EU 2040 Climate Target:

Contributions of the industry sector

Part 2 of 7 studies on sectoral contributions to the 2040 target

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Abbreviations

BECCS	Bioenergy Carbon Capture and Storage
BF-BOF	Blast-Furnace Basic-Oxygen-Furnace
CBAM	Carbon boarder adjustment mechanism
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilisation
CDR	Carbon Dioxide Removal
CO_2e	Carbon dioxide equivalents
CPR	Construction Products Regulation
DACS	Direct Air Capture and Storage
E-AF	Electric arc-furnaces
EEA	European Environment Agency
EED	Energy Efficiency Directive
EP	European Parliament
EC	European Commission
ESABCC	European Scientific Advisory Board on Climate Change
EU	European Union
EU ETS	European Emissions Trading System
GHG	Greenhouse gas
IED	Industrial Emissions Directive
Mt	Million tons
NECPs	National Energy and Climate Plans

RED	Renewable Energy Directive
RRF	Recovery and Resilience Facility
TEN-E	Trans-European Networks for Energy
WAM	Projections with additional measures

Executive summary

The 2040 climate target

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

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

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

Emission trends in industry

While industry has an important role in the European Union's (EU) economy, accounting for about 20% of EU gross value added and 16% of direct employment in 2021 (Eurostat, 2024a), greenhouse gas (GHG) emissions from industry make up roughly 20% of total net GHG emissions in 2021. These arise from fossil-fuel combustion for heat supply as well as from process related chemical reactions that release CO_2.

Between 1990 and 2022, industry has reduced its emissions by 41% which is slightly higher than the net emission reduction for all sectors in total. 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. Across all Member States, industrial GHG emissions have experienced a decrease since 1990 with the exemptions of Cyprus and particularly Malta.[2] Countries with the highest absolute industrial GHG emissions include Germany, Italy and France.

Projections with additional measures (WAM) up to 2040 show that current existing and additional measures do not lead to emission reductions sufficient to achieve climate neutrality by 2050. Although the projections depict a continuation of the downward trend for all sectors, the reduction pace decreases as the projections approach the year 2050. By 2040, emissions for the industry sector are projected to stand at 483 Mt CO_2e which amount to about 21% of total EU emissions[3] in that year. This corresponds to sectoral reductions of almost 60% compared to 1990.

National WAM projections show that for almost all countries current and planned measures will lead to further emission reductions up to 2040. Exemptions include Austria, Estonia, Hungary, Malta, Romania, and Slovakia which assume that their industrial emissions will increase between 2022 and 2040 if they do not take further actions beyond what is already planned. Despite respective additional measures, the three biggest emitting countries in 2040 will remain Italy (68 Mt CO_2e), Germany (67 Mt CO_2e), and France (60 Mt CO_2e) although their order

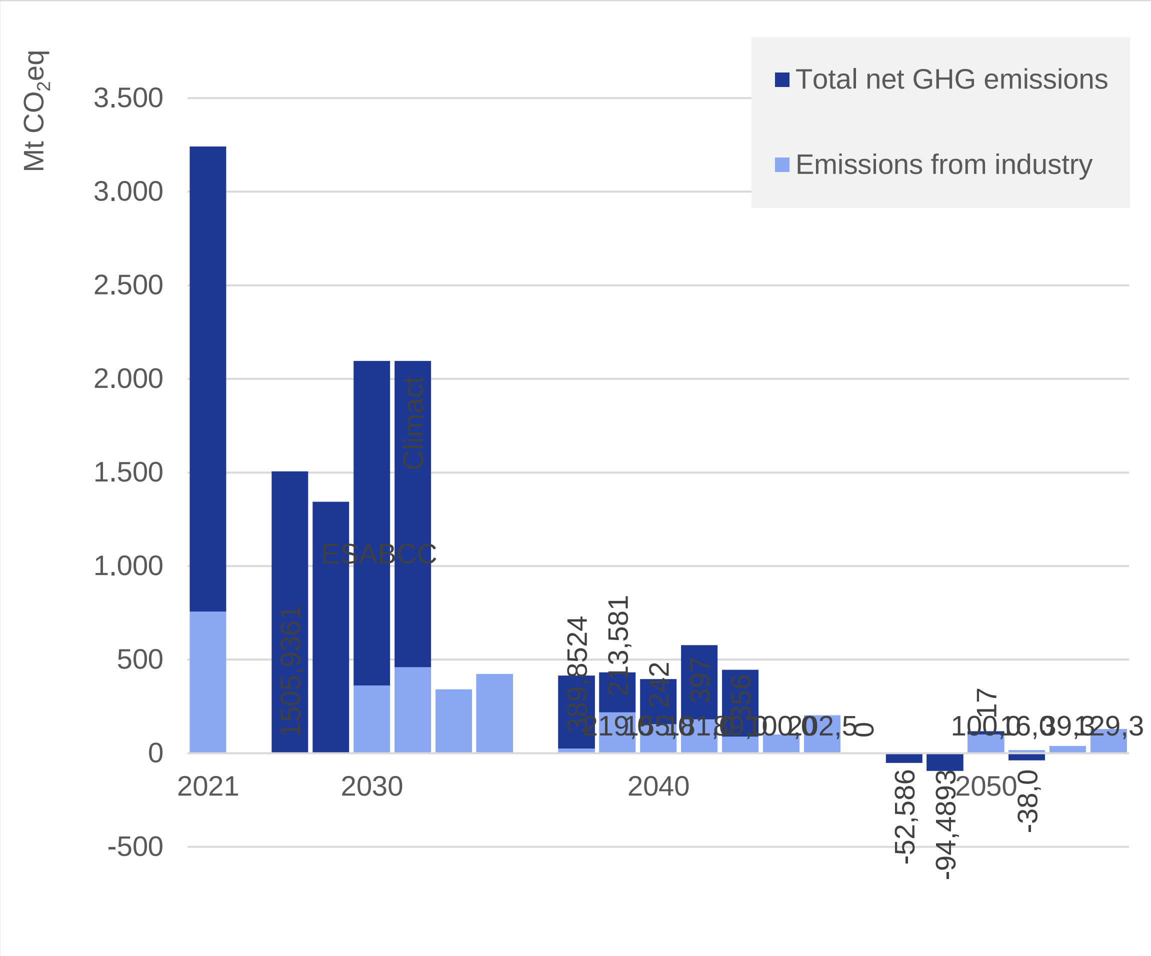
[1] The industry sector is defined as the sum of GHG inventory source categories 1.A.2, Manufacturing Industries and Construction, and 2, Process Emissions.
[2] The notable increase in these countries can be attributed to emissions from refrigeration and air-conditioning equipment
[3] Total gross emissions including international transport as reported in GHG inventories.

somewhat changes when compared to 2022 when Germany was leading the list. Germany stands out for achieving a 59% reduction between 2022 and 2040 in its industry sector.

What does the 2040 target mean for industry?

Depending on the final climate target for 2040, and depending on assumptions on sectoral contributions, the scenarios investigated as part of this paper show that industry emissions need to decrease significantly. The emission reduction ranges from 81 to 98% compared to levels in 1990, or 71 to 97% compared to those in 2021 which generally limits industrial emissions to below 220 Mt CO_2e by 2040 across the scenarios (**Error! Reference source not found.**).

Figure 1: Industrial and all other sectors net GHG emissions by 2040 to reach climate neutrality by 2050



Source: 2021 data from the GHG inventory (EEA, 2023a). For the years 2030, 2040, 2050, scenarios include those used by the ESABCC (2023) (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, 2024), and Climate Analytics' 'high CDR' as well as 'high energy / low CDR' scenarios (Climate Analytics, 2022). For some, only the total emissions are available (dark blue) for specific years, and for others only industry emissions (light blue).

Key challenges

The industry sector faces several challenges to achieve such emission reductions. First, industry requires large amounts of renewable energy, which is not yet available in sufficient quantities and at competitive prices. Second, abatement options in the industry sector in line with climate-neutrality require significant investments. However, the rational business case for investing in low-emission production is unclear. On top of the high capital expenditure, most low-emission production routes have higher operational costs than conventional production. Current and mid-term CO2 prices are not sufficient to make up for this cost gap. Third, transforming industry also requires complex changes in value chains and infrastructure (such as CCS or green hydrogen), necessitating significant investments and upfront (policy) planning. Fourth, not all technologies necessary for a climate-neutral industry have reached full maturity yet, such as hydrogen direct reduction of iron ore, electrification, hydrogen and sourcing of non-fossil carbon in the chemicals industry, and CCS for cement. Finally, the industry transition has serious labour market implications, and requires a (re-)skilled workforce.

In addition to these general challenges, individual sectors face specific challenges. The steel sector operates on lengthy investment cycles. For example, blast furnaces have a lifespan of 15 to 20 years. Most steel production sites have several blast furnaces, so renewal or change-over can take place successively. However, in light of the 2040 goal, investments in low-carbon assets are urgently needed within this decade. By 2030, approximately half of the EU's steel assets will necessitate reinvestment, presenting a significant risk for carbon lock-in. The majority of technologies essential for achieving substantial emissions reductions in cement production are not currently commercially available. These include Oxyfuel-CCS, alternatives employing different binders, and technologies for concrete recycling. In the chemicals sector, enhancing circularity will be crucial in closing carbon cycles and diminishing the need for new virgin feedstocks. Presently, only a small portion of plastics undergo recycling, despite the existence of available technological and commercial options (though not at competitive costs).

What is already in current EU legislation?

The EU already started to address these challenges as part of the European Green Deal and related policy changes. This includes the **EU Emissions Trading System** (EU ETS), encompassing energy-intensive industries and the energy sector, setting an emission cap and allowing trade of allowances. The cap on emissions will go down to zero by around 2039. Currently, the manufacturing industry receives a portion of emission allowances for free based on benchmarking. Starting in 2026, the **Carbon Border Adjustment Mechanism** (CBAM) will progressively replace free allocation as the EU's primary tool to address carbon leakage. Importers into the EU will be required to pay a carbon price equivalent to the allowances' price under the EU ETS in six emission and trade-intensive sectors, thus levelling the playing field between EU producers and international counterparts in the EU market.

In addition, the industry sector is addressed by EU legislation including the **Energy Efficiency Directive** (EED) mandating the implementation of energy management systems for energy consumers with an annual energy usage exceeding 85 TJ, while requiring mandatory energy audits for consumers whose yearly consumption surpasses 10 TJ; the **Renewable Energy Directive** (RED) requires Member States to aim for an annual increase of the renewable energy share in industry by at least 1.6%-points from 2026 to 2030 and to ensure that 42% of hydrogen use in 2030 and 60% in 2035 originates from renewable fuels of non-biological origin (RFNBO).

The **Net Zero Industry Act**, which is close to adoption, aims to cultivate a conducive atmosphere for investments into net-zero technologies. Additionally, it focuses on bolstering skills development by implementing training initiatives like Net-Zero Academies and streamlining the transferability of qualifications in pertinent fields (EC, 2023c). In February 2024, the European Council and the European Parliament agreed on a provisional deal which additionally includes an objective for CCS, setting an annual injection capacity at 50 million tonnes CO_2 by 2030 (Council of the EU, 2024). Also important for creating a favourable atmosphere for net-zero investments are the **Projects of Common Interest (PCIs),** infrastructure projects that connect the energy systems of Member States across national borders. They are important for emission reductions in industry because they can contribute to the establishment of key net-zero infrastructures, such as CO_2 (particularly important for reducing emissions in the steel and cement sectors) or hydrogen infrastructure. Also important for the development of net-zero infrastructure, the **European Hydrogen Bank**, which was initiated in 2022 by the European Commission, aims at unlocking private investments in hydrogen value chains by fostering investment confidence, mainly by establishing an initial market for renewable hydrogen.

The provisional agreement on the proposed new **Ecodesign for Sustainable Products Regulation (ESPR)** reached in December 2023, broadens its scope to encompass nearly all physical products, with a primary goal of shifting to sustainable products by establishing performance and information requirements targeting energy efficiency and circularity. The revision of the **Construction Products Regulation (CPR)** establishes harmonised rules and a common technical language for assessments of construction products within the EU.

Policies, measures and options to further reduce emissions in industry

Despite the existing legislative landscape, further action is required as also shown by the WAM scenario which outlines that existing and currently planned policies do not lead to sufficient emission reductions to meet the 2040 target range. Options to address the challenges include:

Enhance competitiveness of clean technologies: In order to align with the net zero goal for 2050, industries must transition to alternative production technologies and processes; hence, they need to be competitive with traditional fossil-based methods. While the EU ETS carbon price can aid in this effort by raising the (expected) cost of fossil technologies, further actions are needed to address innovation and broader market penetration. Two potential mechanisms, which could also work together, are carbon contracts for difference and green lead markets. Carbon contracts for difference offer a way to reduce price uncertainty and investment risks by setting up an agreement between a government or institution and an agent regarding a set carbon price for a specified duration. Within this agreed-upon timeframe, the agent can vend carbon emission reductions or allowances at the predetermined price. The revision of the EU ETS Directive makes them available as a finance option under the Innovation Fund. Green lead markets create a specific market segment for certain, more environmentally sustainable products through green public procurement, regulations (quota for green products) or as a voluntary feature. Both options increase the investment security to support the shift to clean technologies.

Incentivise electrification: Electrification can serve as a key measure 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. Some progress towards easy and non-discriminatory participation in electricity markets was introduced by the Electricity Directive which Member States must use to foster demand-side response.

Improve planning to allow for adequate infrastructure development: Transforming the industry sector poses a significant challenge due to the complex adjustments required in existing physical infrastructure, including power grids, infrastructure for CO_2 capture and storage (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. National planning may also facilitate the development and connection of regional industrial clusters (and vice versa).

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 developing non-fossil feedstock. However, reuse and recycling routes are often not in place and economic and regulatory incentives are currently not strong enough to instigate a shift from the status quo to more material efficiency in production. 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. They need fast adoption and ambitious implementation. Further consideration of recycling quota as outlined in the circular economy action plan could support improvement of recycling rates.

1 Introduction and conclusion

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). Article 4.4 of the ECL stipulates that “a Union-wide climate target for 2040 shall be set” – with a view to achieving the ECL’s climate neutrality objective. Once the target is adopted, the EU is also set to adopt a legislative package to implement this target. This package will reform relevant EU laws and policies.

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

Industry has an important role in the EU economy, accounting for about 20% of EU gross value added and 16% of direct employment in 2021 (Eurostat, 2024a, 2024b). Greenhouse gas (GHG) emissions from industry arise from fossil-fuel combustion for heat supply as well as from process related chemical reactions that release CO_2.[4]

The European Commission proposed a net emission reduction of 90% by 2040, relative to 1990, in its communication of 6 February 2024. The European Scientific Advisory Board on Climate Change (ESABCC) (2023) recommends a reduction range of 90–95%. This means that all sectors, including industry, will have to contribute significantly to emission reductions. By 2040, there is a need for industry emissions to decrease drastically, ranging from 81 to 98% compared to levels in 1990, or 71 to 97% compared to those in 2021 which limits industrial emissions to below 220 million tons of CO_2 equivalent (Mt CO_2e) by 2040 across different scenarios (see Figure 4). This spread is quite broad and depends on other sectoral emission reductions and particularly natural sinks.

The required industrial emission reductions come with a range of challenges. It is clear that industry cannot rely on marginal emission reductions anymore but has to implement new processes and technologies. Also, the sector needs to produce new materials and products to be able to achieve emission cuts. Other challenges are partly of cross-cutting nature requiring cross-sectoral planning, in particular with the energy supply sector as well as the waste (end-of-life) sector for ensuring reuse and recycling.

[4] These two categories are reported under the common reporting framework (CRF) of the UNFCCC in category 1.A.2 for energy-related emissions and in category 2 for process and by-product emissions.

2 Sectoral trends

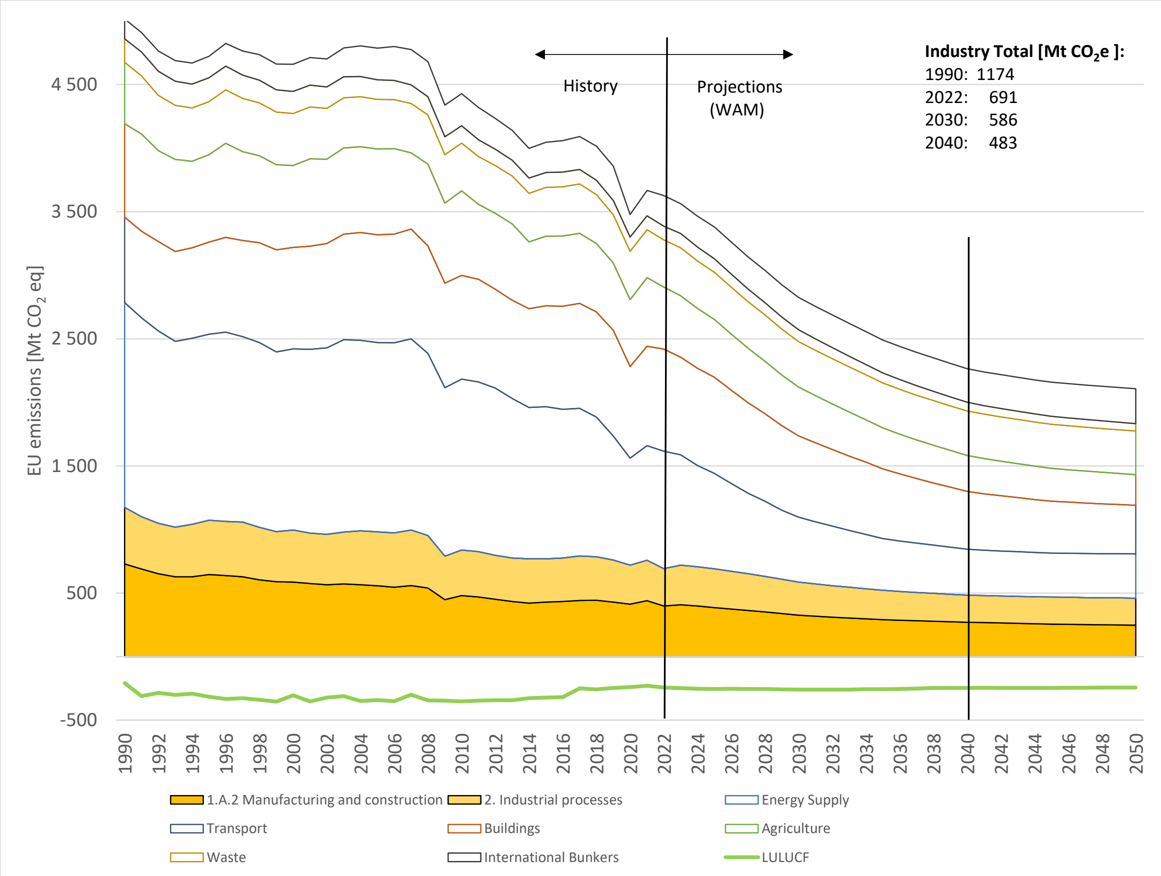
2.1 Historical and projected emission trends on the EU level

Historical data demonstrate a continuously declining trend of GHG emissions for all sectors, with a 39% reduction noted by 2022 in comparison to 1990 levels.[5] Industry reduced its emissions by 41%, from 1,174 Mt CO_2e in 1990, accounting for almost a quarter of total emissions in that year, to 691 Mt CO_2e in 2022 or 20% of total emissions (EEA, 2023a).

Most of these emission reductions happened between 1990 and 2010. Key drivers of the reductions included a shift from coal and oil to natural gas and biomass across the EU countries as well as the restructuring of the industry and efficiency improvements in Germany after reunification (EEA, 2012). The drop in emissions in 2009 results from the 2008 financial crisis, which led to a decrease in industrial production. Between 2010 and 2022, industry saw a 51% increase in gross value added while achieving a 18% reduction in GHG emissions (EEA, 2023a; Eurostat, 2024b). The decline in emissions can be attributed to various factors, such as the restructuring of the European economy indicating a shift of economic activities from more emission-intensive sectors to less emission-intensive sectors, and advancements in energy efficiency. In sectors with high GHG intensity, such as iron and steel, cement, and chemicals, emission reductions have been more modest, particularly during the period 2013 to 2021 and their GHG intensities and use levels stayed relatively constant. This can be attributed to the higher costs associated with reducing emissions in industrial processes compared to other sectors. Additionally, these sectors had fewer readily deployable large-scale net-zero technologies to shift to (EEA, 2020, 2023b; ESABCC, 2024, p. 81). A drop in emissions in 2020 resulted from the lower industrial production as a consequence of the Covid-19 pandemic lockdowns. The declining emissions trend persisted in 2022 which can be largely attributed to elevated energy prices that resulted in decreased output, especially in the fertilisers, metals, and cement sectors (EEA, 2023b, p. 58).

[5] Total net emissions with bunkers

Figure 2: Sectoral historic and projected GHG emission (in Mt CO_2 equivalent)



Source: EEA (2023). 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).

Current existing and additional measures do not lead to emission reductions sufficient to achieve climate neutrality by 2050 as shown by latest available ‘with additional measures (WAM)’ projections of GHG emissions (EEA, 2023b).[6] Although the projections depict a continuation of the downward trend for all sectors, the curve flattens as the projections approach the year 2050. By 2040, emissions for the industry sector are projected to stand at 483 Mt CO_2e which amount to about 24% of total emissions in that year. This corresponds to an almost 60% reduction compared to 1990.

2.2 Future trends in national projections

Across all Member States, industrial GHG emissions have experienced a decrease since 1990. The only exemptions are Cyprus and particularly Malta, which witnessed a notable increase attributed to emissions from refrigeration and air-conditioning equipment (EEA, 2023b).

In 2021 and 2022, countries with the highest absolute industrial GHG emissions include Germany, Italy and France. The comparatively high emissions in Italy and Germany can partly be explained by their economic structures. The contribution to gross value added of the industrial

[6] The projections with additional measures (WAM) include all existing and planned measures for emission reductions, at the point of data collection. The EEA collects projections from all Member States under the Governance Regulation (Regulation (EU) 2018/1999) every two years and combines them into the EU projections.

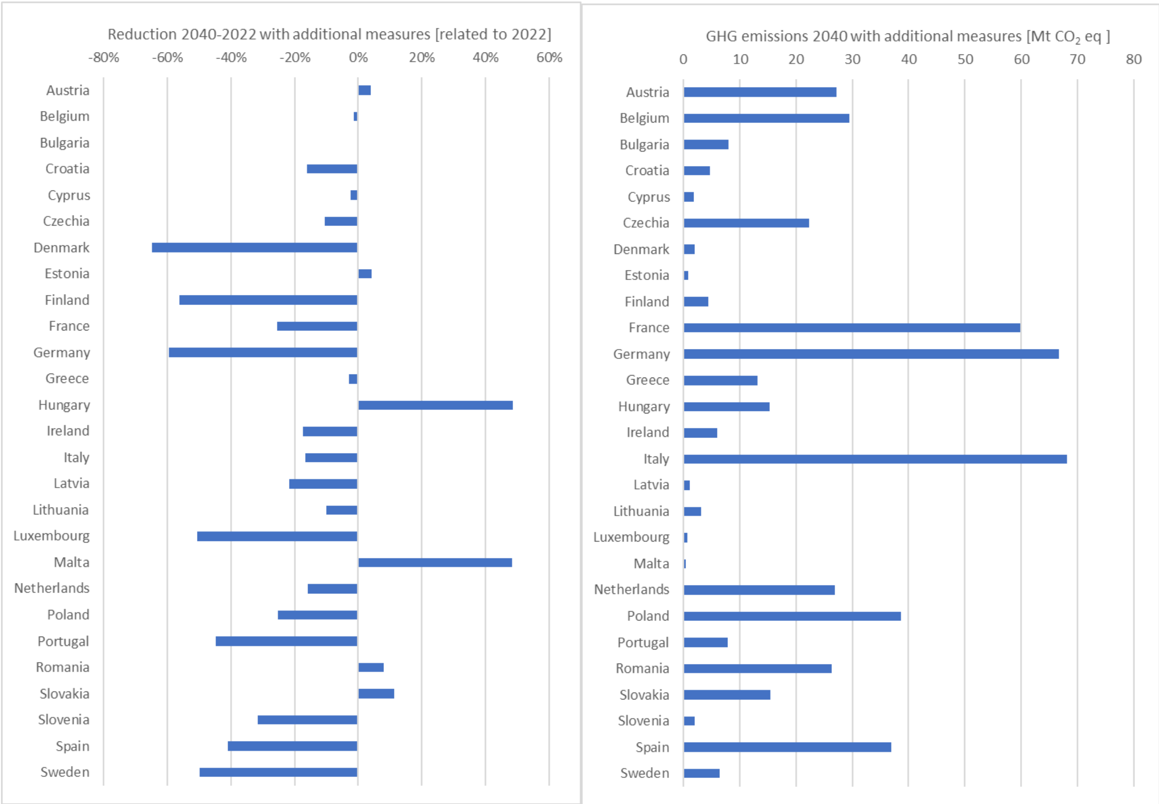
sector in Italy and Germany has been relatively stable over the past twenty years, ranging from almost 25% of gross value added in Germany and 21% in Italy in 2021. In France, the contribution of the industry sector stood below the EU average, at 13%. The EU average amounts to 20% (Eurostat, 2024b).

In 2021, the contribution of manufacturing of chemicals, manufacture of basic metals, and manufacture of other non-metallic mineral products to the gross value added in the industry sector[7] overall is similar in all three countries, ranging from 11% in Germany and Italy to 14% in France. In both Germany and France, the chemicals sector contributes about twice as much compared to the other two sectors to the gross value added. Regarding the contribution of the national industry sectors to EU gross value added, Germany contributes most with 31%, followed with a great margin by Italy (13%) and France (11%) (Eurostat, 2024b). Despite the gross value added not providing any information on the associated emissions, these numbers demonstrate that energy intensive industries are an integral part of the economic structures in all three countries, particularly Germany.

The projections with additional measures (WAM) up to 2040 show that five countries assume that they industrial emissions will increase between 2022 and 2040 if they do not take further actions beyond what is already planned. This includes Austria, Estonia, Hungary, Malta, Romania, and Slovakia (see Figure 3). The three biggest emitting countries in 2040 will remain Italy (68 MtCO_2e, Germany (67 MtCO_2e), and France (60 MtCO_2e) although their order somewhat changes when compared to 2022 when Germany was leading the list. Germany stands out for achieving significant reductions between 2022 and 2040 of 59%. France is projected to lower emissions by 26%, while Italy would reduce its emissions by 17%. Beyond 2040, the WAM scenarios assume a slightly decline in emissions for Germany to 52 MtCO_2e and France to 53 MtCO_2e and for Italy a slight increase to 73 MtCO_2e.

[7] Industry includes all sub-sectors except construction

Figure 3: Member States' industrial emission projections: relative change 2022 to 2040 and absolute level in 2040



Source: (EEA, 2023a) Note: Data shown for national 'with additional measures' (WAM) projections. Industrial emissions include those from energy consumption (CRF cat. 1.A.2), and processes and products (CRF cat. 2).

2.3 Relationship to other sectors

The energy demand in the industry sector – including fuels, electricity and heat from power and combined heat and power plants – translates into a strong sectoral overlap between the energy and industry sector. Mining and extraction activities as well as refineries and power and heat plants, which are covered under the energy sector paper of this series of sectoral papers, energy industries in this paper series, provide solid, liquid, and gaseous fuels, heat and electricity for industrial combustion and processes. The shift towards a low-emission industry relies on having adequate access to these clean energy carriers (ESABCC, 2024). Competition may arise with other demand-side sectors including transport and buildings where electrification and clean fuels will also have to substitute fossil energy consumption.

While the electrification of industry increases the need to produce clean electricity, it may also provide flexibility to the electricity systems. Enhanced demand side flexibility allows consumers to align their electricity consumption with periods of high and low renewable energy generation using electricity with a particularly low or even negative price and reducing electricity consumption when the price is particularly high. This also has favourable impacts on the electricity market, reducing the need for backup generation and increasing cost-effectiveness on the power market (Agora Energiewende & WI, 2020). However, the economic feasibility of technologies enabling sector coupling (direct electrification, power-to-gas/liquids, power-to-heat) encounters significant challenges (Ramsebner et al., 2021).

Competition may arise around CO_2 transport and storage infrastructure if CCS is not primarily reserved for industry but also considered as an option for fossil fuel power generation or technical carbon dioxide removal (CDR) such as bioenergy CCS (BECCS) or direct air carbon capture and storage (DACCS). This is also tied to the issue of limited biomass potential, especially when it comes to energy. In addition, (industrial) CCS needs considerable additional energy which would further affect the energy industries.

Finally, industry provides technologies and products for all other sectors such as machineries for energy generation, vehicles for transport, and materials for construction of buildings. The manufacturing of new technologies and products for the transition on the one hand consumes energy but at the same time provides the basis for emission reductions in other sectors.

3 Mitigation options and key challenges

Many studies have shown the technical and economic feasibility of making the industry sector nearly climate neutral by or before 2050 with deep emission cuts by 2040. To achieve these cuts by 2040, industrial processes relying on low and medium temperature heat must be close to fully electrified. A key lever for this is the roll-out of new infrastructure and renewal of existing infrastructure. Several core mitigation strategies exist for reducing GHG emissions in the industry sector either focusing on changing patterns of energy demand for existing processes or switching to novel, climate neutral production processes (Chan et al., 2019; ESABCC, 2024).

- **Increasing energy efficiency** in existing industrial processes, particularly in the short to medium term, as this does not require significant changes to the existing infrastructure.
- **Electrification** of process heat by switching to, e.g., heat pumps (for low or medium temperature heat), or electrode boilers (for high temperature heat).
- **Switching from fossil to climate neutral energy carriers**, such as green hydrogen, and derived synthetic fuels, and/or biofuels for heat generation and as industrial feedstocks. This often requires a switch to novel production processes, such as a switch from blast furnaces to shaft furnaces for the direct reduction of iron.
- Use of **Carbon Capture and Storage (CCS)** whereby particularly process emissions from chemical reactions are captured directly from the exhaust streams and stored e.g., in geological formations that allow for long-term and permanent storage.
- **Carbon Capture and Utilisation (CCU)** which means to use captured CO_2 e.g., in the chemical industry, for synfuel production or in building materials, is not a long-term and permanent solution for climate mitigation.

While incremental enhancements in efficiency and transitions to alternative fuels, like hydrogen or biogenic sources, continue to play a significant role in reducing GHG emissions, achieving substantial reductions of over 90% by 2050 necessitates a transition to novel, low-emission industrial production processes.

Furthermore, reducing energy and resource consumption through additional measures for circularity and material efficiency can contribute significantly to emission reductions in industry.

- **Material efficiency:** Enhancing material efficiency which aims at reducing demand for emission-intensive materials, e.g. through near-net shaping, avoiding over-dimensioning, lightweighting, or 3D printing.

- Promoting **material circularity** measures which means that materials are repurposed or recycled at their end of life, e.g., through appropriate waste sorting and product design; which aims at reducing demand for emission-intensive materials, e.g. through near-net shaping, avoiding over-dimensioning, lightweighting, or 3D printing;
- **Material substitution** whereby high-emission materials and products are substituted with low-emission alternatives that have the same or similar characteristics, like the switch to alternative binders for cement.

3.1 General challenges

Mitigation options come with several challenges for industry transition. In the following, we highlight some general challenges and more specific challenges that the **steel, cement, and chemicals industries** face.

- Zero-emissions industry requires large amounts of renewable energy, both as electricity and as energy carriers in the form of renewable hydrogen, ammonia, biofuels, or synthetic fuels. Overall electricity demand in different scenarios is expected to increase by 50% to 300%, depending on the decarbonisation pathway (EC, 2023b; Fleiter et al., 2019). This all requires the energy industry to transform which comes with own challenges (see also section 2.3 and energy sector).
- Abatement options, including new processes or CCS, which are in line with climate-neutrality require high capital expenditures. Most marginal abatement options are no longer sufficient. Instead, industry must switch to alternative production processes and technologies. Moreover, industrial assets have long-lifetimes and re-investment cycles (Agora Energiewende & WI, 2020; Material Economics, 2019).
- The rational business case for investing in low-emission production is unclear. In addition to the high capital expenditures, most low-emission production routes have higher operational costs than conventional production. Current and mid-term CO_2 prices are insufficient to bridge this cost gap (Agora Energiewende & WI, 2020; Agora Industry et al., 2022).
- Electricity prices, a key component of operational costs, at many of the current industrial clusters in the EU are expected to be structurally higher than those of competitors, adding to the existing cost disadvantage of EU industry in key industries such as steel (AFRY, 2023; Somers, 2022).
- Not all technologies for a climate-neutral industry are commercially available yet. To put the industry sector on the path to climate neutrality, innovations in low-emission production processes are urgently needed. While many promising technologies are currently in the developmental stage, not all of them have attained full market maturity, such as such as hydrogen direct reduction of iron ore, electrification, hydrogen and sourcing of non-fossil carbon in the chemicals industry, and CCS for cement (ESABCC, 2024).
- Transforming industry requires substantial infrastructural changes (such as electricity grids, CCS, or green hydrogen) (WI, 2020). Missing infrastructure may create chicken-and-egg problems and induce “wait-and-see” behaviour among investors.
- Finally, transitioning to climate neutral industry requires a skilled workforce. Skills and people increasingly become a bottleneck for the transition of industry, e.g., in the construction of DRI plants (Agora Industry & WI, 2023).

3.2 Challenges of selected industries

More specific challenges arise in the steel, cement, and chemicals industries. These basic materials generated roughly 50% of total industrial emissions in 2021 and are therefore an important lever (Agora Industry, 2022b, p. 9; EEA, 2023a). Thereby, iron and steel accounted for 19% according to the GHG inventory (crf. 1.A.2.a and 2.C.1) or 15% according to the verified emissions under the EU ETS (cat. 24). Cement accounted for roughly 15% according to verified ETS emissions while the GHG inventory only outlines cement process emissions (crf. 2.A.1) while energy-related emissions are covered under 'non-metallic materials' (including cement but also lime and glass). Chemicals accounted for 16% according to the GHG inventory (crf. 1.A.2.c and 2.B).

Key challenges for the steel industry

Conventional steelmaking in the EU is largely based on the Blast Furnace Basic-Oxygen-Furnace (BF-BOF) route for primary steelmaking (60%) and electric arc-furnaces (EAF) for secondary steelmaking (40%) (Somers, 2022). For decarbonising primary steelmaking, the key mitigation option is switching to the hydrogen-based direct reduction of iron ore with a subsequent smelting in a converter or an EAF. In addition, most scenarios foresee an increase in secondary steelmaking in EAF using renewable electricity. Other technologies such as alkaline iron electrolysis for primary steelmaking or CCU/CCS for conventional blast furnaces are less promising for large-scale deployment at the current stage (Agora Energiewende & WI, 2020; Chan et al., 2019; Somers, 2022). The latter is also unlikely to be compatible with climate neutrality. The steel sector has a very high potential for emission reductions. By 2040, over 90% of the EU's blast furnaces could be phased-out without a pre-mature shutdown (Agora Industry & WI, 2023). However, the steel sector faces different challenges with regards to emission reductions, in addition to the general challenges outlined above:

- H_2-based-DRI steelmaking relies on green hydrogen as a feedstock, which is currently not available at scale and will likely result in higher costs of steel compared to BF-BOF steel. The future cost of hydrogen is the main determinant for the cost differential between low-emission and conventional steel (Somers, 2022);
- Investment cycles in the steel sector are long. Blast furnaces require relining ca. every 20 years. By 2030, about half of the EU's steel assets require reinvestment (Agora Energiewende & WI, 2020). There is consequently a large potential for carbon lock-in and stranded assets;
- Capital expenditures are sizable but manageable. The projected cumulative investment needed by 2050 to convert the current integrated route to climate-neutral production in the EU has been estimated at between EUR 70 billion and around EUR 100 billion (Agora Industry & WI, 2023). In addition, operational expenditure for low-emission production will likely be higher than conventional steel for a while (Somers, 2022).
- DRI plant engineering and construction capacities are currently a major bottleneck. DRI plant construction is highly concentrated in only 3 providers (SMS group and Primetals, licensed by Midrex; and Tenova) (Agora Industry & WI, 2023).
- Scrap quality is a major constraint for high quality steel from secondary steelmaking in EAF requiring major improvements in recycling (Agora Industry, 2022b).

A comprehensive overview of the challenges in the steel sector can be found in Aydemir et al. (2024), Somers (2022), and Agora Industry (2023).

Key challenges for the cement industry

In contrast to steel and chemicals, cement is mostly produced for regional consumption, due to its low value-to-weight ratio. Nevertheless, there is a liquid market for both clinker and cement, and some EU countries like France and Italy that have access to cheap supply via the Mediterranean Sea and are net importers of both goods (Emele et al., 2022). There are two main sources of cement emissions: process emissions from the calcination of calcium carbonate into lime (about 2/3 of GHG emissions), the main ingredient of cement; and energy-related emissions, as cement production needs very high temperatures and the processing requires electricity (about 1/3 of GHG emissions). Next to demand side measures that reduce the need for concrete, the main strategies for reducing cement emissions involve CCS. CCS is considered inevitable for reducing cement emissions, due to the large share of process emissions. The most promising technologies are Oxyfuel-CCS or post-combustion CCS. The electrification of process heat by switching, for example, to electric kilns is an option, which can be combined with CCS for process emissions. Finally, the switch to alternative binders to replace emission-intensive calcium-silicates would reduce cement emissions (Agora Industry, 2022b; Chan et al., 2019; Marmier, 2023).

The cement sector faces some specific challenges next to the general ones outlined above (Agora Industry, 2022b; Chan et al., 2019):

- Most technologies needed for deep emissions cuts from cement production are not commercially available yet, such as Oxyfuel-CCS, those that use alternative binders, or concrete recycling technologies.
- All climate neutrality pathways in the cement sector rely on CCS, necessitating storage sites and transportation infrastructure which is not available yet.
- Most cement must correspond to specific specifications such as Ordinary Portland Cement, which prevents the adoption of innovative cement types and alternative binders. New market standards that move away from composition-based-requirements are needed, but the construction sector is slow to change.
- There is a limited availability of recycled cementitious materials in construction primarily due to the early stage of relevant technologies and the necessity for locally sourced demolition materials.

For a detailed overview of the challenges in the cement industry see e.g., Marmier (2023) and Schüwer et al. (2024).

Key challenges for the chemicals industry

The chemical sector is complex and considerably more diverse in its products and processes than the cement and steel sectors. However, there are two main sources of emissions (Chan et al., 2019): First, the production of so-called "bulk-chemistry", which is primarily based on the production of ethylene and accounts for 47% of the sector's emissions. At present, ethylene is mainly produced from steam-cracking of fossil fuels (mainly Naphtha). Bulk chemicals are a very important precursors and the start for a large part of the chemical sector's value chain. The second main source of emissions is the production of ammonia, which accounts for about 27% of the sector's emissions. Ammonia is primarily used for fertiliser production, but also a key ingredient in household cleaning products.[8] Next to demand side measures that reduce our

[8] Decarbonising ammonia is already possible at scale today, as the main feedstock is hydrogen. Here the solution is to replace fossil hydrogen with green hydrogen or with natural gas reforming coupled with CCS, so-called blue hydrogen. However, the latter route is questionable and unlikely to be sustainable at scale.

consumption of chemicals, fertilisers, and plastics, there are different technological options for deep emission cuts. These include the electrification of heat and steam generation; the switch to electric steam-crackers; CCS; the switch to alternative feedstocks for ethylene and ammonia, such as methanol and especially hydrogen; and chemical recycling, especially of plastics (Agora Energiewende & WI, 2020; Chan et al., 2019; IEA, n.d.; Marmier, 2023).

The main challenges for deep emission cuts in the chemicals sector relate to the availability of low-emission feedstocks (especially hydrogen), competitive electricity prices, and improving the recycling rate of plastics:

- Availability of relatively cheap and clean hydrogen is a main bottleneck. Uncertainty about future supply and cost can induce uncertainty and prevent the timely switch to alternative production processes. Low-cost hydrogen will also be essential for phasing out gas, reducing the chemical's sector high dependency;
- Direct electrification of process energy depends on the availability of competitive electricity prices;
- Increasing circularity will be essential for closing carbon cycles and reducing demand for virgin feedstocks. At the moment, only a fraction of plastics is recycled, although options are technologically and commercially available (though not at competitive cost) (Agora Industry, 2022b).

For a detailed overview of the challenges in the chemicals industry see Kloo et al. (2023).

4 Sector contributions to the 2040 climate target

4.1 What is already in current EU legislation?

The industry sector is mainly regulated at EU level to create a single market for EU industry. The legislative framework includes regulatory instruments as well as financial support with some instruments focussing on climate mitigation while others target other EU goals, e.g. to foster a favourable environment for net-zero investments or manufacture more sustainably produced products. When considering the key mitigation options and related challenges (see section 3), the EU has delivered first approaches to address these:

The key climate policy in place is the **EU Emissions Trading System (EU ETS)**. It covers the energy-intensive industries as well as the energy sector, sets a cap on emissions and allows for emission allowance trading between participants. The cap on emissions is reduced based on a linear reduction factor of 2.2% up to 2023 and is further tightened to 4.3 % from 2024 to 2027 and 4.4 % from 2028 (Directive 2003/87/EC). As a result, the cap will go down to zero by around 2039 and questions arise with respect to market functioning and market behaviour leading up to and beyond 2039 that must be addressed in the near-term (see e.g., Pahle et al., 2023). For a portion of their emissions, the facilities receive a free allocation. The amount of the free allocation is based on benchmarking. While industry received most of their share of emission allowances for free in the past, free allocation is continuously reduced aligned with the cap reduction. In 2021, free allowances covered 90% of industrial emissions (EEA, 2022). The **carbon border adjustment mechanism (CBAM)** gradually replaces free allocation as the EU's main carbon leakage instrument from 2026 onwards. Under the CBAM, importers to the EU will have to pay a carbon price that mirrors the price for allowances under the EU ETS in six emission and trade intensive sectors[9]. The CBAM therefore levels the playing field between EU producers and international competitors on the EU market. Free allocation is phased out only gradually starting in 2026 until it reaches zero in 2034. The CBAM is correspondingly phased-in (Regulation 2023/956).

The **Energy Efficiency Directive (EED)** introduces energy management systems for large energy consumers with an annual energy consumption of above 85 TJ. Energy audits are mandatory for energy consumers with an annual consumption which exceeds 10 TJ (Directive (EU) 2023/1791). The **Renewable Energy Directive (RED)** requires Member States to strive for an increase of the share of renewable energies in industry of at least 1.6%-points per year over the period 2026-2030. Member State must also ensure that 42% of hydrogen used in 2030 and 60% in 2035 should come from renewable sources of non-biological origin (Directive (EU) 2018/2001, Article 22 (a)).

The proposed **Net Zero Industry Act** does not directly address industrial energy consumption or emission but seeks to foster a favourable environment for net-zero investments and aims at enhancing skills development, e.g., by putting in place training programmes through Net-Zero Academies and simplifying the portability of qualifications in relevant professions (EC, 2023d). The Act follows the **Green Deal Industrial Plan** (COM/2023/62). In February 2024, the European Council and the European Parliament agreed on a provisional deal on the regulation establishing a framework of measures. The deal additionally establishes an objective for CCS, aiming for an annual injection capacity of 50 million tonnes CO_2 by 2030 (Council of the EU, 2024). Furthermore, the **Projects of Common Interest (PCIs)**, which are infrastructure projects that connect the energy systems of member states across national borders, play an important role in contributing to infrastructures for CO_2, an important enabling condition for cutting emissions in the chemical and cement industries. Also, they can advance hydrogen development by fostering the availability of electrolysers and hydrogen pipelines.

Also important for the development of net-zero infrastructure, the **European Hydrogen Bank**, which was initiated in 2022 by the European Commission, aims at unlocking private investments through fostering both investment confidence and generating business prospects for both European and global renewable hydrogen production. Importantly, it also establishes an initial market for renewable hydrogen. Furthermore, the European Hydrogen Bank is intended to enhance the coordination of information supporting infrastructure development and the coordination of current support mechanisms within the EU and its member states (e.g. technical aid and investment support both domestically and internationally) (EC, 2023a).

While these measures mostly tackle the supply side to make production more environmentally sustainable, demand side policies aim to make sustainably produced products the norm.

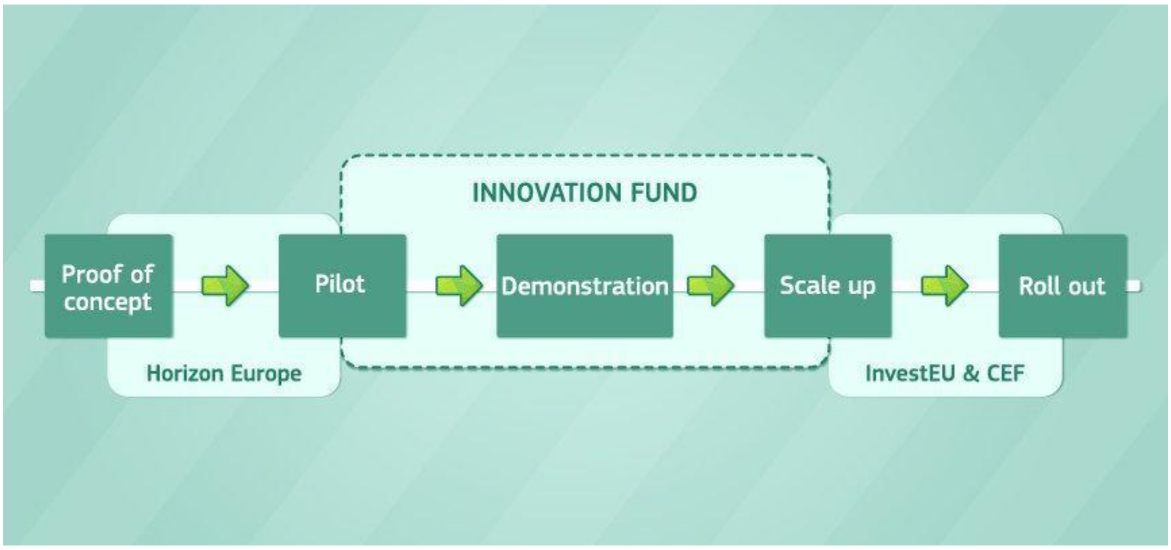
The provisional agreement on the proposed new **Ecodesign for Sustainable Products Regulation (Ecodesign Regulation)** (EC, 2022b) was reached in December 2023, with the formal adoption by the European Parliament and the Council expected in early 2024. The new Regulation significantly expands its scope to basically all physical products. A key objective is to level the playing field for sustainable products and establishing performance and information requirements for products diffused on the EU internal market targeting both energy efficiency and circularity, specifically through boosting product durability, reusability, upgradability, and repairability (EC, 2023f). The Parliament introduced that the Commission must prioritise specific products including iron, steel, aluminium, and chemicals in their work programme (EP, 2024a).

[9] The CBAM applies to selected basic materials and basic material products in the following sectors namely cement, iron and steel, aluminium, fertilisers, hydrogen, and electricity. For a concise summary of the CBAM regulation compare UBA - Umweltbundesamt (2023).

The **Construction Products Regulation (CPR)** (Regulation 305/2011) establishes harmonised rules for marketing of construction products and a common technical language for assessments of construction products within the EU to make sure that information on the performance of construction products is standardised and available to stakeholders in a transparent way. The Commission proposed a revision of the regulation in March 2022, setting out environmental product requirements for construction products and defining a list of general sustainability requirements (EP, 2024c).

All these existing instruments are flanked by **financial support for the development, deployment, and diffusion** of net-zero technologies. Supporting research and development, the EU has put in place the **Horizon Europe** programme which runs until 2027 and has a budget of EUR 95.5 billion. One of its thematic clusters specifically targets the industrial sector (Cluster 4: 'Digital, Industry and Space') with a focus on manufacturing technologies, circular industries, and low carbon and clean industries (Regulation 2021/695). The **Innovation Fund** particularly supports the demonstration of innovative and net-zero technologies of the energy and industry sectors (Regulation 2019/856). It receives its budget from the auctioning of allowances of the ETS. The 2023 revision of the ETS Directive strengthened the Fund by increasing the volume of ETS allowances from 450 million to 530 million. This translates into about EUR 40 billion from 2020 to 2030 under the assumption that one allowance will cost around EUR 75 (EC, 2023e). As a result, the EU ETS is anticipated to bolster the pilot and demonstration phase of clean technologies via the Innovation Fund (ESABCC, 2024). The **Recovery and Resilience Facility (RRF)** provides EUR 723.8 billion in grants and loans to Member States to support, among others, the industry transition as well as employment initiatives fostering job creation and enhancing skills development. 37% of the money is earmarked for climate action (Regulation 2021/241). The **InvestEU programme** aims at stimulating investment totalling over EUR 372 billion between 2021 and 2027 through an EU budget guarantee of EUR 26.2 billion, e.g., for sustainable infrastructure, innovation, and skills enhancement. Other support is available for infrastructure projects that may also facilitate infrastructure development for connecting industrial facilities. This includes e.g. the Connecting Europe Facility (CEF) and the Projects of Common Interest (PCIs).

Figure 4: Stages of funding support



Source: EC (n.d.-b)

Other EU legislation include:

- In April 2022, the Commission proposed a revision text for the 2010 **Industrial Emissions Directive (IED)** (Directive 2010/75/EU) (EC, 2022a), following the **Zero Pollution Action Plan** (EC, 2021). The IED regulates pollutant emissions from industry and agriculture, covering 52,000 installations, such as production of metals, cement, and chemicals. National authorities must regularly inspect whether the installations adhere to the conditions around the use of Best Available Techniques (BAT) (EP, 2024b).
- The Commission proposal for a **Critical Raw Materials Act** aims to secure EU access to critical raw materials, which are crucial for reaching net-zero by 2050 (EC, 2023c). Due to global decarbonisation efforts, the demand for critical raw materials is expected to increase significantly worldwide. The global demand for many critical raw materials will quadruple up to 2040 (IEA, 2022). In the EU, the demand for rare earth materials is estimated to rise six times by 2030, and the demand for lithium is expected to increase twelve times by 2030 (as of 2023) (EC, n.d.-a).

4.2 Possible range of emissions 2040 – with a glimpse on 2050

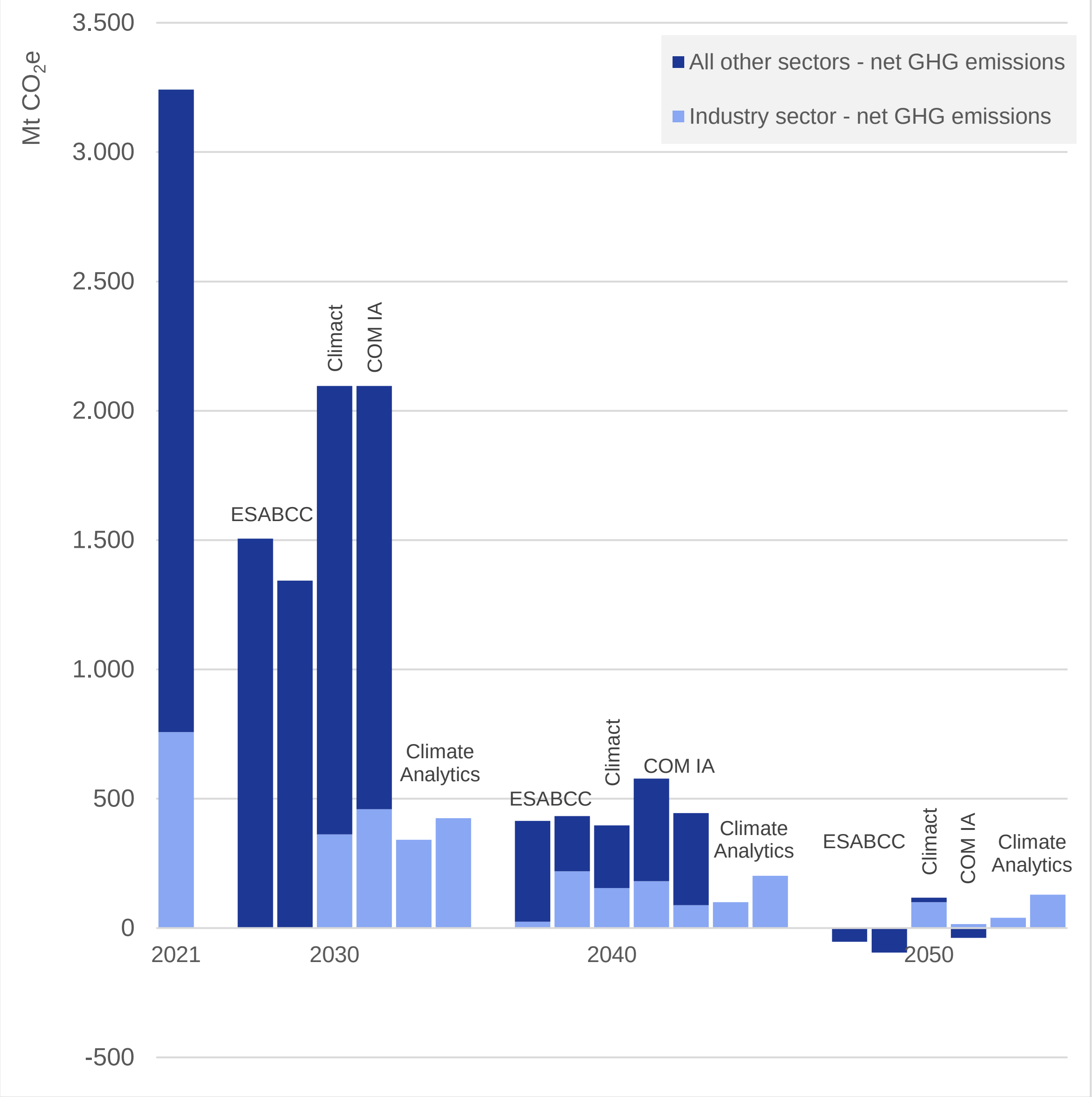
The EU wants to achieve climate neutrality by 2050 and has an interim target for 2030 of reducing net GHG emissions by at least 55% compared to 1990. It still has to decide on its 2040 target. The Commission recommends a net emission reduction of 90% while the ESABCC outlines a need to go for 90–95% reductions. Tabling the legal proposal for the 2040 target will be the responsibility of **the next Commission**. Nonetheless, the Commission's impact assessment as well as other studies outlining a 2040 emission reduction in a similar scale, allow to draw some conclusions about the contribution of industry (Climate Analytics, 2022; ESABCC, 2023; European Commission, 2024; Kalcher, 2023).

By 2040, industry emissions need to fall by 81 to 98% compared to 1990 or 71 to 97% when compared to 2021 when considering a range of scenarios whereby the ESABCC scenarios outline the maximum and minimum edges. According to these scenarios, industrial emissions must land below 220 Mt CO_2e by 2040 (see Figure 3) ([10]). More specifically, this would require that energy-related emissions fall to roughly between 120 Mt CO_2e in the S2-Scenario of the COM's IA and -31 Mt CO_2e in a ESABCC scenario. Process emissions are lowest in the Climate Analytics 'high CDR' with only 7 Mt CO_2e emitted in 2040 and highest in their 'high energy / low CDR' scenario with 137 Mt CO_2e.

Besides these variations, it is clear that all industrial sectors have to significantly lower their emissions by 2040 – with the cement, chemicals, and steel and iron sectors accounting for about three quarters of emissions in 2040 (see e.g., European Commission (2024), Climate Analytics (2022). In comparison, the WAM scenario currently outlines only a 60% reduction by 2040 compared to 1990 or 482 Mt CO_2e in 2040. This indicates that existing and currently planned policies do not lead to sufficient emission reductions to meet the 2040 target range.

[10] This is excluding a scenario by Climate Analytics which assumes a strong decline in energy consumption across all sectors which would allow industry to emit 266 Mt CO_2 in 2040.

Figure 5: Industrial and all other sectors net GHG emissions by 2030 and 2040 to reach climate neutrality by 2050



Source: 2021 data from the GHG inventory (EEA, 2023a). For the years 2030, 2040, 2050, scenarios include those used by the ESABCC (2023) (upper end & lower end), the scenario developed by Climact (Kalcher, 2023), the S2 and S3 of the Commission's Impact assessment on a 2040 Climate Target (European Commission, 2024), and Climate Analytics' 'high CDR' as well as 'high energy / low CDR' scenarios (Climate Analytics, 2022). For some, only the total emissions are available (dark blue) for specific years, and for others only industry emissions (light blue).

The required reductions of industrial emissions will have to come from several if not all of the above-mentioned mitigation options (see section 3). Their contributions, however, can vary significantly depending on the different scenarios:

Key levers in industry that are highlighted in all scenarios include **energy efficiency** and **electrification**. Energy consumption for energy generation and as feedstock falls across scenarios by e.g., 14% in the COM's IA scenarios. At the same time, electricity consumption increases by about 50% when compared to 2021 across several scenarios reaching around 1.300 TWh and roughly 40% of final energy demand. This follows electrification of low and medium temperature industrial processes with industrial heat pumps. Also, direct electrification-based technologies such as such as molten oxide electrolysis or alkaline iron electrolysis, while often not commercially viable yet, will require electricity in the future (Agora Industry & WI, 2023).

In addition, virtually all scenarios see a large increase in the **demand for hydrogen**, both for process heat as well as a feedstock in the industry sector. However, renewable hydrogen requires renewable electricity for its production which comes with own challenges in terms limited RES-E resources in the EU, costs and availability of imported hydrogen and derivates, and of respective raw materials (see also energy sector paper). Compared to direct electrification, renewable hydrogen necessitates 2-4 times the renewable electricity (Agora Energiewende & Agora Industry, 2021). The ESABCC (2023) scenarios reflect on the wide range indicating a share of hydrogen in final energy demand between 6% and 23%. This range depends on the fuel's cost and availability, the degree of direct electrification of process heat, and the extent to which precursors are imported. For example, if more green iron or green ammonia is imported (i.e., the hydrogen is produced outside the EU and imported embedded in fuels or materials), this may reduce domestic demand for hydrogen. Generally, domestically produced hydrogen tends to be cheaper and favoured over imports, but it presupposes a reliable and competitive domestic renewable energy supply (Agora Energiewende & Agora Industry, 2021).

Bioenergy can be used as an alternative to fossil energy in industry, but its availability is limited by its impact on land, food production and biodiversity (see also energy sector paper) so that its use should be restricted to specific industrial processes where no other option is available such as a feedstock for the chemicals sector (see e.g., ESABCC, 2023; Fleiter et al., 2019; Material Economics, 2019). Almost all scenarios expect the role of biomass to be limited, and rather decreasing in industry following electrification or the use of other fuels to generate heat including the COM's IA outlining a reduction of around 20% when compared to 2021. Scenarios which do not impose strict sustainability constraints on biomass tend to see a potentially greater use for it in process heat (Lechtenböhmer & Samadi, 2022). This seems the case for the scenarios of Climate Analytics (excluding the scenario on low energy demand) where consumption of biomass increases by roughly 50-80%. Some also see a role for waste for co-firing in cement kilns (Pfluger et al., 2023).

CCS is mainly applied to capture and store residual emissions. The findings of the Commission's Impact Assessment indicate that the degree of climate ambition attainable in the energy and industry sectors by 2040 is partly dependent on the quantity of carbon captured and by carbon removals (European Commission, 2024, p. Annex 8, section 1.1.3.2). Some scenarios also show that less CCS is required to achieve deep emission cuts when high electrification and hydrogen inputs reduce remaining fossil fuel inputs to close to zero. Some scenarios also consider biomass use in industrial facilities combined with CCS to lead to CO_2 removal. However, regarding the availability of CCS, challenges arise from still to be developed infrastructure and economic operation in the longer-term (European Commission, 2024, p. Annex 8). Using no CCS would increase the industrial emissions in the COM Impact Assessment and ESABCC scenarios to roughly 240 Mt CO_2e in 2040.

Increasing **material circularity, substitution and efficiency** is essential to reduce the upstream raw material demand and leads to reductions of energy-related and process emissions in industry. Circularity and substitution do not necessarily reduce the production and added value of industry but require new routes to enabler reuse and recycling as well as the production and use of new materials. Material efficiency instead can lead to a reduction in EU consumption of specific materials which would either leave more of such materials for export or reduces their production in the EU. Agora Industry (2022b) outlines that a stronger role for enhanced recycling and material efficiency has the potential to reduce electricity demand by over 400 TWh per year for the steel, cement, and chemicals sectors, hydrogen demand by 33%, and limit the demand for CCS to just 47 $MtCO_2$ per year compared to a low circularity decarbonisation scenario. There are similar findings for Germany (Lechtenböhmer & Samadi, 2022; Pfluger et al., 2023).

Table 1: Harmonised 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 (2023) (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, 2024), 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, 2023b; 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.

5 How to achieve the necessary contribution: Discussion of possible policies and measures and options

Industry has to reduce its emissions by 71 to 97% by 2040 below 2021 to contribute to the achievement of the 2040 target. This range depends on the interim EU 2040 target and the other sector contributions. Key mitigation options include increasing energy efficiency, electrification of processes particular heat generation, material efficiency, circularity and substitution, clean fuels including (green) hydrogen and biomass, and CCS. Depending on different scenarios for emission reductions, substitution effects exist between increasing electrification and direct use of renewables on the one side and improving energy efficiency on the other (Riemer et al., 2023). For quantified contributions of different mitigation options, please refer to table 1. All these mitigation options are considered across scenarios to achieve deep emission cuts, but most are not readily available facing different challenges (see section 3 and 4.2). Options to address these include:

Enhance competitiveness of clean technologies

To reduce its emissions in a way that is commensurate with the net zero goal, industry has to shift to alternative production technologies and processes. For this, it is key to make them competitive with established, fossil-based technologies and accelerate their market penetration. Many technologies needed to achieve net-zero are not yet commercially available nor economically viable. This is a significant bottleneck and a European solution to providing stable funding is an important enabler for the development of clean technologies. One possible lever to increase funding could be the EU's Innovation Fund. It has already distributed €3.6 billion in 2023, while its estimated disbursement capacity is €82 billion from 2025 to 2030. To effectively meet the needs of clean teach in the EU, another €22 billion are needed for the period 2025-2029 (Humphreys, 2023). While the EU ETS carbon price can enhance the competitiveness of clean technologies by increasing the (expected) cost of fossil technologies, making clean alternatives more attractive, additional action is needed to drive down the cost of clean production processes including innovation and broader market deployment.

Two potential instruments to bridge this gap increasing the investment security to support the shift to clean technologies, which may also operate in conjunction, are **carbon contracts for difference** and **green lead markets**. The first option, carbon contracts for difference, are agreements between a government or institution and an agent regarding a set carbon price for a fixed duration that can reduce price and investment uncertainty. The revision of the EU ETS Directive makes them available as a finance option under the Innovation Fund for future calls and some testing has started in Germany. The latter option, green lead markets, creates a specific market segment for certain, more environmentally sustainable products. Green lead markets can be created through green public procurement, regulations (quota for green products) or through voluntary actions. To establish such lead markets enabling conditions must be fulfilled, including labelling systems, tracking systems and product standards, clarifying what products are considered "low-carbon" or "climate-neutral" (Agora Energiewende, 2021; Agora Energiewende & WI, 2020; Agora Industry, 2022a; Deloitte, 2023; Mähönen et al., 2023).

Incentivise flexible electrification

Electrification plays an important role to reduce industrial emissions, both directly for heat generation (particularly low- and mid-temperature heat) and electrified processes, but also indirectly via green hydrogen and hydrogen derivatives, which can replace fossil fuels or feedstocks in industry. Yet for electrification to work, the electricity price must be competitive with other energy carriers (in particular natural gas). One important aspect of direct electrification is that it opens potential for demand-side flexibility. In industry, this could include thermal storage (power-to-heat) as well as adjusting production volumes, allowing consumption to increase or decrease depending on the availability of (surplus) renewable electricity, and therefore its price.

Investments and changes to industrial processes should incentivise such flexibility, thereby lowering the system cost of a renewable-based electricity grid and opening up a potential revenue stream for industry (IRENA, 2019). This requires easy and non-discriminatory participation in electricity markets. While the Electricity Directive foster demand-response, there is still some work to do in the Member States to implement the provisions (see e.g., smartEn, 2022). In addition, direct purchasing of green electricity from renewable energy projects may further allow for reducing the electricity price for industrial consumption.

Improve planning to allow for adequate infrastructure development

A key challenge is that transforming the industry sector requires complex adjustments to the existing physical infrastructure, including power grids, CO_2 (for Carbon Capture Utilisation and Storage (CCUS)) and heat, as well as (green) hydrogen, derivatives, and infrastructure for recycled materials needed for a circular economy, including waste management infrastructure ensuring the storing, treating, and disposing of industrial waste and materials. In most instances, investments into emission reductions are only viable if the necessary infrastructure is in place or will be put in place in a timely manner with reasonable certainty and at reasonable cost. For instance, the accessibility of electricity, hydrogen and CO_2 infrastructure for industrial sites requires coordinated infrastructure planning that establishes accessible and reliable grid systems. To deliver the necessary infrastructure, adequate planning must be ensured. This should happen at EU but particularly also on Member State level. National infrastructure planning should be part of the National Energy and Climate Plans (NECPs). This may also facilitate the further development and designation of regional industrial clusters and their interconnection. The NECPs could subsequently also function as benchmarks for other planning initiatives and EU financial instruments, like the Trans-European Networks for Energy ("TEN-E") or Projects of Common Interest (PCIs) (Agora Energiewende & WI, 2020).

Improve material circularity and efficiency of products

Reducing energy and resource consumption through additional measures for material circularity and efficiency can unlock significant emission reductions and lower the dependence on imports. Mechanical and chemical recycling have the potential to drive the development of non-fossil feedstock, substituting fossil fuels in products. However, material costs currently play a secondary role in economic decisions. There is a need for new material flows within the industry sector and from the end of a product's life back to the industry. This entails the development of innovative upcycling of materials and resource-efficient industrial processes. In some processes energy and material efficiency are already largely optimised, but in others the more efficient use of CO_2-intensive materials along value chains and different consumption areas can be targeted to significantly reduce emissions. Given that many CO_2-intensive products are used in construction, this sector plays a crucial role in increasing product circularity (see e.g., Agora Industry, 2022b; European Commission, 2024; Pfluger et al., 2023).

The regulatory framework plays a key role in unlocking the emission reduction potentials. This includes the proposal for an Ecodesign for Sustainable Products Regulation, building on the already existing Ecodesign Directive, as well as the proposal for a revision of the Construction Products Regulation (CPR) which is close to adoption. The former should also be concluded soon with holding-up the environmental ambition (ESABCC, 2024). The following work programme for specific products should make use of the opportunities delivered in the Regulation including lifecycle information and performance standards for products. The EU wide approach for standardising product information and performance, also in terms of recycling and reuse, work in favour of the EU Single Market and thereby ensures alignment of product standards across Member States. The proposed CPR is aligned with the proposed Ecodesign Regulation on climate and environmental sustainability requirements and on the digital product passport (see e.g., Agora Industry, 2022b; EP, 2024c). In addition, standards for minimum recycling quotes of materials with particularly high carbon-contents could further leverage existing potentials ensuring a business case such as recycled content requirements as outlined in the circular economy action plan. Measures to increase material efficiency include e.g., optimising the use of concrete and steel in construction through more precise calculations (Agora Energiewende & WI, 2020; ESABCC, 2024).

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