Towards EU climate neutrality

Progress, policy gaps and opportunities

Chapter 5: Industry

Assessment Report 2024

European Scientific Advisory Board on Climate Change

Contents

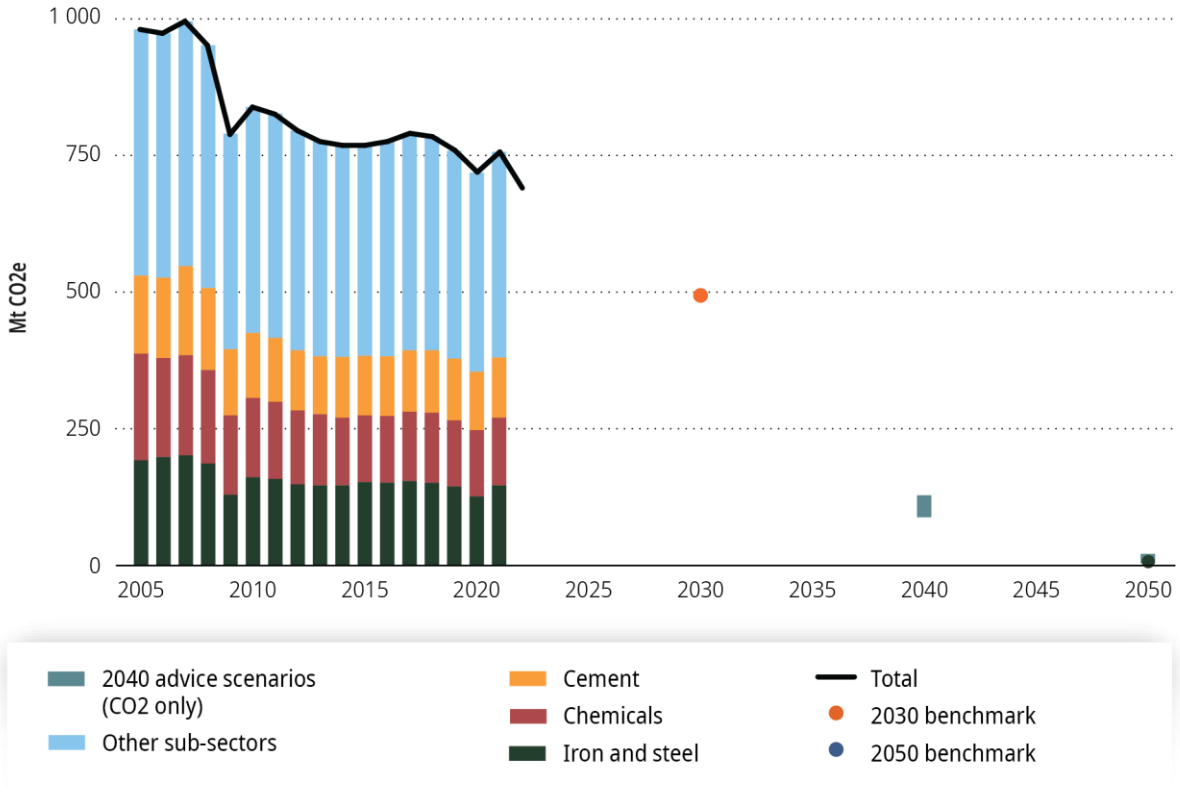
5 Industry

Key messages

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

The industry sector reduced its GHG emissions by 30 % in 2005–2022 (see Figure 20), while its gross added value increased by 33 %. In GHG-intensive sectors (iron and steel, cement, and chemicals), reductions were mainly driven by lowered production, while their use levels and GHG intensities [1] remained relatively stable. The increase in gross value added, in combination with declining production levels in GHG-intensive industries, suggests a shift of activities to less GHG-intensive subsectors.

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



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

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

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

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

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

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

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

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

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

Dedicated policies are needed to help low-emission industrial technologies reach full maturity (2)**.**

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

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

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

5.1 Scope and sectoral assessment framework

Scope

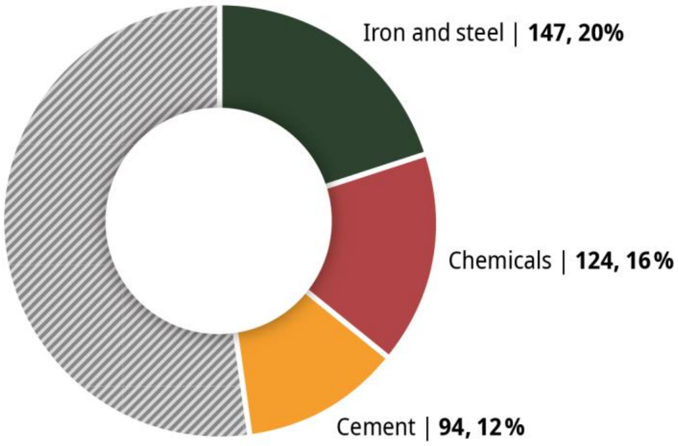
This chapter covers both the energy- and process-related GHG emissions from the EU industrial sector (CRF categories I.A.2 and 2 in the GHG inventories). It includes F-gases and emissions from construction activities but excludes emissions from petroleum refining and fossil fuel extraction (which are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

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

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

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

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



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

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

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

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

Assessment framework for the industry sector

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

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

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

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

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

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

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

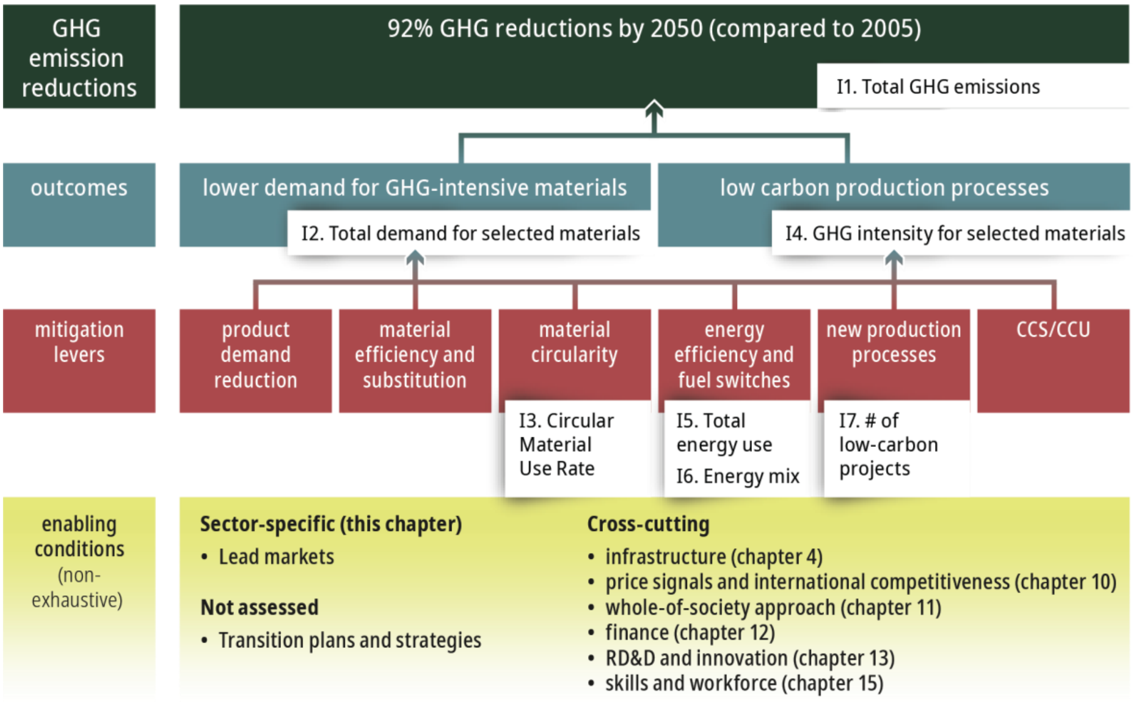
- **Price signals** – e.g. by means of carbon-pricing policies – can steer both consumer's choices and industrial producers' investment and operational decisions (see also Chapter 10 'Pricing emissions and rewarding removals').
- **Transition plans and strategies** are needed to coordinate the different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

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

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

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

Figure 22 Assessment framework for the industry sector



Source: Advisory Board (2024).

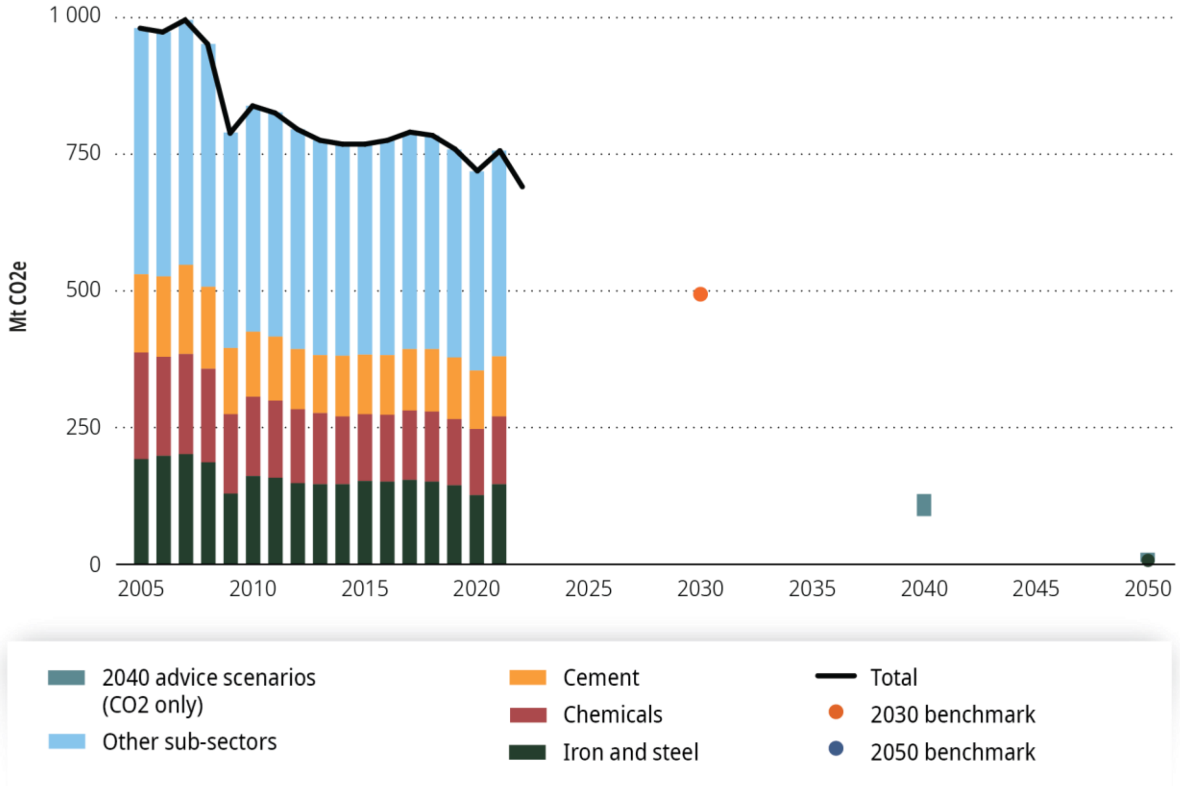
5.2 Emission reduction progress

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

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

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

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



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

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

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

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

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

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

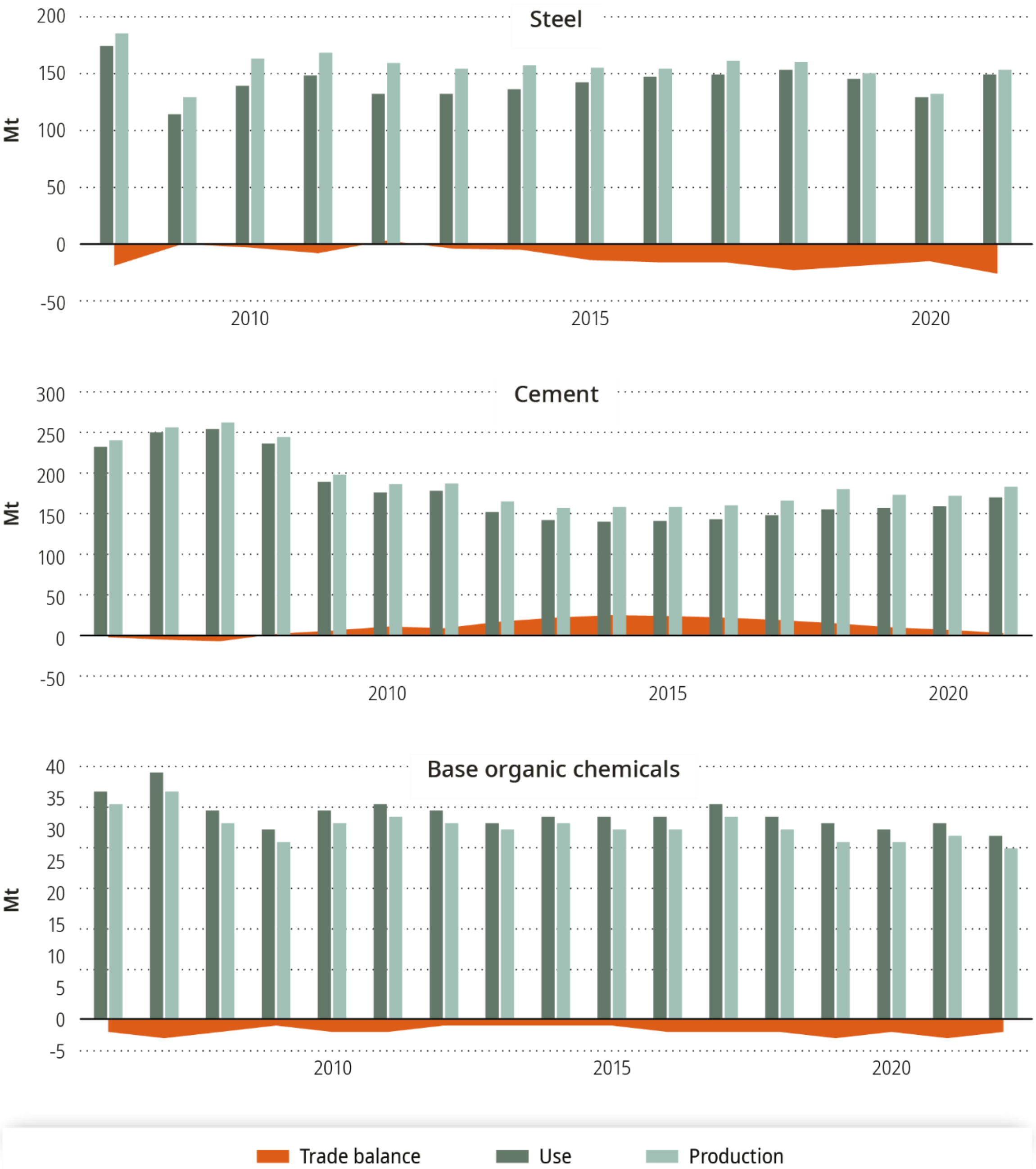
Figure 24 shows estimates of the use and production of steel, cement and chemicals in the EU, illustrating a pattern that largely follows economic cycles. The demand for these GHG-intensive materials decreased in 2008–2009 in the context of the economic crisis, and, although it has recovered somewhat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

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

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

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

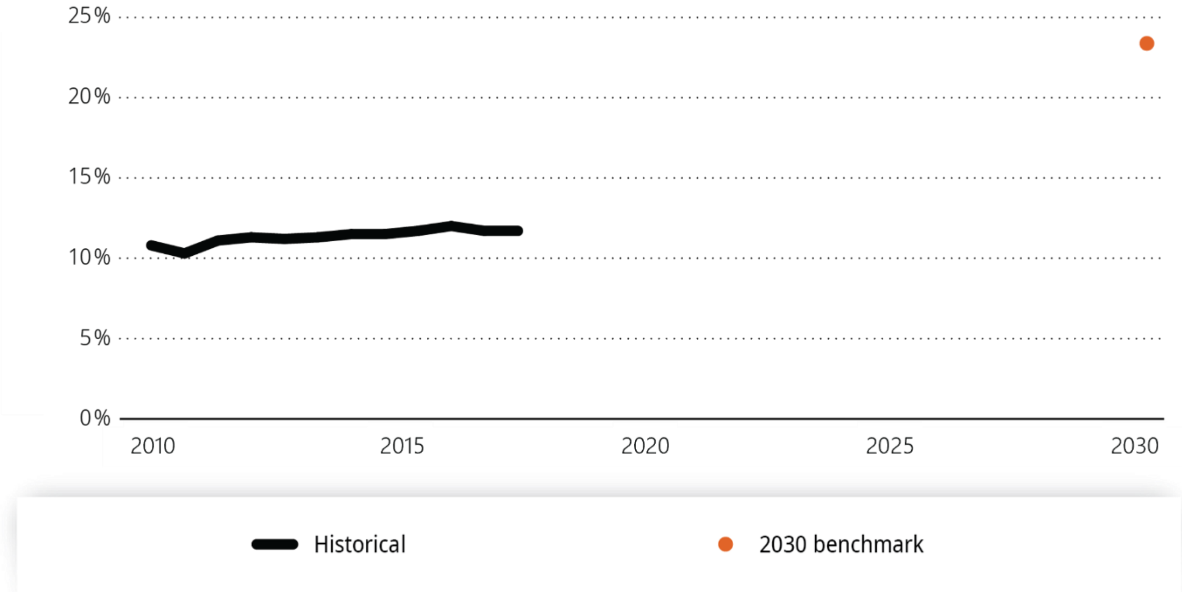
Figure 24 Indicator I2 – production, use and trade balance of steel, cement and base organic chemicals



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

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

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



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

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

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

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

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

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

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

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

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

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

5.4 Outcome 2: low-emission production processes

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

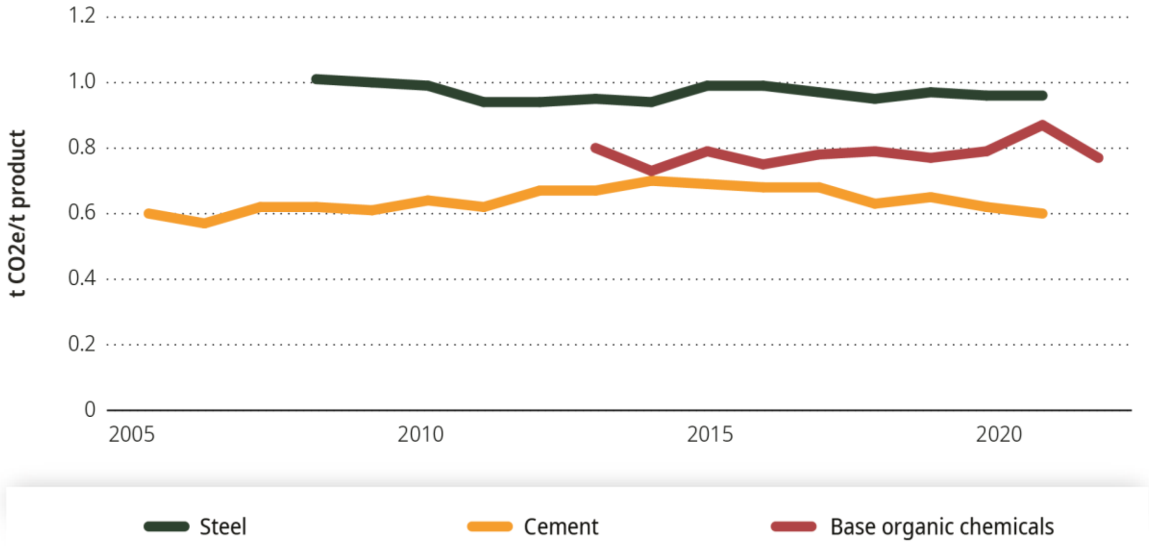
Estimates suggest that the GHG intensity of the selected GHG-intensive materials (steel, cement and chemicals) in the EU has been relatively stable or even slightly increasing, and observed trends in total emissions have been driven mainly by changes in production levels rather than reductions in emission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

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

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

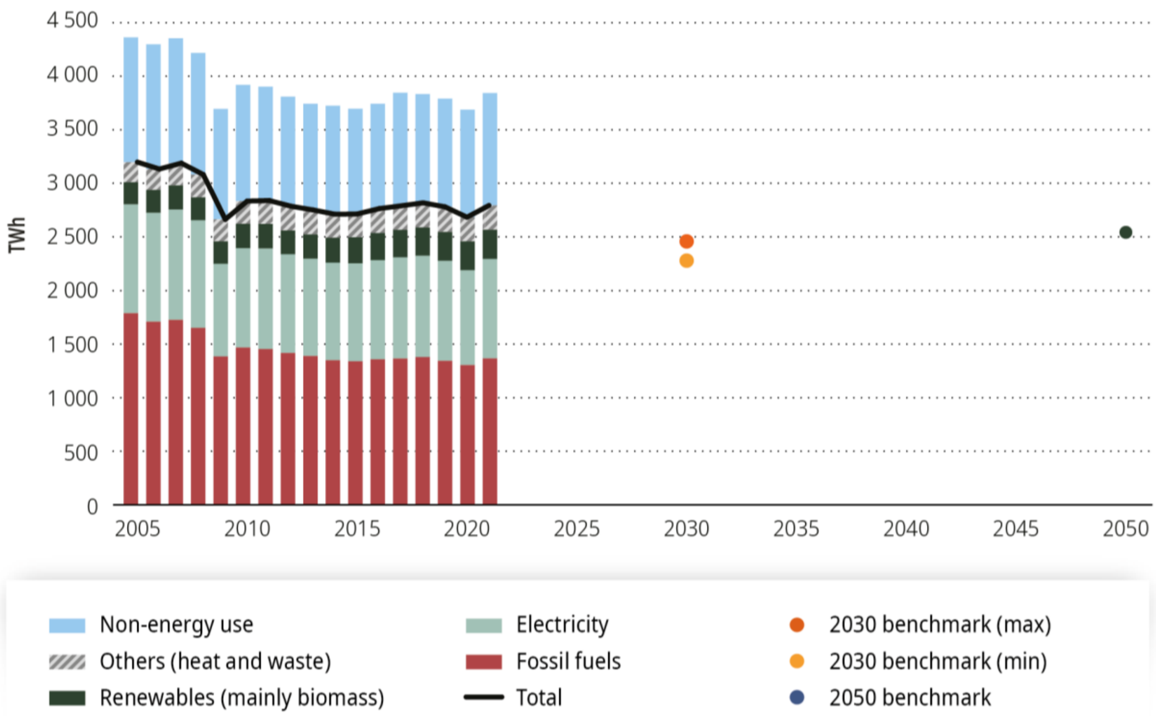
Under the European Commission's scenarios that underpin the EU's climate objectives, industrial energy use would need to reduce by on average 38 TWh per year up to 2030 (– 57 TWh per year under REPowerEU), which requires a reversal of recently observed trends.

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



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

Figure 27 Indicator I5 – final industrial energy use



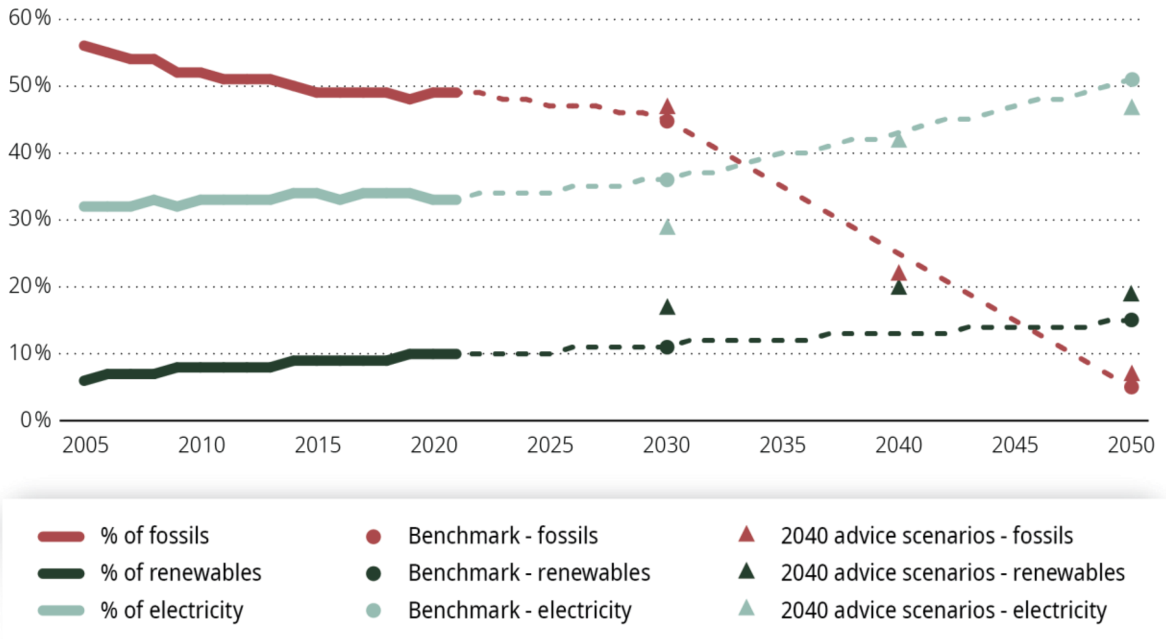
Notes: The max and min 2030 benchmarks based on the Fit for 55 MIX scenario and REPowerEU scenario respectively. The 2050 benchmark is based on the MIX scenario from the Climate Target Plan impact assessment (see Figure 67). All values were converted from kilotonnes of oil-equivalent to TWh.

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

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

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

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



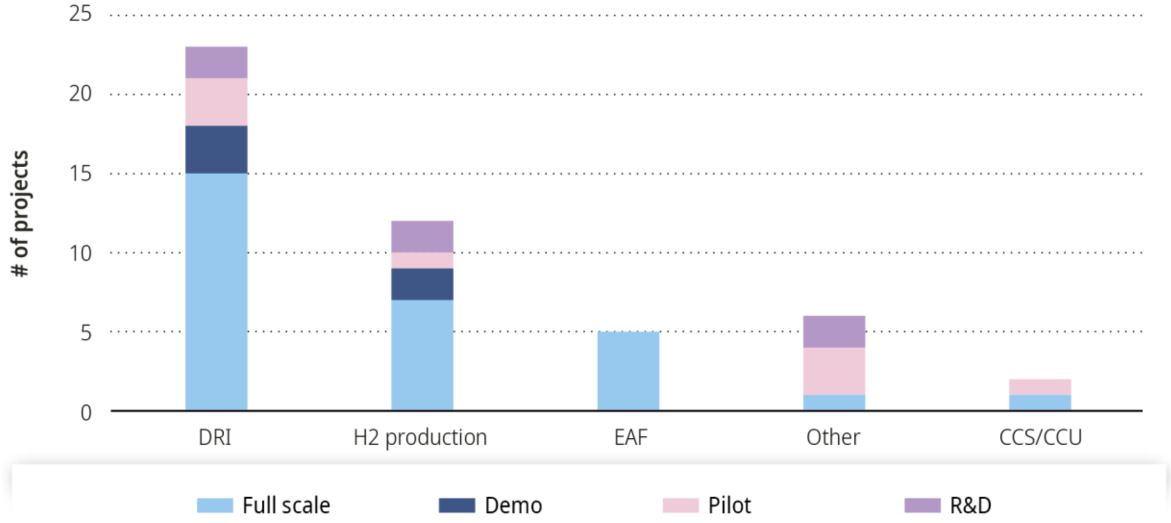
Notes: 2030 and 2050 benchmarks are based on the MIX scenario from the Climate Target Plan impact assessment (see figure 67). The 2040 advice values are based on the scenarios which underpin the Advisory Board's 2040 advice. The linear trajectories are shown to increase the readability of the figure,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

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

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

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

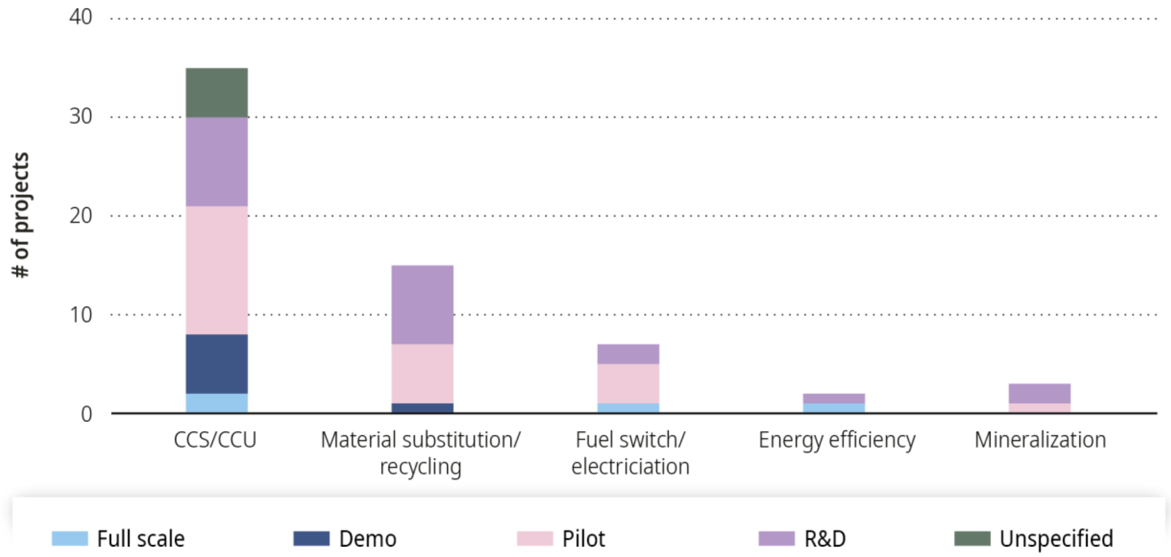
Figure 29 Indicator I7a – low-carbon projects in the steel sector by technology group and project scale



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

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

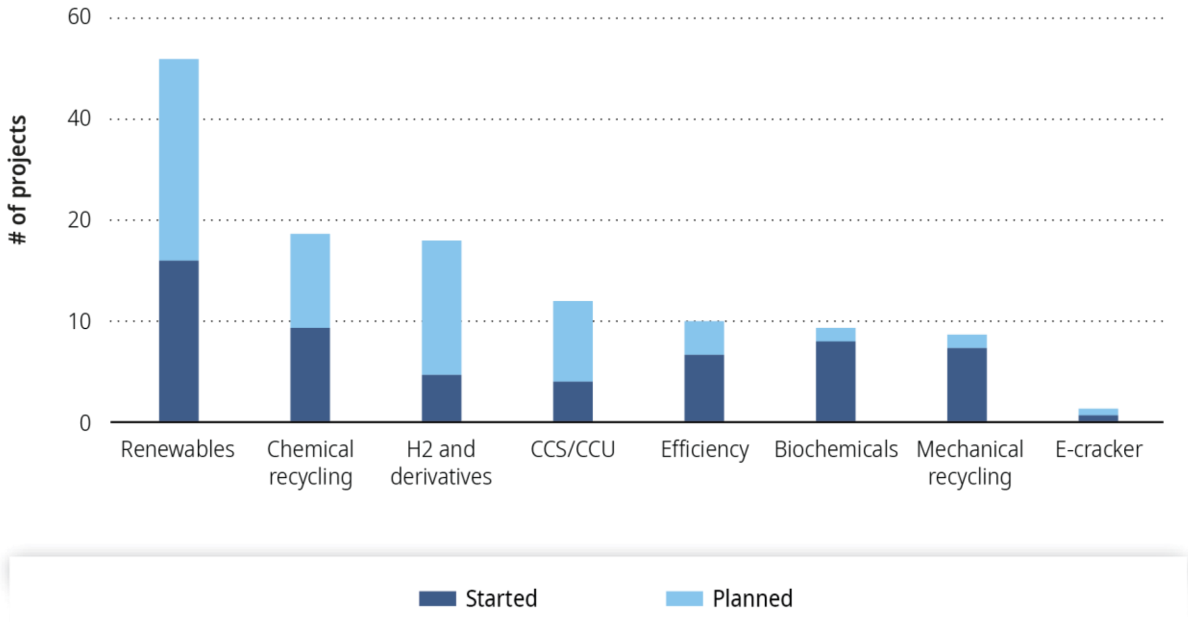
Figure 30 Indicator I7b – number of low-carbon projects in the cement sector by technology group and project scale



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

The chemical sector has reported 85 low-carbon projects that have already started in the EU, with another 86 currently planned ([3]), as shown in Figure 31. These projects cover a wide range of technologies, reflecting the different mitigation options available to the chemicals sector. The bulk of the projects relate to renewable energy, but these include many on-site solar PV parks, which are likely to contribute only a small share of those sites' energy needs. Chemical and mechanical recycling is also well represented, as are projects related to the use of low-emission hydrogen (and derivates) and the application of CCS/CCU technologies. Electric cracking is only being pursued by two projects. The sector overview does not provide consolidated information regarding the scale of the various projects, unlike the steel and cement sectors.

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



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

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

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

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

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

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

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

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

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

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

In addition to creating lead markets, new technologies could be supported by direct financial support by the EU and its Member States, which could cover investment or operational costs. CCfDs have been recommended to provide operational support for three reasons: firstly, they make it possible to provide adequate levels of support for new, low-carbon, but more costly technologies, without the need to increase the carbon price for the entire economy. Secondly, they increase investor certainty by providing a predictable, long-term level of support, which would also reduce financing costs ([4]). Finally, they reduce public expenditures and avoid windfall profits if the carbon price increases in future years (Chiappinelli et al., 2021; Neuhoff et al., 2019; Vogl et al., 2021). On the downside, there is a risk that CCfDs could lead to overcompensation, depending on the ability of producers to pass on the cost premium for low-carbon technologies. Furthermore, if CCfDs are allocated through tendering – which would be the most efficient approach – they would put regions with lower access to low-cost, renewable electricity at a disadvantage. Additional transitional support might be required for such regions to ensure a just transition towards climate-friendly industry (Vogl et al., 2021).

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

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

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

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

5.5 Summary tables

Table 6 Progress summary - industry

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

Legend

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

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

Table 7 Policy consistency summary - industry

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

European Scientific Advisory Board on Climate Change