. More specifically, they are about €36 billion per annum (12%) lower on the supply side and about €5 billion (15%) lower in industry.
- **Lower energy demand in road transport:** Total amount of energy consumed by cars and vans decreases in the LIFE variant slightly more than in the other scenarios, due to lower transport activity.
- **Reduced food waste:** Total food waste reduction of around 11 Mton in 2040 (compared to 2020) was achieved in the LIFE variant with reductions from primary agriculture, processing and distribution, as well as retail and households.
- **Lower carbon removal needs:** Demand-side actions and enhanced LULUCF net removals can reduce the need for industrial removals and, even, eliminate the need for DACCS by 2040. According to the IA, the LIFE scenario requires substantially less removals from BECCS and no removals from DACCS as shown in the following table.

Figure 2: Carbon removals by source and use



Source: PRIMES.

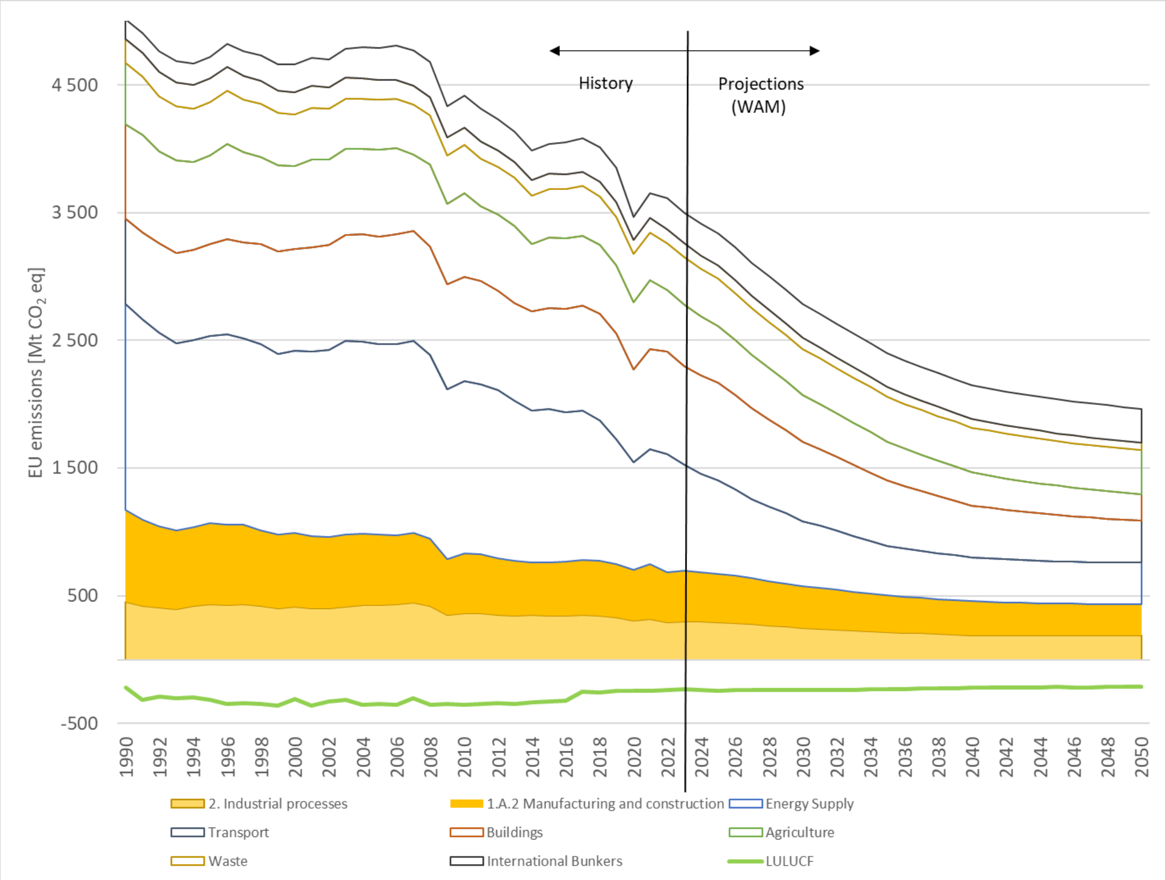
3 How can sectors contribute?

3.1 Industry

3.1.1 Emission trends in industry

Between 1990 and 2022, industry has **reduced its emissions by 41%**. Key drivers included the shift from coal and oil to natural gas and biomass as well as energy efficiency improvements and some restructuring of industry. To contribute to the net emission reductions of 90% by 2040 as proposed by the Commission, industry emissions need to continue to decrease strongly. According to S3 of the Commission's IA, **industry emissions will have to decrease by 92%** compared to levels in 1990 which limits industrial emissions to 89 Mt CO_2e by 2040. Projections with additional measures show that emissions of the industry sector will fall by only roughly 61% compared to 1990.

Figure 10 Sectoral historic and projected GHG emission (in Mt CO_2 equivalent)



Source: EEA (2023a). 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. Industrial emission trend marked in yellow and include those from energy consumption (CRF cat. 1.A.2, Manufacturing and construction), and processes and products (CRF cat. 2, industrial processes).

3.1.2 Key building blocks and challenges

To achieve reductions in emission from the industry sector of –92% by 2040, the following **building blocks** are indispensable according to all scenarios: (1) improving energy efficiency, (2) electrification of production processes, (3) availability of green hydrogen, (4) CCS and (5) material circularity, substitution and efficiency. The following table compares projected needs regarding energy efficiency, electrification and green hydrogen and the status quo of 2021 (Kögel et al., 2024).

Table 3 Harmonized table with min/max contribution to 2040 climate target

Parameter	Unit	2021	2030	2040	2050
GHG emissions	Mt CO_2e	757		25 – 219	
… energy-related	Mt CO_2e	440		-31 – 120	
… process-related	Mt CO_2e	318		7 – 104	
CCS	Mt CO_2	0		5 – 111	
CCU	Mt CO_2	0		0 - 166	
Final energy demand	TWh	3,854		2,570 – 3,315	
Hydrogen	TWh			157 – 640	

Biogenic sources	TWh	378	293 – 679
Electricity	TWh	930	1,130 – 1,396
E-fuels	TWh		8 – 116

Source: EEA (2023a), 2021 data from the GHG inventory (EEA, 2023a). For the years 2030, 2040, 2050, scenarios include those used by the ESABCC (2023a) (upper end & lower end), developed by Climact (Kalcher, 2023), the S2 and S3 of the Commission's Impact assessment on a 2040 Climate Target (European Commission, 2024a), and Climate Analytics' 'high CDR' as well as 'high energy / low CDR' scenarios (Climate Analytics, 2022). The data was partly complemented and reviewed with (EC, 2023; Fleiter et al., 2019; Material Economics, 2019).
Note: this table shows the order of magnitude for specific parameters across a set of scenarios that reach a total net emission reduction of 81% to 98% by 2040 compared to 1990. Data is given for industry, but definition may vary across the scenarios. Data are not available for all parameters for all scenarios; some data are calculated and/or estimated.

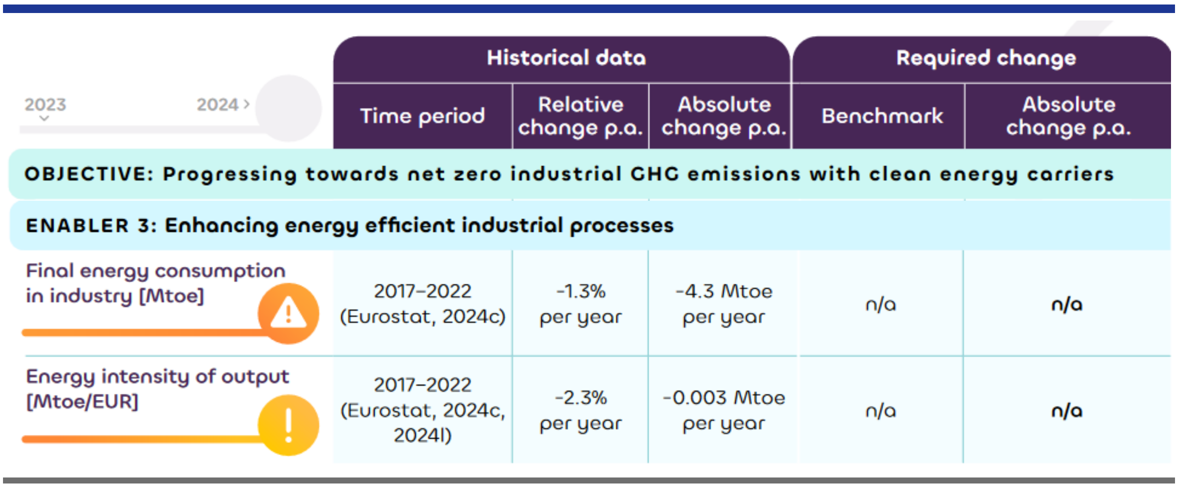
Building block 1: Electrification

To contribute to overall EU emission reductions of net 90%, industrial processes with low and medium temperature heat need to be almost fully electrified by 2040. A crucial factor in this transition is the deployment of new infrastructure and the modernization of existing infrastructure (Kögel et al., 2024). This encompasses electrifying process heat through the use of technologies such as heat pumps (for low to medium temperature needs), or electrode boilers for high temperature applications.

Building block 2: Energy efficiency

Increasing energy efficiency in industrial processes is another crucial building block, particularly in the short to medium term. Depending on various emission reduction scenarios, there are substitution effects between increasing electrification and direct renewable energy use on one hand, and enhancing energy efficiency on the other (Riemer et al., 2023). The ECNO report, however, shows that progress in the area of final energy consumption is 'far too slow' and reduction of energy intensity of output is 'too slow' (Velten et al., 2024).[10]

Figure 11 Details on indicators' past progress in energy efficiency uptake



2023 / 2024	Historical data: Time period	Historical data: Relative change p.a.	Historical data: Absolute change p.a.	Required change: Benchmark	Required change: Absolute change p.a.
OBJECTIVE: Progressing towards net zero industrial GHG emissions with clean energy carriers					
ENABLER 3: Enhancing energy efficient industrial processes					
Final energy consumption in industry [Mtoe]	2017–2022 (Eurostat, 2024c)	-1.3% per year	-4.3 Mtoe per year	n/a	n/a
Energy intensity of output [Mtoe/EUR]	2017–2022 (Eurostat, 2024c, 2024l)	-2.3% per year	-0.003 Mtoe per year	n/a	n/a

Source: Velten et al. (2024)

[10] Notably, the assessed data concludes in 2022, a year in which the sector continued to expand its activity compared to 2021, despite the onset of the energy crisis. These positive developments were partly driven by the volatility in global energy markets following Russia's full-scale invasion of Ukraine in February 2022 (Velten et al., 2024).

Building block 3: Hydrogen

All scenarios predict a significant rise in **hydrogen** demand, both for process heat and as a feedstock in the industrial sector. However, producing renewable hydrogen requires renewable electricity, posing challenges due to limited renewable energy sources in the EU, the costs and availability of imported hydrogen and derivatives, as well as the availability of necessary raw materials. The availability of affordable and clean hydrogen is a significant bottleneck as discussed above in section 2.5.

Building block 4: Carbon Capture and Storage

Transforming the industry sector necessitates shifts in value chains and infrastructure, including technologies like CCS, which demand substantial investments and have yet to reach full market maturity. In the cement sector, CCS is considered inevitable for reducing emissions, due to the sector's significant share of process emissions (Kögel et al., 2024). In contrast, without CCS, industrial emissions in the IA and ESABCC scenarios would increase to around 240 Mt CO_2e by 2040. Competition over CO_2 transport and storage infrastructure could emerge if CCS is not exclusively prioritized for industry but also considered for use in fossil fuel power generation or technical carbon dioxide removal (CDR) methods, such as BECCS or DACCS (Kögel et al., 2024).

Building block 5: Circular economy

In addition to these building blocks, **increasing material circularity, substitution and efficiency is essential for achieving required emission reductions**. It reduces the upstream raw material demand and leads to reductions of energy-related and process emissions in industry. Research by Material Economics indicates that implementing circular economy measures could decrease CO_2 emissions from materials production in the EU by 56% by 2050 (Material Economics, 2018). Moreover, increasing recycling and material efficiency has the potential to reduce emissions by over 400 TWh per year for the steel, cement, and chemicals sectors. It has also the potential to reduce hydrogen demand by 33% and limit the demand for CCS to just 47 $MtCO_2$ per year compared to a low circularity decarbonization scenario (Agora Industry, 2022).

According to ECNO, however, improvements in the area of circular economy in recent years were insufficient to contribute to the reduction targets in the industrial sector. There is persistent lack of advancement in circular material use, despite the goal of doubling it by 2030 compared to the 2020 level, as set out in the Circular Economy Action Plan (European Commission, 2020). Even though the EU has so far adopted various regulations and directives, many legislative procedures are likely to experience delays (Velten et al., 2024).

Figure 12 Progress and required change for boosting circular economy

2023 2024 ›	Historical data			Required change	
	Time period	Relative change p.a.	Absolute change p.a.	Benchmark	Absolute change p.a.
OBJECTIVE: Progressing towards net zero industrial GHG emissions with clean energy carriers					
ENABLER 2: Boosting circular economy					
Circular material use rate [%]	2017–2022 (Eurostat, 2024b)	-0.1% per year	-0.01%-points per year	23.4% by 2030 (EC, 2020h)	1.5%-points per year (2022–2030)
Resource productivity [PPS/kg]	2017–2022 (Eurostat, 2024p)	3% per year	0.1 PPS/kg per year	n/a	n/a

Source: Velten et al. (2024), p. 61

3.1.3 Key measures and policies

The EU's legislative framework for industrial transition spans multiple policies. The revision of the Emissions Trading System (ETS) Directive and the Carbon Border Adjustment Mechanism (CBAM) will provide a stronger carbon pricing signal for industrial enterprises to cut emissions. The revisions of Renewable Energy and Energy Efficiency Directives stimulate energy savings and uptake of renewable energy sources. The sector is also impacted by the revision of the Energy Performance of Buildings Directive (EPBD), including stricter requirements concerning lifecycle carbon footprint of buildings. Policy support for scaling up the production of the EU's cleantech and industrial decarbonization technologies is a part of the Green Deal Industrial Plan, with the Net Zero Industry Act (NZIA) and Strategic Technologies for Europe Platform (STEP) as headline sets of measures (which do not involve financial instruments). The Circular Economy Action Plan (CEAP) and the Industrial Carbon Management Strategy (ICMS) enhance circularity and the deployment of carbon capture and storage (or use) technologies.

Furthermore, Commission President Ursula von der Leyen announced in her political guidelines that the incoming Commission will introduce a **Clean Industrial Deal**. This initiative will serve as a key component to advance the European Green Deal in her second term. The Clean Industrial Deal will include several initiatives, such as an Industrial Decarbonisation Accelerator Act to boost infrastructure and industry investments, a European Competitiveness Fund, and lead markets for clean technologies (von der Leyen, 2024). The development of this Deal will be informed by an analysis on the future of European competitiveness, prepared in September 2024 by former ECB president and former Italian prime minister Mario Draghi (Draghi, 2024b).

Despite these new rules, significantly more ambitious action is required. The WAM scenario shows that even planned additional policies do not reduce emissions by 92%. To achieve these emission reductions, the following measures are indispensable: (1) Incentivize electrification, (2) Improve planning to allow for adequate infrastructure development, (3) Improve material circularity and material efficiency of products:

- **Incentivize electrification:** Electrification is key for reducing industrial emissions particularly from heat generation. However, for electrification to be cost-effective, electricity prices must be competitive with alternative energy sources, especially natural gas, which requires fast and cost-effective renewable capacity additions. Demand-side flexibility, enabling industries to incorporate thermal storage (power-to-heat) and adjust production levels based on available market signals, can help to reduce system costs for renewable-based grids while creating new revenue opportunities through active electricity market participation (Kögel et al., 2024).

Some progress towards easy and non-discriminatory participation in electricity markets has been achieved, e.g. through the implementation of the Electricity Directive which Member States must use to foster demand-side response. Furthermore, electrification depends on the proper infrastructure—not just renewable energy generation assets like solar photovoltaics and wind turbines, but also the transmission and distribution grids that facilitate system integration (incl. technologies such as batteries and demand-side management). However, many technologies required to reach the net-zero goal are not yet economically viable nor commercially available and thus need initial support to become available and competitive. This presents a significant bottleneck, not only with regard to advancing electrification in industry, but for the decarbonization of the industry sector overall (Kögel et al., 2024). An additional €22 billion will be required from 2025 to 2029 to effectively support clean tech initiatives in the EU (Humphreys, 2023).

- **Align key policy planning instruments:** Transforming the industry sector poses a significant challenge due to the complex adjustments required in existing physical infrastructure, including power grids, infrastructure for CCS as well as heat systems, and infrastructure for green hydrogen and recycled materials essential for a circular economy. Investments in emission reductions are typically feasible only if the necessary infrastructure is either already in place or will be established at the same time. Therefore, coordinated planning at both the EU and Member State levels, including integration into National Energy and Climate Plans (NECPs), is crucial to ensure the delivery of essential infrastructure.

  For infrastructure planning, the EU – in cooperation with national actors - must decide what is needed, what can be used in the long-term, and what should be prioritized, within and across national borders. Additionally, national policy planning may facilitate the development and connection of regional industrial clusters (and vice versa) (Kögel et al., 2024). Other key planning instruments include publications by the ENTSO-E (European Network of Transmission System Operators for Electricity) and ENTSO-G (European Network of Transmission System Operators for Gas), especially the draft joint scenarios published in May 2024. These will serve as the foundation for the 2024 Ten-Year Network Development Plans (TYNDPs) for electricity and gas. Unfortunately, the ESABCC states that the draft joint scenarios are not sufficiently aligned with the requirements set out in the TEN-E regulation (European Union, 2022), with the ACER guidelines (ACER, 2023) and previous recommendations issued by the ESABCC (ESABCC, 2022, 2023b).

  To ensure that the required infrastructure will be installed in time for the industry sector to transform, these planning instruments should be better aligned. The ESABCC recommends, among other steps, that all essential stages of the TYNDP and Project of Common Interest (PCI) processes—such as scenario development, system needs assessment, and Cost–benefit analysis (CBA), along with all intermediary steps—should be guided by and adhere to the EU climate targets. Also, the draft joint scenarios for up to 2030 rely on mostly outdated national data and do not incorporate the draft updated NECPs. Relying on these scenarios in their current form could lead to inadequate energy infrastructure planning and development. This may pose various risks for the EU, including exceeding the EU's GHG budget, higher import dependency, and increased energy and cost inefficiency (ESABCC, 2024).

- **Facilitate EU funding for net zero technologies:** To achieve the net zero target by 2050, industries must shift to alternative production technologies and processes that are competitive with traditional fossil-based methods. Thus, the industry sector's transition towards climate neutrality depends on the availability of critical clean technologies that facilitate the transformation of business models and value chains towards achieving climate neutrality.

  Although the EU ETS carbon price can support this transition by increasing the expected cost of fossil technologies, additional measures are needed to foster innovation and expand market adoption. Two potential strategies with the potential to complement each other are Carbon Contracts for Difference and green lead markets. Carbon Contracts for Difference help mitigate price uncertainty and investment risks by establishing an agreement between a government or institution and a stakeholder on a fixed carbon price for a specified period (Kögel et al., 2024).

  Moreover, EU funding, such as through the Innovation Fund, has to become more easily accessible and less risk averse (Martini et al., forthcoming). Accessing funding for the green transition in the EU is challenging, with a fragmented structure and a strong emphasis on capital expenditures (CAPEX). Funding for operational costs is frequently excluded, and financial support is usually subject to a lengthy, case-by-case evaluation of investment projects and associated costs (Draghi, 2024a). This makes accessing funding particularly difficult for SMEs (Martini et al., forthcoming). Measures should focus on how to de-bureaucratize the application process. Overall, to ensure sufficient financial resources for the transition to climate neutrality, EU funding must become more reliable and readily accessible.

- **Improve material circularity and material efficiency of products:** Reducing energy and resource consumption through enhanced material circularity and efficiency can lead to significant emission reductions and decrease dependence on imports. Mechanical and chemical recycling offer potential for reducing fossil feedstock. However, reuse and recycling routes are often not in place and economic and regulatory incentives are currently not strong enough to incentivize a shift from the status quo to more material efficiency in production. Regulatory frameworks, such as the Ecodesign for Sustainable Products Regulation and the revision of the Construction Products Regulation, are crucial for unlocking emission reduction potentials and promoting material efficiency in industries. They need fast adoption and full implementation. Further consideration of recycling quota as outlined in the circular economy action plan could support improvement of recycling rate (Kögel et al., 2024).

3.2 Transport

3.2.1 Emission trends in transport and required emission levels in 2040

In 2023, the share of domestic transport emission in overall EU emissions was 27% while international transport accounted for 8% of the EU emissions (EEA, 2023a). The transport GHG **emissions have increased by 19% between 1990 and 2023**. According to Member States' projections, existing polices and measures are expected to reduce GHG emissions from domestic transport to a level 4% above 1990 levels by 2030 (EEA, 2023a). **Until 2040, national projections estimate an 21% reduction with existing measures and a 39% reduction with additional measures compared to 1990 levels.**

Emissions from **international aviation** are projected to be 151% above 1990 levels with existing measures by 2040. With additional measures, emissions are expected to be 135% above

1990 levels. In **international maritime transport**, the increase of emissions until 2040 is projected to be less pronounced, with 35% above 1990 levels with existing measures and 32% above 1990 levels with additional measures.

These **projected emission cuts fall dramatically short of the required contribution** of the transport sector to achieving emission cuts of net 90% by 2040. The IA projects that domestic *and* international transport GHG emissions must be cut by 73% in scenario 3, while emissions from domestic transport fall by 82% (compared to 1990).[11] In either case, the cuts are more than double the amount that is likely to be achieved by additional measures. It should be noted that other scenarios project emission cuts at different levels in domestic transport. The CLEVER scenario, for example, projects domestic transport emissions to fall by 83% in 2040 (compared to 1990 levels), while the EU Gas Exit Pathway Scenario assumes reductions of 53%.

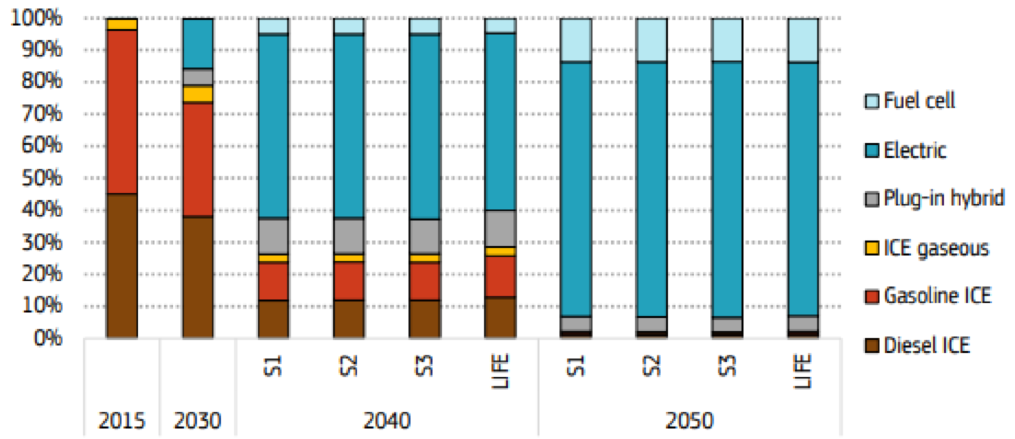
3.2.2 Key building blocks and challenges

To achieve emission reductions of 73% by 2040 in transport and 82% in domestic transport respectively, these building blocks are indispensable – according to all scenarios: (1) electrification of road transport, (2) shifting transport to cleaner modes, (3) reducing the GHG intensity of the fuel mix and increasing energy efficiency and (4) decreasing transport volumes.

Building block 1: Electrification of road transport

In all scenarios, **quick electrification of road transport** is the cornerstone for reducing domestic transport emissions. The IA projects that the share of internal combustion engine (ICE) **passenger cars** in the EU's car stock will decline from nearly 100% in 2015 to 26% in 2040 and 2% in 2050 while the share of battery-electric cars is expected to increase to 57-58% in 2040. According to the IA, shares of fuel-cell cars and plug-in hybrids are projected to increase to 5% and 11% respectively in 2040 as outlined in the following graphic.

Figure 13 Distribution of the EU passenger car stock per type of drivetrain



Source: PRIMES.

[11] Transport emissions drop by 69-78% compared to 2015, primarily due to large-scale deployment of electric vehicles in road transport in all scenarios, along with a further switch from fossil fuels to e-fuels and advanced biofuels in maritime, aviation and road transport in S2 and S3. Relative to 1990: CO_2 reductions of 62% in S1, 69% in S2 and 73% in S3 by 2040.

Similar to passenger cars, the total **share of ICE vehicles in the EU's heavy goods vehicles (HGVs) stock drops from virtually 100% in 2015, to 62-64% (depending on the scenario).** The share of battery-electric vehicles in the HGV stock increases to 24-25% in 2040, and the share of hydrogen HGVs grows to 12-14% in 2040. Liquid fuel demand by remaining ICE vehicles in 2040 is largely met by liquid biofuels, biogas, and e-fuels. The IA anticipates that the fleet of buses and coaches in the EU will undergo a similar transformation.

If the vehicle fleet in the EU does not undergo this transformation as quickly as estimated by the IA, transport emissions are very unlikely to be cut by 82% as projected in S3. Today, **the uptake of battery-electric vehicles (BEV) is significantly too slow.** Despite huge growth in recent years mainly due to CO_2-emission standards, BEVs represent only 1.7% of the European cars fleet in 2023 (EEA, 2023c; Eurostat, 2024b). To achieve IA projected increase to 57-58% BEV share in 2040, the uptake of BEV needs to accelerate significantly. In this context, it should be noted that the adoption of zero-emission vehicles (ZEVs) varies significantly among Member States. While Denmark reached a share of 7.1% at the end of 2023, in Poland it was only 0.2% (Eurostat, 2024c). Additionally, subsidy schemes in various Member States have been weakened. The lack of clear commitments to electric vehicles from several political players has added to uncertainty for manufacturers and consumers.

The electrification of road transport is a critical component for achieving the necessary emission reductions. **However, even if fully implemented, electrification will not be sufficient to cut road transport emissions on the required scale.** Although fewer new combustion engine cars may be registered in the future, these vehicles will remain in the fleet for many years. The challenge becomes particularly evident when comparing the lifespans of passenger cars across Member States. While the average lifespan of passenger cars in Western European Member States is around 18 years, it extends to around 28 years in Eastern European Member States (Held et al., 2021). As a result, ICVs will likely remain on EU roads well beyond 2050, when the EU is required to achieve climate neutrality.

Building block 2: Shift to rail and other cleaner modes of transport

All IA scenarios indicate a modal shift towards rail in both passenger and freight transport. According to the IA, **rail is the mode with the greatest projected increase in activity relative to 2015, featuring a growth of 65-67% in 2040** and 83-86% in 2050. [12]

However, today these **shifts of transport to rail are not occurring at the necessary speed and scale**. Instead, recent trends are moving in the opposite direction. The share of passenger and freight transport by road is increasing, while their share by rail is decreasing. The following table provides a detailed overview.

[12] At the same time, emissions from rail transport decrease by 62-78% in 2040 compared to 2015 and are almost fully eliminated by 2050, according to the IA. This reduction is driven mostly by large-scale electrification combined with a switch to zero- and low-emission fuels (i.e., advanced liquid biofuels, biogas, and e-fuels)

Figure 14 Progress and required change for enabling modal shift

2023 2024	Historical data			Required change	
	Time period	Relative change p.a.	Absolute change p.a.	Benchmark	Absolute change p.a.
OBJECTIVE: Progressing towards net zero industrial GHG emissions with clean energy carriers					
ENABLER 2: Enabling modal shift					
Share of passenger transport volume on road [%]	2016–2021 (Eurostat, 2023f)	2.2% per year	1.7%-points per year	75.2% share by 2050 (EC, 2018)	-0.4%-points per year (2021–2050) → **needs U-turn**
Share of passenger transport volume on rail [%]	2016–2021 (Eurostat, 2023f)	-4.1% per year	-0.3%-points per year	9.6% share by 2050 (EC, 2018)	0.1%-points per year (2022–2050) → **needs U-turn**
Share of freight transport volume on road [%]	2016–2021 (Eurostat, 2023e)	0.8% per year	0.6%-points per year	68.7% share by 2050 (EC, 2018)	-0.3%-points per year (2021–2050) → **needs U-turn**
Share of freight transport volume on rail [%]	2016–2021 (Eurostat, 2023e)	-2.1% per year	-0.4%-points per year	24.1% share by 2050 (EC, 2018)	0.2%-points per year (2021–2050) → **needs U-turn**

Source: Velten et al. (2024)

Moreover, motorways in the EU 27 plus Norway, Switzerland and the UK grew from 51,494 km to 82,493 km between 1995 and 2020 – marking an increase of 60% (Rudolph et al., 2023). In 15 of these countries, motorway lengths even more than doubled in the same period. **At the same time, the railway network in the EU shrunk by 7.5% between 1990 and 2022** (Eurostat, 2024d). 13,717 km of regional passenger rail lines have been temporarily or permanently closed since 1995 (Eurostat, 2024d). Between 1995 and 2018, investment in road infrastructure was 66 % larger than funding in rail. While the EU 27, Norway, Switzerland and UK spent €1.5 trillion between 1995 and 2018 to extend their road infrastructure, investment in to extend railways amounted to €931 billion (Eurostat, 2024d). This illustrates the necessity to shift investments to rail infrastructure,

Building block 3: Sustainable fuels

According to the IA, aviation (including both domestic and international air transport) is projected to **reduce its CO_2 emissions by 23-28% in 2040 relative to 2015** (the exact shares depend on the scenario). These reductions are mainly driven by the uptake of sustainable aviation fuels (SAF). The mandates in ReFuelEU Aviation are expected to increase the share of liquid biofuels in the total energy consumption increases to 24% in 2040, and the share of e-fuels grows to 10-13% in 2040. Hydrogen is projected to represent 0.2-1.1% of the aviation fuel mix in 2040.

Similar to aviation, the **IA assumes that emissions from shipping will be mainly reduced by replacing liquid oil products with other fuels**. For domestic navigation, the IA projects that liquid biofuels, biogas, and e-fuels will represent 76-77% of the total energy consumption in 2050, while electricity and hydrogen will account for 16%. For international navigation, the IA projects that the EU's fleet will transition from consuming almost exclusively liquid fossil fuels in 2015 to using less than 10% by 2040 and zero by 2050. By 2040, electricity, hydrogen, e-gas, biogas, e-liquids and liquid biofuels are projected to be nearly the only fuels in use.

However, it is uncertain whether **the projected uptake of zero or low emission fuels will be implemented in time and on the necessary scale, and whether it will have the necessary climate benefits**:

- **Scarcity of sustainable biomass, green electricity, and hydrogen:** The uptake of these fuels as projected requires the availability of sustainable biomass, green electricity, and hydrogen in large volumes on time. This is challenging given the scarcity of these resources (see above). All these resources will be increasingly employed in other sectors. For example, biomass plays an essential role in the bioeconomy, while green electricity is vital for decarbonizing transport, buildings, and industries. Diverting these feedstocks could cause indirect emissions if their existing applications start using less sustainable materials, including fossil fuels.
- **Zero rating of biomass fuels questionable:** Most of the emission reductions in aviation and shipping are based on the assumption that emissions from burning biomass can be rated as zero. This assumption is questionable. In theory, emissions from burning biomass can only be rated zero when the burned biomass regrows. However, burning biomass still releases greenhouse gases, adding to the atmospheric greenhouse gas concentration. In a changing climate, it becomes less likely that biomass will regrow at the required scale. In other words, burning biomass adds to the world's carbon debt, and it is uncertain whether this debt can be repaid, especially when natural sinks are declining.
- **Inefficient use of resources:** Using land for growing biofuel is inefficient and has led to land-use changes and deforestation. Growing biofuel crops is also likely to increase the use of pesticides, fertilizers, and water.

Building block 4: Decreasing transport volumes

Given the uncertainties surrounding the uptake of BEVs and the availability of sustainable fuels, decreasing the miles travelled by cars and trucks is particularly important (Plötz et al., 2021). Reductions through decreased transport volumes are difficult to quantify but they can be implemented quickly at significant scale. According to a study by the International Council on Clean Transportation, reducing dependence on cars in urban areas and improving freight logistics contributes 18% of the reductions under the All Out Scenario as shown in the following table (Sen et al., 2023).

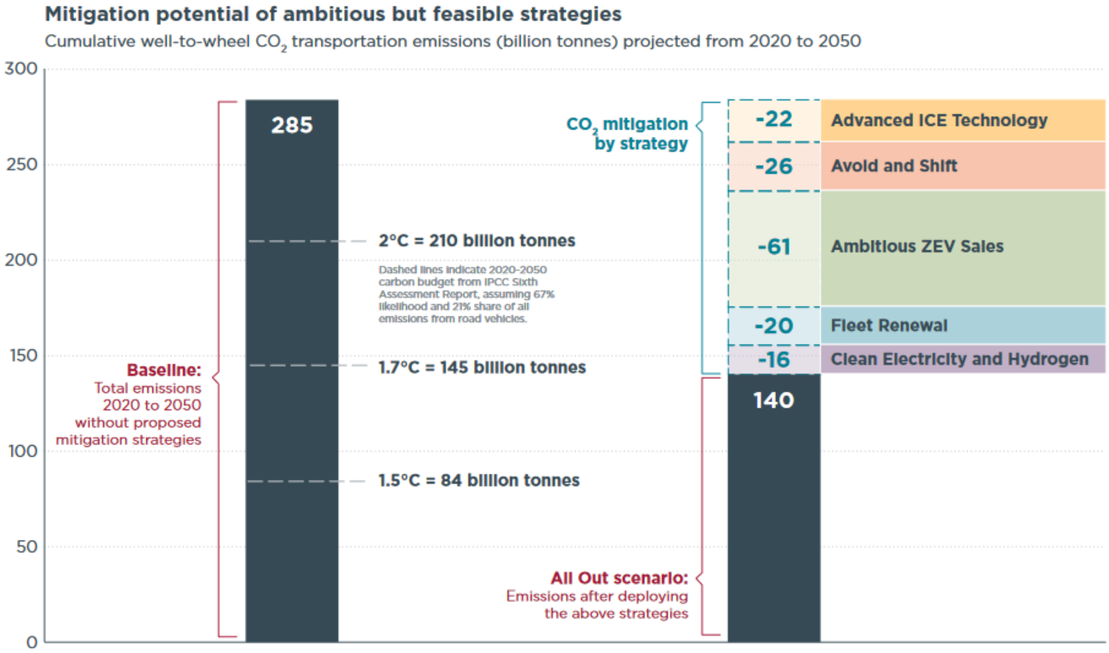


Figure ES-2. Cumulative well-to-wheel CO_2 emissions in the Baseline and All Out scenarios and relative mitigation potential of each strategy, with reference lines for vehicle carbon budgets through 2050 compatible with 1.5°C, 1.7°C, and 2°C targets. Data labels are rounded to the nearest Gt.

Along similar lines, the **CLEVER Scenario** assumes a reduction of total passenger traffic in the EU 27 by 21% in 2050 compared to 2019 would help reduce the sector's final energy consumption by 77% and its decarbonization by 2050.

However, **trends in transport volumes are moving in the opposite direction**. For example, the IA projects that total passenger transport will increase by about 27% under the three main scenarios. Even in the LIFE scenario, total passenger transport activity (excluding international navigation and extra-EU aviation) continues to increase, but at a slower rate than in the three main scenarios.

3.2.3 Key measures and policies

Against this backdrop, key measures for reducing **emissions from road transport include, in particular**:

- **Ending sales of ICEV by 2035:** Regulation (EU) 2019/631 sets CO_2 emission performance standards for new passenger cars and vans. According to the revised Regulation, all car and van manufacturers must comply with a 100% CO_2 emission reduction target from 2035 onwards. It is questionable whether the transformation of the vehicle fleet would be completed by 2050 if current emission standards were to be repealed as demanded by some political players. In turn, it is essential to maintain the new fleet emission standards. The ETS 2 alone will not deliver the end of ICE vehicles (see text box below).
- **Reducing and shifting road transport:** Given the extremely high speed of passenger car electrification assumed by most scenarios, the sector's transformation requires moderation of transport activity. Although politically contested, road transport cannot reduce emissions as required if avoiding transport does not become a central pillar of action. In urban areas, avoiding road transport for example through new urban planning

concepts, promotion of cycling and walking, car-free zones, and more attractive public transport are essential tools to achieve the necessary emission cuts.

- **Accelerate fleet turnover:** The longevity of passenger vehicles presents a significant challenge to the rapid electrification of road transport. Policy tools that reduce vehicle lifespans, such as scrapping programs or export restrictions, are likely to spark considerable debate. Less controversial approaches include incentives for retrofitting or technical requirements for new ICEVs that allow for easier retrofitting.
- **Energy efficiency of ZEVs:** One shortcoming of regulating CO_2 emissions is its failure to account for the energy consumption of zero-emission vehicles (ZEVs). There are currently no requirements for the energy consumption of ZEVs. The Ecodesign Regulation currently awaiting adoption, explicitly excludes motor vehicles from its scope. This exclusion does not reflect the fact that ZEVs are expected to be among the largest consumers of electricity in Europe. Consequently, new regulation should set energy-efficiency targets of ZEVs. These energy-efficiency targets should refer as much as possible to real-world consumption as monitored by OBFCM data. Even though improving energy efficiency of ZEVs has no direct effect on GHG emissions of the transport sector, the inefficient use of electricity by vehicles will continue to lead to considerable additional challenges in the decarbonization of the electricity supply and indirectly to higher GHG emissions and costs.

Key areas of action / measures for **shifting transport to rail include, in particular**:

- **Updating rail infrastructure:** The upgrading of rail infrastructure is central for shifting transport from road to rail. This upgrading requires political commitment and financial resources. These financial resources could be channelled by supporting the Member States in implementing the European Train Control System (ETCS), just as there is support for the implementation of the TEN-T corridors today. The support should be targeted and consider the different economic capacities of the Member States, as well as their transit traffic loads. A separate TEN-T Rail could take account of the special role of rail transport in the modal shift.
- **Alignment of pricing policies:** Pricing policies, such as mandatory toll systems, should prioritize rail transport over road transport.
- **Booking platforms:** Opening booking platforms is key to facilitating cross-border passenger rail transport. Political guidelines of the new Commission President highlight the importance of introducing such booking platforms.

In addition to measures increasing the availability of SAFs (see above), key measures for **reducing emissions from international aviation and shipping** include, in particular:

- **Reducing air travel:** Given the many limitations of zero or low emission fuels – the main tool to reduce emissions from aviation according to the IA –, moderating demand in air transport is indispensable if emissions are to be cut as required. In addition to increasing costs of air travel through taxes and other levies, reducing airport capacities through reformed noise protection rules or reduced landing and starting slots are other tools to cut GHG emissions. To reduce short distance flights, attractive rail systems are essential.
- **Expanding ETS coverage:** Coverage and ambition have been improved through the tightening of the ETS 1 and the adoption of the FuelEU Maritime Regulation and ReFuelEU Aviation Regulation. However, extra-EU aviation and 50% of extra-EU shipping is not covered by the ETS 1 and not covered by effective other international or national

measures. The same applies to non-CO_2 effects in aviation. Scheduled reviews of the EU ETS 1, ReFuelEU Aviation Regulation, and FuelEU Maritime Regulation are crucial for expanding coverage, enhancing ambition, providing additional incentives for climate-neutral fuels, and addressing potential policy implementations at the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO). Expanding coverage of the EU ETS 1 should also comprise ships below 5,000 gross tonnage which the Commission shall present a feasibility report on by the end of 2026 (Wissner & Cames, 2023).

- **Scope of 2040 climate target:** International transport should be included in the scope of the EU 2040 climate target to sustain the recently acquired policy momentum.

Will the Emission Trading System 2 deliver the required reductions in road transport?

The ETS 2 sets a cap for emissions from road transport, buildings and small industry installations at 1,040 million allowances in 2027. The cap will diminish by 5.35% annually, eventually reaching zero by 2044. In 2019, road transport accounted for 56% of the sectors included in ETS 2. The **Commission projects a CO_2 price between €48 and €80 if the EU cuts emissions by 55% by 2030.**

However, if the transport sector does not reduce consumption of fossil fuels much more quickly, prices could increase to between €200 and €300. **These price increases could possibly lead to energy costs exceeding the levels of 2022** (Keliauskaitė et al., 2024; Müller & Nesselhauf, 2023)**.** Such price increases are economically, socially and politically costly and could trigger interventions from governments, possibly by allowing more emissions and thus reducing the instrument's effectiveness.

Moreover, it remains unclear whether price increase at this scale would actually drive the required emission cuts. According to a study conducted in Germany, even a carbon price of 200 EUR/t CO_2 in 2023, escalating to 350 EUR/t CO_2 in 2030, **would result in emission reductions of only approximately 17% in the transport sector** (compared to a carbon price of 23 EUR/t CO_2) (Keliauskaitė et al., 2024). Given the limited uptake of EVs and sluggish progress in shifting to rail and other sustainable transport modes, households and businesses often lack viable alternatives to cleaner transport modes. Consequently, they cannot avoid increased energy costs and are unable to reduce emissions at required scale.

Like in the building sector, the **ETS 2 is only a complementary measure**. It is not the most important measure to cut emissions in the transport sector – if the EU intends to avoid socially and economically unacceptable price levels. Carbon pricing can support the shift to low-carbon modes such as rail, public transit or cycling, but it will not achieve the necessary greenhouse gas reductions on its own (Plötz et al., 2021). It cannot substitute other measures such as CO_2 fleet targets and quotas.

3.3 Energy supply

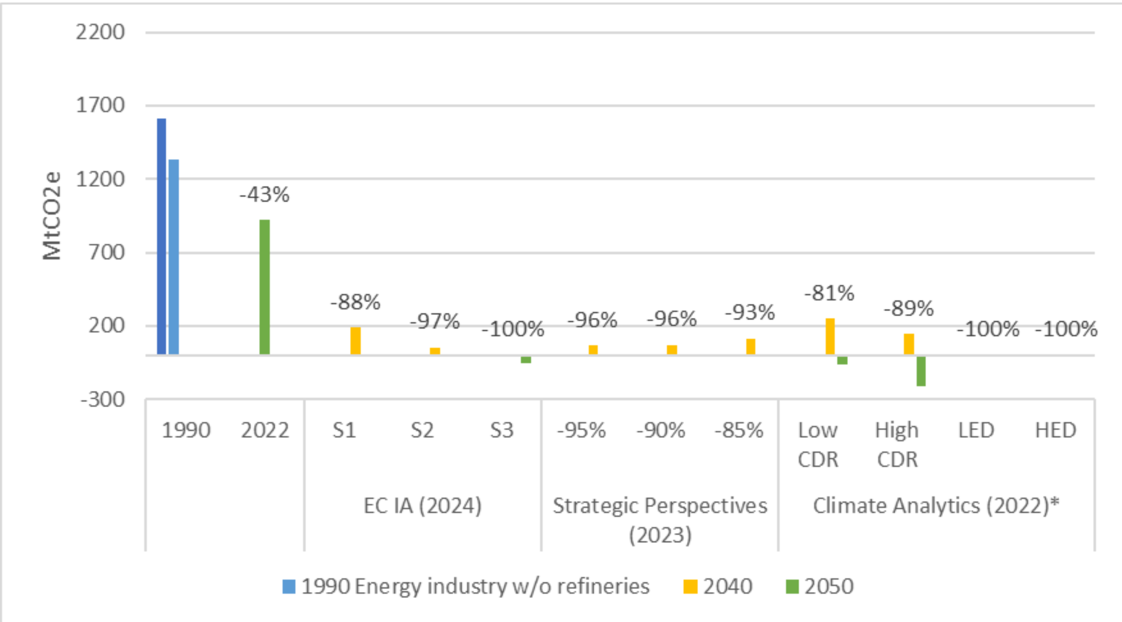
3.3.1 Emission trends in energy generation and required emission levels in 2040

With a reduction of 43% for the period 1990 to 2022, the energy supply sector has reduced emissions more than any other sector. It has made by far the largest contribution to EU's overall emission reductions. While emissions from the sector declined by only 8% between 1990 and 2005, they have since decreased at a much faster rate, with multiple annual reductions of more than 5% recorded over the last decade. In 2023, emissions from the sector fell by an unprecedented 19%. The shift from coal to natural gas in power generation has been an important factor. However, **the expansion of renewable energy has been the main driver in recent decades**. Without the deployment of renewable energy, emissions in the energy supply sector in 2022 would have been about 52% higher than actual emissions (own calculations based on (EEA, 2023a)).

Member State projections indicate a continuation of the past declining trends until 2030 and beyond. With existing *or* additional measures, projections assume a 64 to 68% reduction of emission from the energy supply sector by 2030. For 2040, projections indicate reductions of 79%, leaving the energy sector at an emission level of 344 Mt CO_2e. Barely any further reduction occurs after 2040 as effects of policies and measures are not as far-reaching, resulting in emissions in 2050 still at 327 Mt CO_2e (EEA, 2023a).

While these are very significant reductions, they fall short of making the necessary contribution of the sector to the EU reductions in the range of 90% net. According to the IA, net emissions from the energy supply sector fall by 88% in S1, or by almost 100% in S3 (if removals from BioCCS and DACCS are accounted for in this sector), while other scenarios assume even steeper reductions as indicated in the following graphic.

Figure 15 Net GHG emissions from the energy supply sector in 1990, 2022, 2040 and 2050 from different scenarios



Source: (Climate Analytics, 2022; European Commission, 2024a; Kalcher, 2023; Nissen et al., 2023)

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.

3.3.2 Key building blocks and challenges

To achieve emission reductions at this scale, IA scenarios assume that the following building block are in place:

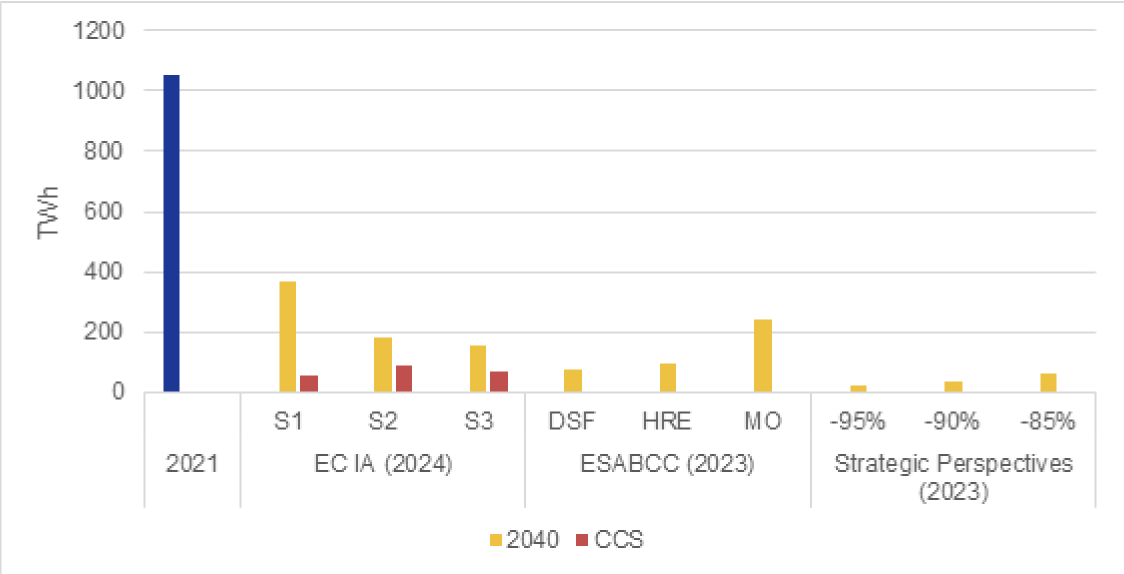
Building block 1: Expansion of renewable energy

According to the IA, the **expansion of renewable energy is the backbone** of decarbonizing energy supply sector. Section 2 discusses the needs and challenges to expand of renewable energies, including the expansion of storage capacities and grid.

Building block 2: Phasing out fossil fuel use for power generation

Phasing out of the use of fossil fuels in electricity and combined electricity and heat generation is another essential building block. The IA projects that installed fossil-fuel-fired capacities will decline from 324 GW in 2020 to 155-170 GW by 2040. Of this, 90% will consist of gas-fired units, with the remainder being oil- and coal-fired capacities. Carbon capture for power generation is expected to increase to 10-20 GW by 2040. The following graphic provides an overview of fossil-based electricity generation in 2021 and 2040.

Figure 16 Fossil fuel-based electricity generation in 2021 and 2040, and generation from units equipped with carbon capture from different scenarios



Note: DSF: demand side focus; HRE: high renewable energy; MO: mixed options. Sources: European Commission (2024), ESABCC (2023a), and Kalcher (2023).

In 2022, coal-fired generation accounts for 450 TWh (16%) of electricity generation and a share of 47% of EU-27 total GHG emissions from the energy sector[13]. Natural gas-fired generation accounts for 535 TWh (19%) of electricity generation and 245 $MtCO_2e$, and a share of 27% of EU-27 total GHG emissions from the energy sector, in 2022. **Although the ETS 1 is set to phase out fossil-based power generation, it is a challenge to implement this phase-out, in particular for Member States that even do not have plans to phase out coal before 2040.**

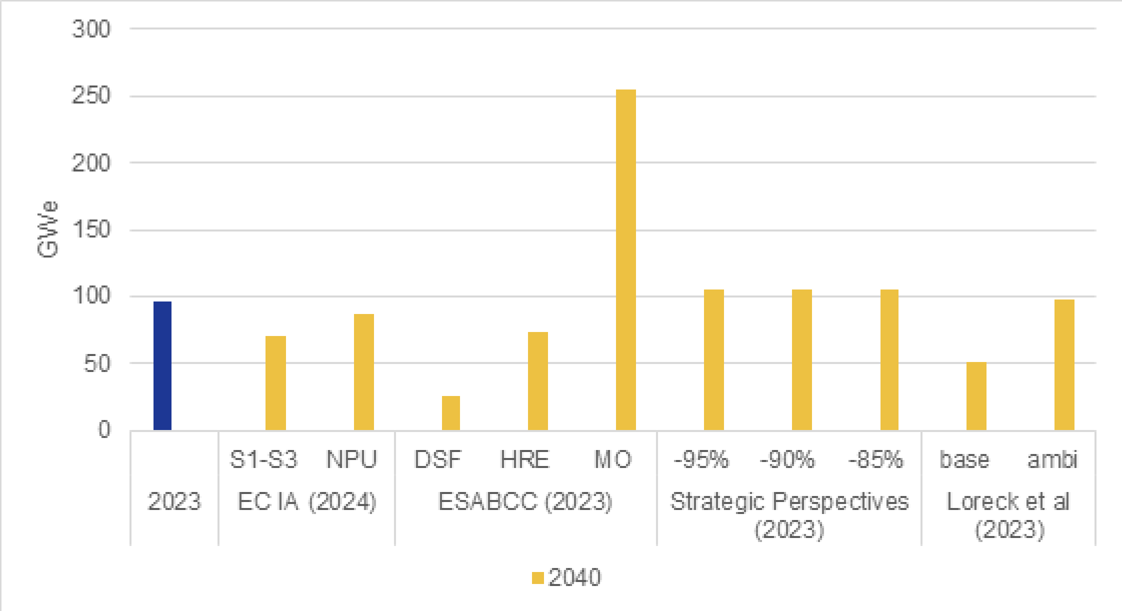
Building block 3: Nuclear power

Nuclear power is another option discussed to achieve the 2040 climate target. Based on an installed nuclear capacity of 96 GWe by the end of 2023, scenarios for the future development of the EU-27 energy sector expect large differences in nuclear power capacities in 2040. The DSF scenario assumes a sharp decline to around 27 GWe – corresponding to the

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

decommissioning of existing capacities after a technical lifespan of 50 years and without new capacities. Other scenarios, however, predict a significant increase in nuclear power capacity to 255 GWe by 2040. The IA projects that nuclear capacity in the EU will slightly decrease and be at around 71 – 88 GWe in 2040. The following graphics provides an overview of selected scenarios (Mendelevitch et al., 2024).

Figure 17 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 (2023a) are calculated by on reported electricity generation, assuming a utilization rate of 50%. Source. International Atomic Energy Agency (2024), European Commission (2024), ESABCC (2023a), Strategic Perspectives (2023) , and Loreck et al. (2023).

However, due to rising construction costs and lead times of 15 years or more to build new capacity, **nuclear power is unlikely to contribute reliably to decarbonizing the energy sector**. This also applies to sodium-cooled fast reactors (SFRs) which are labelled as 'novel technologies' although many of these concepts were already researched and developed during the initial phases of nuclear technology in the 1940s and 1950s and which already faced these challenges in the widespread adoption (Pistner et al., 2024). Even under very favorable conditions – such as long lifetime extensions for existing reactors and the construction of new plants on time – only around 100 GWe of nuclear capacity could be installed by 2040 (Loreck et al., 2023). Considering frequent delays in nuclear projects and escalating costs, these projections appear unrealistic. Moreover, historic Levelized Cost of Electricity (LCOE) from nuclear power plants are higher than those from opens pace photovoltaics or wind, both onshore and offshore. This trend is going to continue in the future (see e.g. Göke et al., 2023). In fact, even maintaining current capacity levels until 2040 would require significant lifetime extensions and the addition of over 15 GW in new capacity (Mendelevitch et al., 2024). In addition to these challenges, it should be noted that a substantial portion of the nuclear supply chain relies on Russia, raising concerns about the security and sustainability of the sector.

3.3.3 Key measures and policies

EU legislation is set to decarbonize the energy supply sector quickly. Emissions of the energy supply sector are mainly covered by the ETS 1, smaller installations under the ETS 2.

Emission caps will be zero by around 2039 (ETS 1) and 2043 (ETS 2) with current LRFs. Consequently, it is essential to reduce gross emissions from the energy supply sector by around 100 % in 2040 The ETS is a major instrument to drive this development and needs to be maintained.

However, the ETS does not automatically reduce emissions at this scale. To reduce risks of non-compliance with the ETS cap, additional complementary measures are important. Key complementing measures for reducing **emissions from energy supply include, in particular**:

- **Legally binding RES targets for the time after 2030:** The revised Renewable Energy Directive mandates a minimum of 42.5% renewable energy in EU total energy consumption by 2030, with an aspirational goal of reaching 45%. Legally binding targets for installed renewables capacities or RES-E electricity generation on Member States level could help create a clear framework for future investments. The continuation of the Renewable Energy Directive after 2030 remains a central element and driver for the expansion of renewable energies in the energy sector in the future.
- **Reducing energy demand:** 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. Such policies can also help to reduce energy demand in areas where the ETS price signal in itself is not sufficient to drive energy demand reductions.
- **Design of electricity markets:** With new large-scale electricity demand e.g., from hydrogen production, heat pumps and e-mobility, an increasing role for flexibility and a radical change in the nature of installed generation technologies (small, decentralized units vs. large-scale generation units on central grid nodes), the electricity market design also needs to coevolve and adhere to future system design. The unified proposal for the reformed Energy Market Directive sets the framework to organize needed backup capacities, RES-E installations and flexibility options. New capacities and/or flexibility is to allow phasing-out fossil fuel-fired capacities without jeopardizing security of supply or strong increases in electricity supply costs.
- **Expansion of power grip and energy storage:** 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 demand significant investments over the next 10-15 years. Success hinges on establishing an appropriate regulatory framework, integrated infrastructure planning, and providing incentives for resilient supply chains (European Commission, 2024a).

3.4 Buildings

3.4.1 Past emission trends and reduction requirements for 2040

Emissions from buildings account for 15% of overall EU GHG emissions in 2023. Since 1990, the **buildings sector's GHG emissions have been reduced by 38% in 2023**. This has been achieved through a combination of energy efficiency gains, increased use of renewable energies for heating, and a recent shift towards heat pumps and district heating.

Member States' projections from 2023 estimate a 55% reduction with existing measures and reductions of 65% with additional measures compared to 1990 levels by 2040 (EEA, 2023a). **The emission cuts projected with existing and additional measures, however, fall dramatically short of the required contribution of the buildings sector.** According to the IA, emissions from the buildings sector are cut by 92%.[14] Reductions of this scale are the sector's contribution to achieving the EU climate target of net 90% by 2040.

3.4.2 Key building blocks and challenges

The IA assumes that emission cuts at this scale will rest largely on the following building blocks:

- Emissions from buildings fall by 57% between 2022 and 2030.
- Energy savings in buildings reach 35-38% across scenarios in 2040.
- Fuel switching from fossils to renewable electricity.
- Expansion of green district heating.
- Moderating growth of floor area.

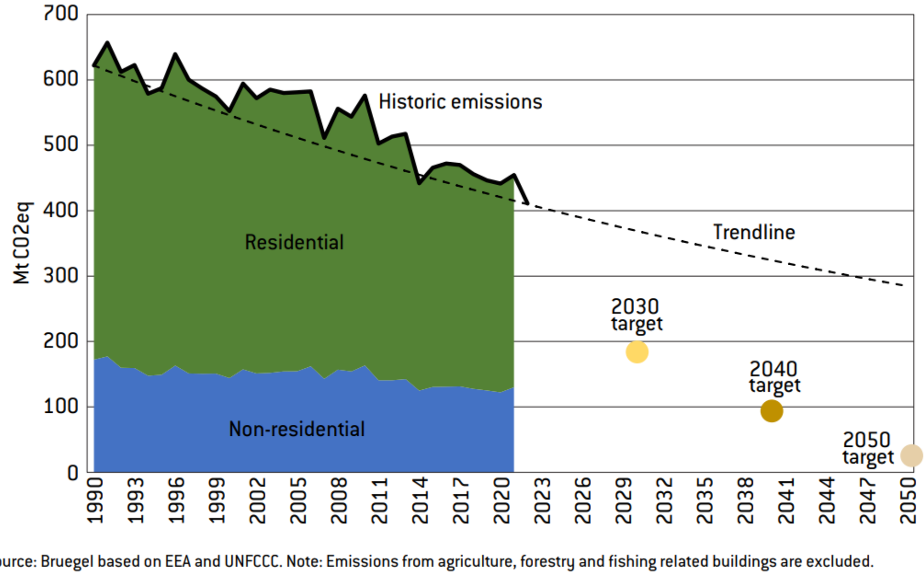
However, it is uncertain whether these building blocks will be in place on time. **There are various caveats that need to be addressed:**

- **Halving building emissions by 2030:** The implementation of the 2040 target critically hinges on achieving the 2030 targets. According to the IA, direct CO_2 emissions from buildings experience a rapid decrease already in this decade, from about 450 $MtCO_2$ in 2015 to 190 $MtCO_2$ in 2030, i.e., 57%. To achieve such drastic cuts in very short periods of time, it is crucial to fully implement the recently adopted 2030 framework.

  However, according to Member States' national projections from 2023, existing policies and measures will reduce GHG emissions from buildings to a level 42% below 1990 levels by 2030 (EEA, 2023b). For comparison, it should be stressed that the emissions from the buildings sector fell by 27% over the last 32 years. Now they are projected to decrease roughly by the same amount over eight years. A study by Bruegel assumes that annual reductions must almost triple (Keliauskaitė et al., 2024). It should also be noted that the IA's steep declines in emissions from the buildings sector are based on a reduction of gas consumption by 64% from 2015 to 2030. Such reductions in gas consumption in such a short period are unprecedented.

Figure 18 Fossil-fuel use in heating and cooling in residential and non-residential sectors, emission reductions, 1990-2022, Mt/CO_2eq

[14] The Commission's recommendation is in the middle of other scenarios, which assume GHG emissions reductions of between 88% and 99% by 2040.



Source: Keliauskaitė et al. (2024)

- **Energy efficiency:** Strongly improved energy efficiency of buildings is another essential building block for achieving required emission cuts. Improved energy efficiency in existing buildings requires a much higher renovation rate than current trends. The IA assumes that the residential sector will double the building shell renovation rate over the course of this decade – from 0.9% in 2020 to 2.2% in 2030. For the decade after 2030, the IA projects a renovation rate of 1.9%. The Buildings Performance Institute Europe (BPIE) estimates that an even higher annual deep rate of 3% of all renovations – is required to achieve the 2030 targets (BPIE, 2022).

  However, regardless of patchy data, renovation rates in Member States have been well below these rates. The current rate of energy-renovation in the EU is 1% annually, and the rate of deep renovation stands at 0.2% overall (BPIE, 2022). As a result, renovation rates need at least to double. Currently, no Member State implements such renovation rates. Demand for affordable housing, the lack of skilled labor and financing render the required renovation rates very challenging.

- **Fuel switching:** Fuel switch from fossil fuels to renewable energy is another central building block for achieving the required emission cuts. While in 2015 fossil fuels accounted for almost 50% of the final energy consumption in buildings, its share will account only for 9-15% under the S1-S2-S3 scenarios. According to the IA, the consumption of oil and coal in buildings will be almost entirely phased out in all scenarios by 2040. By 2050, natural gas is phased out from buildings as well.

  This fuel switch is largely driven by electrification. Electricity becomes the backbone of heating and cooling the buildings sector. Electrification of space heating and cooling is driven by the uptake of heat pumps. The IA projects that heat pumps will reach more than 80 million in 2040.

  However, the EU is off track to meet its aspiration of installing 60 million heat pumps by 2030. A recent report from the European Heat Pump Association (ehpa, 2024) shows that in 2023, 3.02 million heat pumps were sold – a decrease of 6.5% compared to 2022. If annual sales remain at the level of 3 million, only around 45 million heat pumps will be installed by 2030 – about 25% short of the EU's aims for 2030. To install 60 million, the annual deployment rate needs to be increased to 5,6 million. Given high electricity prices, unstable public support schemes in various Member States and the lack of skilled labour (European Commission, n.d.b)[15], such annual deployment rates are very challenging (Gibb & Rosenow, 2024).[16]

- **District heating:** If decarbonized, district heat could be another key building block to decarbonize buildings (Directorate-General for Energy (European Commission) et al., 2022)[17], particularly in urban areas. Scandinavian and Baltic countries demonstrate the potential of district heating for achieving large emission cuts in the building sector. Unlike other Member States, these countries combine high shares of district heating and cooling in the building sector[18] with a high share of low-carbon fuels in district heating, making them the EU's "best performers" in heating and cooling decarbonization, with more than a 45% RES-H share (Directorate-General for Energy (European Commission) et al., 2022). District heating could meet more than half of EU heating demand (Keliauskaitė et al., 2024).

  Despite this potential, the IA projects that district heating increases its share of total energy demand in buildings only slightly, reaching approximately 11% in 2040. The IA does not substantiate this projection in more detail. It should be noted, however, that the share of district heating in several Member States is below 1%. Additionally, district heating production predominantly comes from cogeneration plants (63%) (Directorate-General for Energy (European Commission) et al., 2022). Two-thirds of this supply is generated using fossil fuels, mainly natural gas, while biomass, biofuels, and renewable waste constitute the primary low-carbon sources, accounting for about 27%. Moreover, larger shares of district heating entail that the total number of dwellings connected to district heating increases. This requires significant investment in infrastructure and improvements in energy efficiency of buildings.

- **Biomass projected to have declining importance and its demand to be limited:** Biomass is the dominating source for renewable heating in Member States, reaching more than 80% in some Member States (Braungardt et al., n.d.). In 2015, biomass accounted for 17% of residential energy consumption in the EU. However, the IA does not expect biomass to play a major role in achieving necessary emission cuts. It projects that the consumption of biomass will almost halve between 2015 and 2050 – at the same pace as total energy consumption in the residential sector. For the services sector, the IA assumes that the share of biomass remains stable but a very low level of around 3%. Moreover, the demand in biomass needs to be reduced, as discussed above.

- **Moderating growth of floor area:** The IA projects that the total floor area of households will grow by 21% and 26% in 2040 and 2050, respectively, compared to 2015, although the population in the EU is projected to remain stable until 2050. This growth is driven by two factors: (1) a decline in the average number of inhabitants per household and (2) an increase in the average size of houses.

[15] 750 000 more installers are needed and at least 50% of existing installers will have to be reskilled to work with heat pumps (European Commission, n.d.).

[16] EU will need around 60m heat pumps by 2030 to get on track for net-zero by 2050, according to modelling from the European Commission. As of the end of 2023, there were roughly 23m heat pumps across the 21 EU nations included in the data. This means that an average of around six million annual installations would be necessary until 2030, in order to hit the 60m milestone. The current pace of growth, however, is closer to 2.5m per year. In 2023, trends went in the opposite direction to what would be required. There was a general downturn in sales by about 5% compared with a year earlier, as shown in the figure below (Gibb & Rosenow, 2024).

[17] Renewable energies sources (biomass, geothermal, biogas, solar thermal, ambient energy, and renewable electricity) and waste energy sources (power generation, industrial production, tertiary buildings, data centres, and underground railways) can be integrated in DHC systems, rendering them potentially climate neutral.

[18] Sweden 50%, Denmark 46%, Lithuania 40%, Estonia 39%

If the EU aims to achieve the required reduction in the building sector, it is essential to discuss to what extent it is realistic to reduce emissions by 92% while the total floor area grows as projected. A significantly larger floor area is more likely to increase overall emissions, even though new buildings generally emit considerably less than old buildings. A larger floor area will also absorb resources, funding, and labor needed to decarbonize the existing building stock. It is also likely to conflict with land and conservation objectives.

3.4.3 Key measures and policies

As a result, the **building sector is nowhere near achieving the necessary emission reductions**. The sector needs urgent attention. Implementing additional measures to achieve the projected 62% reduction by 2040, as outlined in the WAM projections, is already a challenge. Achieving reductions of 92% is a different order of magnitude.

Legislation critical for the decarbonization of the building sector have been revised recently. The revised ETS directive sets a cap on emissions from road transport and buildings. Starting in 2027, the number of emission allowances will decrease linearly by 5.10% of the reference quantity annually, and from 2028 onwards, by 5.38%. The total reduction in the buildings, transport and small industry sectors by 2030 should reach 43% compared to 2005 levels. By 2040, emissions from buildings are expected to be reduced by 86%. By 2044, no more allowance will be available in the ETS 2. This linear reduction path will constantly increase prices for heating with fossil fuels.

The **EPBD was recast in late 2023**, establishing binding targets to decrease the average energy performance of national residential buildings, enhancing standards for new buildings to be zero-emission, and requiring the calculation of whole life-cycle carbon for new buildings. The recast EPBD also gradually introduces minimum energy performance standards for non-residential buildings and mandates a gradual phase-out of boilers powered by fossil fuels, starting with the end of subsidies for stand-alone fossil fuel boilers from 1 January 2025.

The Energy Efficiency Directive (EED), another law critical for the decarbonization of the building sector, was also revised in 2023. The new EED increases the annual energy savings requirement from 0.8% (current) to 1.3% (2024-2025), 1.5% (2026-2027), and 1.9% from 2028 onwards. It introduces an annual energy consumption reduction target of 1.9% for the public sector as a whole and extends the annual 3% building renovation obligation to all levels of public administration. Additionally, it mandates that Member States prioritize vulnerable customers and social housing within the scope of their energy savings measures.

The **revisions of these directives are steps in the right direction, but they are insufficient to cut emissions by 92% by 2040**. To achieve emission cuts at this scale, the following measures and policies are instrumental:

- **Minimum energy performance standards (MEPS):** MEPS have been included in the recast EPBD, but not for residential buildings. Most scenarios show that for achieving climate targets in the buildings sector it is essential to also establish MEPS (and the corresponding renovation obligations) for residential buildings. Targeting and renovating the worst performing buildings (WPD) first not only has the greatest potential for reducing greenhouse gas emissions but is also the most economical way of achieving this. Against this backdrop, it is essential that a new EPBD includes not only more stringent MEPS but also covers residential buildings.
- **Higher shares of renewable energies in the building sector:** The EU heating and cooling sector is still largely based on fossil fuels. Renewable energy only provides 22%

of gross final energy demand. With an average increase of the renewable share in heating and cooling of less than 1% per year over the past 15 years, the pace of phasing out fossil fuels in the heating and cooling sector needs to dramatically increase to achieve climate neutrality by 2050. For this purpose, current RED targets for 2030 are insufficient. In the decade after 2030, the level of ambition would have to rise threefold from the annual target amount of 1.1% in 2026 to 2030 to an annual increase of 3.4% for the 2030 to 2050 period.

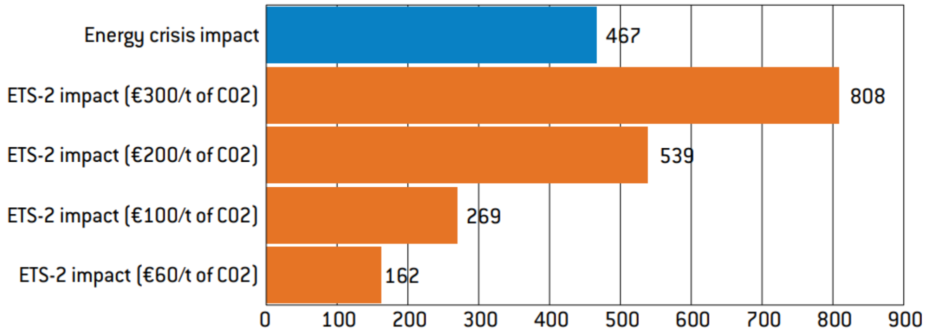
- **Ecodesign Directive:** New boilers can have a lifespan of 20-25 years; they would still be in operation in 2050 when the EU is obliged to achieve climate neutrality. For this reason, it is crucial to stop installing new fossil fuel boilers as soon as possible. The Ecodesign Directive is one possible vehicle to phase out stand-alone fossil boilers by setting efficiency requirements exceeding 100%. However, a Commission proposal to de facto end the sale of stand-alone fossil fuel boilers EU-wide by September 2029 was rejected by Member States.
- **EED:** Achieving the targets outlined in Article 4 of the EED demands considerable additional efforts from Member States, particularly in the buildings sector. The Commission should formulate robust and clear guidance for Member States regarding ambitious implementation, ensuring the availability of the corresponding financial support. Heat planning regulations as set out in the recast EED present an important tool for establishing a comprehensive approach to the buildings sector transformation on a district and municipal level. It is important that Member States fully implement the provisions as specified in Art. 25 of the EED.
- **National building renovation plans:** Phasing-out fossil fuels by 2040 is stated as a non-binding objective in the EPBD. Member States are to provide details on the "transformation of existing buildings into zero-emission buildings by 2050" in their national building renovation plans. These plans need to be consistent with the objective of full decarbonization by 2050. Making phase-out plans binding in the next EPBD revision cycle would be an option to further strengthen the ambition level with regard to the 2040 targets.
- **More efficient uses of existing building stock and moderating growth in floor area:** Given the many constraints in the building sector to reduce emissions at the required scale and speed, it is important to begin a broad and honest discussion on the use of existing building stock and on moderating projected growth in the floor area. There are many examples where existing buildings have been put to better uses, e.g. through converting empty office building in residential buildings, but these examples have not been scaled up and they have not shaped a politically difficult matter.

ETS alone unlikely to deliver the required emission reductions in the building sector

As discussed above, the ETS 2 requires that emissions from buildings decrease by 5.35% annually, eventually reaching zero by 2044. The Commission (2021) estimates the price could range between €48 and €80 if the EU plan to cut emissions by 55 % by 2030 compared to 1990 is fully implemented.

However, unless emissions covered by the ETS2 are cut more quickly, prices could reach €200 or even €300 (Günther et al, 2024; Müller & Nesselhauf, 2023). An ETS 2 price of €200, for example, would increase the energy bills of the average EU household with a gas boiler by more than they rose during the 2022 energy crisis (Keliauskaitė et al., 2024).

Figure 19 Yearly financial impact (additional heating cost in EUR) on the average EU household with a gas boiler



Source: Bruegel. Note: the figure does not include support to households that might be provided by governments through the use of ETS2 revenues in case of high ETS2 prices.

Economic theory suggests that such carbon prices could deliver the required emission cuts, but political reality is different. Most households have only limited options to cut emissions to avoid such a price increase. Demand reduction (e.g. lower room temperature) has some potential and is easily implementable, refurbishing homes is not possible for tenants or if the owner cannot afford the required investments. According to a study conducted in Germany, emission reduction in the building sector **would fall by only around 14% with a carbon price of 125 EUR/t CO_2** (Keliauskaitė et al., 2024).

The **next cycle of directive revisions needs to further increase the level of ambition.**[19] This will be challenging. High investment costs, shortage of affordable housing in many Member States, the long lifespans of heating systems and other building components, make achieving the required emission reductions in the building sector challenging – economically and politically. Low renovation rates and the persistent high market share of fossil fuel heating systems add to the challenge. Crucially, measures to cut emissions from buildings have become politically much more contested. Once a technical discussion among experts, they are now often part of political identity and identity politics. It is also problematic that some of the necessary measures have recently been negotiated but failed to receive the required support.

3.5 Agriculture

3.5.1 Past emission trends and reduction requirements for 2040

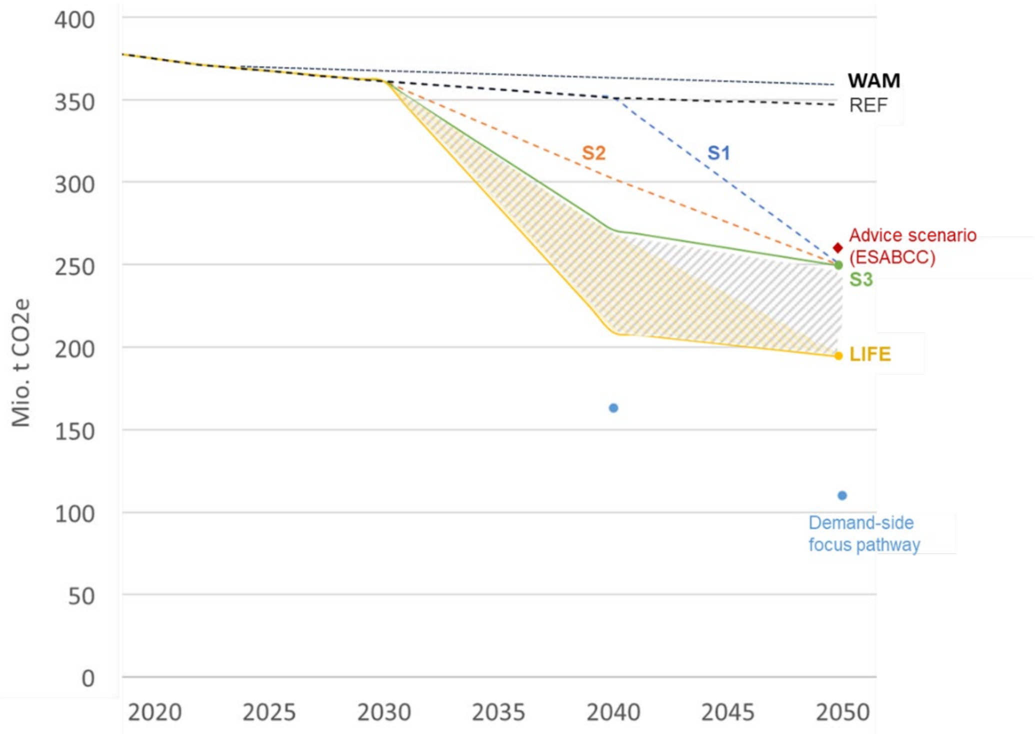
Emissions from agriculture account for 10% of EU GHG emissions in 2022 (EEA, 2024). Emissions from agriculture declined by 24% between 1990 and 2022. Since 2005, **emission reductions have remained nearly stagnant** (EEA, 2023b). While livestock emissions remained relatively stable, emissions from soils increased slightly in the last 10 years by about 4% (on a three-year average).

These **trends are not expected to change significantly until 2050.** If additional measures are implemented (WAM), a stabilization compared to the level of 2023 is expected until 2030, which is a reduction of 6 % compared to 2015. Until 2040 a further reduction of two percentage

[19] The revised directives are compromises that were significantly weakened during the legislative process. For example, the Commission's initial proposal for the minimum energy performance standards under the EPBD was more ambitious than the Council's position and the MEPS of the finally adopted EPBD. Similarly, the Commission's proposal for the EED was more ambitious than the Council's general approach and the adopted EED. While the Council supported the energy efficiency targets of the Commission's proposal, it called for national contributions to be non-binding and increased the annual ESOs more gradually, rising in steps from 1.1% (2024-2025) to 1.5% (2028-2030).

points is projected, and two additional percentage points until 2050, adding up to a reduction of 10 % compared to 2015. These emission cuts fall significantly short of what the IA and EABCSS have outlined as necessary contribution of the sector to achieving emission cuts of net 90% by 2040. The IA projects GHG emissions to be 30% lower than in S 3 (all compared to levels in 2015). In the LIFE scenario, emissions are cut by 46%.

Figure 20 Broad range of agricultural GHG reduction pathways within different scenarios

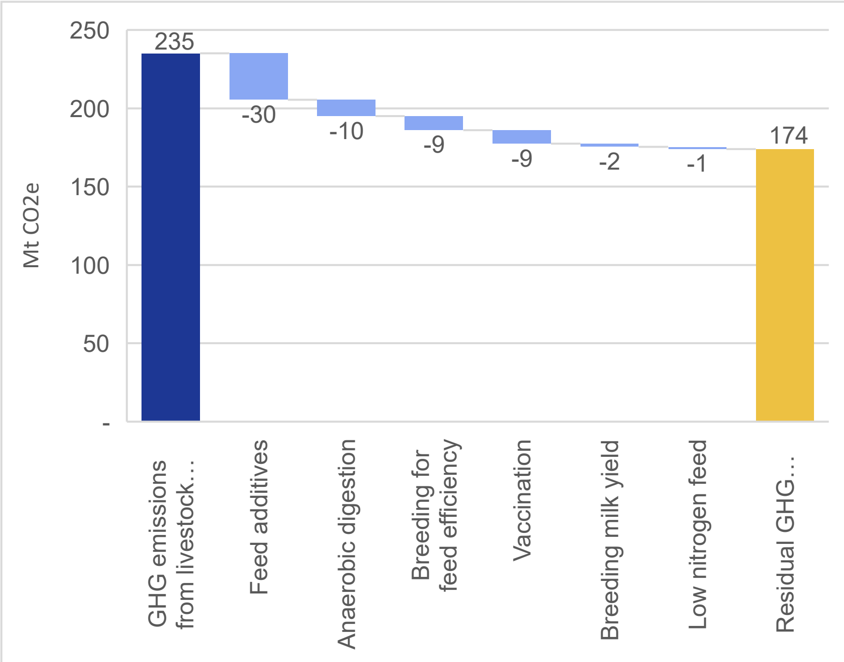


Source: Own figure, based on European Commission (2024b) and ESABCC (2023a).
Note: S3: full adoption of technical measures; LIFE scenario: with 25% shift to optimal plant based diet in 2040, food waste reduction, more sustainable food production; Demand-side focus pathway: shift to optimal plant based diet in 2040 for EU citizens

3.5.2 Key building blocks and challenges

It is an important characteristic of the agriculture sector that (1) livestock emissions consistently make up around two-thirds of all emissions, and (2) technical mitigation measures have only a limited potential to reduce these emissions. The following graph, illustrating data of the Joint Research Centre of the European Commission, provides an overview of the **limited technical potential to reduce livestock emissions**.

Figure 21 Technical mitigation potential of livestock emissions



Source: Own figure in (Scheffler & Wiegmann, 2024), based on (Joint Research Centre (European Commission) et al., 2020). Note: Only direct CH_4 emissions from enteric fermentation and CH_4 and direct N_2O emissions from manure management are included. Emission reductions are scenario assumptions on maximum feasible implementation and mitigation potential of the technical measures. This is in some cases not 100% of the technical potential, but includes already an assumption on what is feasible, e.g. only farms with more than 200 livestock units are eligible for anaerobic digestion of manure in biogas plants.

Accordingly, technical mitigation options, such as feed additives, can reduce livestock emissions only by around 25%. **The remaining 75% can only be reduced by lowering livestock numbers or shifting towards less emission-intensive animals[20].** These emission reductions are only attainable through demand-side changes, such as reducing animal product consumption, coupled with corresponding reductions in livestock numbers on the supply side. The impact of demand-side changes becomes evident the LIFE scenario proposed by the European Commission and the Demand-side focus scenario outlined by the ESABCC.[21] The extent of demand-side modifications, combined with the adoption of technical mitigation options, could lead to emission reductions ranging from 44% to 56% compared to the 2022 baseline. It should also be stressed the long-term impacts of feed additives on human and animal health as well as the environment are uncertain (Honan et al., 2021). It is also unclear to what extent these measures to reduce CH_4 emissions from enteric fermentation can reduce emissions over the long term (Shukla et al., 2022).

It should be noted that the **reduced livestock is not only an essential building block for achieving the 2040 climate target, but it is also instrumental for increasing removals from natural sinks (and foster biodiversity)**. According to the IA, the LIFE scenario produces a higher LULUCF net removal, because agricultural land is converted into high-diversity landscape elements covered with buffer stripes, hedges and other landscape elements or provided

[20] Which is capable for meat but limited for milk production

[21] A recent study by Agora Agriculture confirms these findings. According to this report, “a 50% reduction in the consumption of animal products by 2045 leads to a similar decrease in livestock production”. Agora Agriculture (2024): Agriculture, forestry and food in a climate neutral EU. The land use sectors as part of a sustainable food system and bioeconomy. https://www.agora-agriculture.org/fileadmin/Projects/2024/2024-09_EU_Agriculture_forestry_and_food_in_a_climate_neutral_EU/AGR_336_Land-use-study_WEB.pdf

for carbon farming activity (afforestation). This allows for a considerable increase in the forest sink by around 30 $MtCO_2$-eq and decreases net emissions on agricultural land by around 15 $MtCO_2$-eq.

Moreover, **reduced livestock numbers are also indispensable to achieve other critical political objectives**:

- **Land use and biodiversity:** In comparison to S2 and S3, the changes in the food system outlined in LIFE lead to additional forest land of around 4.0 Mha. It also results in more high-diversity landscape features, such as buffer stripes, hedges, fallow land and other natural vegetation (+6.8 Mha), as well as rewetted organic soils (+0.3 Mha). The IA projects that agricultural areas with a high value for biodiversity and ecosystems will increase by 14% within the EU compared to S2 and S3. On a global scale, too, livestock production is one of the leading causes of biodiversity loss (Parlasca & Qaim, 2022; Scheffler & Wiegmann, 2024).
- **Food prices and security:** About 90% of soy and two-thirds of the cereals consumed in the EU are used to feed animals to produce meat, eggs, fish, and dairy (European Commission, n.d.a; Scheffler & Wiegmann, 2024). This practice is driving food inflation and insecurity. To address this, it is crucial to significantly reduce our meat and milk consumption - by 75%. The war in Ukraine and the resulting shortages in international cereal grain markets further emphasize the need to feed less grain to animals to support food security (University of Bonn, 2024).
- **Water consumption**: Animal-sourced foods are responsible for more than one-quarter of humanity's freshwater footprint. About 20% of global nitrogen and phosphorus applications are attributable to animal-sourced foods, contributing to the pollution of, inter alia, aquatic ecosystems (Parlasca & Qaim, 2022).
- **Health**: Various studies show that reduced meat consumption has significant health benefits. For example, a recent study of the US adult population estimated the potential impact of reducing consumption of processed and unprocessed red meat on the incidence of type 2 diabetes, cardiovascular disease, colorectal cancer and mortality (Kennedy et al., 2024). Accordingly, a 30% reduction in processed meat and unprocessed red meat intake could lead to 1 073 400 fewer cases of type 2 diabetes, 382 400 fewer cases of cardiovascular disease, 84 400 fewer occurrences of colorectal cancer, and 62 200 fewer all-cause deaths during the 10-year period.

It is important to stress that the LIFE scenario **does not envisage a radical reduction of livestock but a modest one according to the following table**:

Table 4 Livestock population in the EU

[in Million LSU]	2020	2040	
		S1, S2, S3	LIFE
Cattle	54.4	51.1	37.0
of which dairy cows	*20.9*	*19.2*	*17.3*
of which suckler cows	*9.4*	*8.9*	*3.2*
of which other cattle	*24.0*	*23.1*	*16.6*
Pigs	35.4	34.9	25.5
Poultry	7.6	6.8	5.3
Sheep and goats	13.9	15.0	12.1

Source: (2024b)

3.5.3 Key measures and policies

In view of the above, the agricultural sector is falling far short of the required reduction in emissions. The sector needs urgent attention during the EU's next political cycle. Even with additional measures the sector is set to reduce emissions by only 7.4% by 2050, while the IA assumes reductions of 30% in S3 and 46% in Life. Such reductions are of a different order of magnitude and require new and much bolder approaches.

Given the limited technical mitigation options, the **reduction of livestock is one of the key building blocks for achieving the required reduction of agricultural emissions** (Clark et al., 2020). As stated in the IA, reducing food loss and food waste, dietary shifts away from animal protein and use of land resources for nature-based mitigation solutions are "***unavoidable*** to get to climate neutrality". Measures to be considered for dietary changes and reducing livestock include, for example:

- **Taxation on meat and dairy products:** Taxing is one option to reduce consumption of meat and dairy. Costs are one of the most important reasons for reducing meat and dairy consumption – in addition to environmental and health concerns (Kemper et al., 2023).[22] National tax laws can levy taxes on these products – e.g. on GHG emission of animal-based products or Value Added Tax (VAT) rates for meat and dairy that are higher than for other foods. Taxation through EU legislation is another option which means that EU legislation sets requirements for national tax rules, including minimum tax rates. These already allow higher tax rates for meat and milk but are not binding. Taxes on meat tend to be socially regressive but the effect on inequality is mild and can be dampened by using meat tax revenues for lowering value-added taxes on fruit and vegetable products, for example (Klenert et al., 2023).

  Regardless of these benefits, taxation of meat and dairy products is politically contested. The adoption of EU taxation rules also requires unanimity in Council, making the adoption of impactful rules difficult. Moreover, it must be ensured that taxes actually increase the prices of meat and dairy products, instead of decreasing margins of farmers. Given the imbalances in market power between retailers and farmers, this is challenging.

- **Quota for livestock per hectare:** Another option to reduce livestock is to limit the absolute number of animals. Examples are the former EU milk quota or tradeable production rights for pigs as well as buy-out schemes to cap the total number of animals in the Netherlands. Additional environmental regulations help to limit the livestock density per hectare at farm level or in a region to avoid concentration in favored areas.

  However, limiting livestock density as a stand-alone measure does not guarantee reduction in absolute number of animals, as there are many regions in the EU with low livestock where it would be possible to further increase the number of animals. Unlike taxation, this option addresses the issue of meat and dairy exports from the EU, but it does not address meat imports.

- **Animal welfare rules:** Various EU rules regulate animal wellbeing on farms. These rules include requirements for stocking density for hens, pigs or calves. Stricter stocking density rules could *de facto* help reduce the number of livestock.

[22] As a prominent example, Denmark intends to introduce such tax. According to a political agreement between the Danish government and various stakeholders, farmers will be taxed 300 Danish kroner ($43) per tonne of CO_2e from livestock in 2030, increasing to 750 kroner ($108) in 2035. However, farmers will be entitled to an income tax deduction of 60%, reducing the actual levy per tonne to 120 kroner ($17) initially, increasing to 300 five years later.

- **ETS 3:** There is considerable debate on an ETS in the agricultural sector. Although several questions remain unanswered regarding practical implementation, it is conceivable that certain segments of the agricultural sector could be covered by an emission trading scheme.

  However, an ETS 3 also raises many concerns. If prices alone are to incentivize the necessary emission cuts, they must be high enough to encourage reduced consumption of animal products and reduce herd size of ruminants. As consumer prices rise, external safeguards are needed to prevent carbon leakage. A carbon border adjustment mechanism (CBAM) could provide external greenhouse gas-intensive products, such as animal products or nitrogen fertilizers, to mitigate carbon leakage.

  Technical options are only able to reduce agricultural emissions by about 25% (see 3.5.2). An ETS 3 can also lead to further regional intensification of animal farming (to achieve lower specific emissions per kilogram of product) - and the end of production in the other regions. In addition, feed additives are likely to be used on a large scale, as they can reduce livestock emissions. However, an assessment of their long-term efficacy and impact on human and animal health and the environment is still uncertain. An ETS 3 is unlikely to promote ecosystem restoration.

- **CAP reform:** Currently, animal-based foods use 82% the EU's agricultural subsidies (38% directly and 44% through animal feed) (Kortleve et al., 2024). As a matter of priority, the next Common Agricultural Policy (CAP) reform needs to change this misallocation of funding. It should also be noted that around 40% of CAP funding is meant to be used for objectives relevant to climate change[23], while, at the same time, the impact of climate action measures under the CAP is often limited. The European Court of Auditors criticized the EU's failure to apply the polluter-pays principle to agricultural GHG emissions.

- **Legally binding targets for agriculture:** Binding targets are a prerequisite for an ambitious and effective climate policy, independent of the choice of instruments for implementing agricultural policy. Without a clearly defined target, it is impossible to assess the effectiveness of the instruments used.

[23] This self-imposed target is listed in the preamble to the Strategic Plan Regulation (Recital 94). Even if the target is not yet binding, it indicates the importance of climate policy and the Green Deal. Article 100 of the Cap Strategic Plan Regulation therefore also specifies how climate expenditure will be tracked using a simple and common methodology (e.g. Rio Marker), see Regulation (EU) 2021/2115.

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