European Environment Agency



Europe's industrial transformation

From environmental progress to clean competitiveness

EEA report

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Luxembourg: Publications Office of the European Union, 2026

ISBN: 978-92-9480-795-3
ISSN: 1977-8449
doi: 10.2800/9237455
TH-01-26-043-EN-N

EEA report 14/2026

Cover design: European Environment Agency
Cover photo: © European Environment Agency
Layout: Eworx/EEA

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Acknowledgements

The European Environment Agency (EEA) would like to thank its partners from the European Environment Information and Observation Network, its Scientific Committee, the Directorate-General (DG) for Environment, DG for Climate Action, DG Research and Innovation, DG for Energy, DG for Regional and Urban Policy, the European Commission Joint Research Centre — in particular for its guidance on analysis of data from the Integrated Database of the European Energy System — Cement Europe, as well as other reviewers and participants in expert workshops for their valuable contributions and input. It would also like to express gratitude for the contributions and analysis provided by Logika Group and Aether under contract to the European Environment Agency.

Key messages

- EU legislation has successfully contributed to mitigating industrial pollution; in the last 10 to 15 years **releases of key air pollutants from industry have more than halved.**
- **Progress has also been made on industrial resource efficiency**; since 2010, the EU's manufacturing sector generates significantly more economic value for each unit of water and raw material consumed.
- Despite progress, industry as a whole is a significant contributor to the EU's environmental and climate pressures, which in some areas are growing. As such **Europe needs to urgently scale clean industrial transformation**, while harnessing its benefits for strategic autonomy, resilience and long-term competitiveness.
- **While industrial resource efficiency has improved, the manufacturing sectors total water use is broadly unchanged** since 2010, despite growing concerns over water scarcity and resource dependency. In addition, the EU's **material footprint is above global average and circularity rates have stagnated.**
- Further, while total greenhouse gas (GHG) emissions have fallen substantially across industrial sectors, looking at emissions per tonne of product presents a less positive picture. For high-emitting sectors such as cement, and iron and steel, **CO_2 emissions per tonne of product produced have seen only marginal change or decline during the last 15 years**, indicating that much of emission reductions to date has not come from fundamental shifts towards decarbonized production processes.
- This evidence suggests that **key industrial sectors — particularly energy-intensive industries — have considerable scope to advance their clean transformation**; this presents an important opportunity to further support progress towards the EU's climate goals.
- The main challenge is no longer technology readiness, but system readiness. Despite technological progress, Europe is not on track towards establishing the enabling conditions needed for a clean industrial transformation; **funding gaps, insufficient infrastructure, high energy costs, weak demand and supply-chain constraints** continue to delay investments and the deployment of low-carbon and circular solutions at scale.
- The deep process changes required to transform energy-intensive industries will need to take place amid intensifying global competition. As a result, **environmental regulation, carbon pricing and stronger enabling conditions alone may not be sufficient** to steer industry through the transition while maintaining competitiveness.

- A coherent green industrial policy framework presents a critical opportunity for directionality for Europe by aligning competitiveness, environmental and climate objectives. This report argues that such a framework requires a carefully designed and integrated policy approach that balances:
    - **shielding**: protecting industry during the transition;
    - **scaling**: creating markets and scaling up clean solutions;
    - **restructuring**: restructuring and repositioning industry to align its strengths with clean value chains.

Executive summary

This report's three main objectives are:

- to take stock of EU industry's environmental and climate performance over the past 10 to 15 years;
- to assess progress in establishing the enabling conditions for a clean transformation;
- to identify strategic options towards a clean and competitive industrial base.

The evidence in this report suggests that Europe's industrial transformation challenge is now less about developing new technologies and more about deploying them at scale. While many industrial facilities already use viable low-carbon and circular technologies, wider uptake depends on policy certainty and the availability of enabling conditions such as the right infrastructure and clean and affordable energy. The scale and pace of industry's clean industrial transformation may increasingly depend on how quickly these conditions can be put in place. In an increasingly complex geopolitical landscape, decision-makers are faced with the challenge of balancing competing objectives and priorities. The report identifies three strategic options towards a clean and competitive EU industrial base in the long term:

- protecting industry during the transition;
- creating markets and scaling up clean solutions;
- restructuring and repositioning industry to align its strengths with clean value chains.

Clean industrial transformation is a strategic necessity for Europe's competitiveness and resilience

Europe's industry is central to the EU economy and provides essential products, jobs and technologies. Industrial activities also put significant pressure on the environment through greenhouse gas emissions, pollution, resource use and waste. Moreover, new pressures are emerging. These include a growing demand for critical raw materials, increasing exposure to climate risks, intensifying dependencies and competing demands for natural resources.

The transition to a cleaner, more circular and resource-efficient industry is therefore essential to achieving the EU's climate and environmental objectives, while strengthening industrial resilience. Investing in electrification, energy and water efficiency, circular business models, pollution prevention and low-emission production can reduce dependence on fossil fuels, exposure to resource scarcity, volatile energy prices and environmental risks.

The transition also presents opportunities for enhanced competitiveness. By using energy and materials more efficiently, European industry can improve productivity and operational efficiency, lower costs and create new economic and social opportunities. It can also help European firms tap into growing markets for low-carbon materials, clean technologies and circular solutions, while developing strategic value chains and new competitive advantages.

Pollution control has delivered results; transforming production is the next challenge

Evidence suggests that EU policies have already reduced key pollutants while maintaining overall economic growth. Over the past 10 to 15 years, releases of major air pollutants have fallen substantially: sulphur oxides (by 80%), nitrogen oxides (58%), particulate matter (76%) and heavy metals (80%). Water pollutants have fallen as well, albeit less significantly. Waste generation has decreased by 19%, while manufacturing has managed to generate the same economic value using less material and water inputs. These improvements reflect a combination of factors, including an evolving regulatory environment, end-of-pipe pollution controls, energy efficiency gains, fuel switching and changes in the structure of the European economy.

However, progress has been uneven. Although manufacturing has become more water-efficient, total water abstraction has increased by 3%. The EU's material footprint remains above the global average, and circularity rates have changed little since 2010. While total industrial greenhouse gas emissions have fallen and economic value has increased, reductions in CO_2 emissions per tonne of product produced have been more modest and uneven across sectors. This report looked at four sectors in depth and found that carbon intensities (CO_2 emissions per tonne of product) of cement, and iron and steel have seen only a marginal decline during the last 15 years, while emissions per tonne of product for aluminium and basic chemicals have declined more markedly, in particular in the more recent years. This suggests that part of the observed decoupling of total emissions from economic value reflects structural economic change — such as shifts towards higher-value activities — rather than a deep transformation of production processes.

In contrast to the trend in carbon intensity, the intensity of air and water pollutants has fallen more sharply because of the wide use of pollution-control technologies and the influence of environmental regulation, including emission limit values for major pollutants. However, these improvements are also showing signs of slowing. Overall, progress appears to have stalled across several environmental areas. These factors suggest that many of the gains achievable through incremental measures — such as energy and resource efficiency improvements, process optimisation and pollution controls — have already been realised. Achieving further reductions in environmental and climate impacts will require deeper transformations of industrial processes, technologies, value chains and business models.

Europe's clean industrial transformation is increasingly constrained by system readiness rather than technology readiness

The report finds that investment gaps, infrastructure bottlenecks, limited access to affordable clean energy and shortages of materials and skills continue to slow progress towards deep industrial transformation. The evidence suggests that despite a growing economic and environmental case for action, Europe has not yet created the necessary enabling conditions, resulting in delayed investment decisions. Increasingly, the pace of industrial transformation depends less on technological innovation itself and more on the coordinated development of supporting ecosystems.

First, Europe needs to close the estimated EUR 30 to 60 billion annual funding gap for industrial transformation by 2040 by using well-targeted public support to mobilise private investment. This goal requires further efforts to reduce investment risk and create a predictable demand for cleaner industrial outputs.

Second, key barriers to the transition need to be addressed. This effort includes speeding up infrastructure development for electricity, hydrogen and carbon capture, ensuring secure access to sustainable and recycled materials and strengthening Europe's technical skills base.

Third, Europe should reduce its dependence on imported fossil fuels by accelerating the deployment of low-cost, domestically produced renewable electricity and electrification. At the same time, Europe's strong innovation and patenting activity in clean technologies should be translated into greater deployment, particularly in the most emission- and resource-intensive sectors.

Finally, the transition will require policies that move away from unsustainable practices, build new industrial capabilities and ensure that workers and communities benefit from the changes.

The road to a cleaner industry

The next phase of industrial transformation will occur amid growing geopolitical tensions, resource constraints and international competition. As opportunities for incremental improvement become increasingly limited, environmental regulation, carbon pricing and support for enabling conditions alone may not be sufficient to steer industry through the transformation while maintaining competitiveness. In this context, a green industrial policy is an increasingly important complement to environmental policy, offering a critical opportunity for directionality and aligning the EU's competitiveness agenda with environmental and climate objectives. The evidence suggests that a successful transformation requires a well-designed and coherent policy approach that balances shielding, scaling and restructuring the EU's industrial base.

'Shielding' refers to safeguarding strategically important capabilities and avoiding the loss of industrial capacities during periods of rapid change. However, competitiveness and sustainability cannot be reconciled through protection alone. This gap points to a need for industrial policies that not only safeguard existing economic activity but also facilitate the structural changes required for long-term sustainability and competitiveness. **Scaling** involves accelerating the growth and deployment of emerging industries, technologies and business models that can contribute to competitiveness and sustainability objectives. **Restructuring** recognises that some industrial activities, production processes and regional economies will need to adapt more fundamentally to changing environmental, economic and technological realities. These measures could help industry manage the significant upfront costs of the transition, remain competitive in the short to medium term and deliver the long-term environmental, economic and social benefits of a cleaner and more resilient sector.

Box ES.1

Evidence base for assessing industrial transformation

This assessment draws on a diverse evidence base, which includes regulatory reporting, facility-level environmental data, industrial and economic statistics and other publicly available information. Together, these sources make it possible to identify and track the emerging signals of industrial transformation across sectors.

However, the strength of the evidence varies considerably. Some signals are supported by well-established, detailed and comparable datasets, while others rely on more fragmented or qualitative information. As a result, confidence levels differ between signals and should be considered when interpreting the findings. Additionally, important data gaps persist that limit our understanding of industrial transformation. These include a lack of baseline data on technology uptake at facilities.

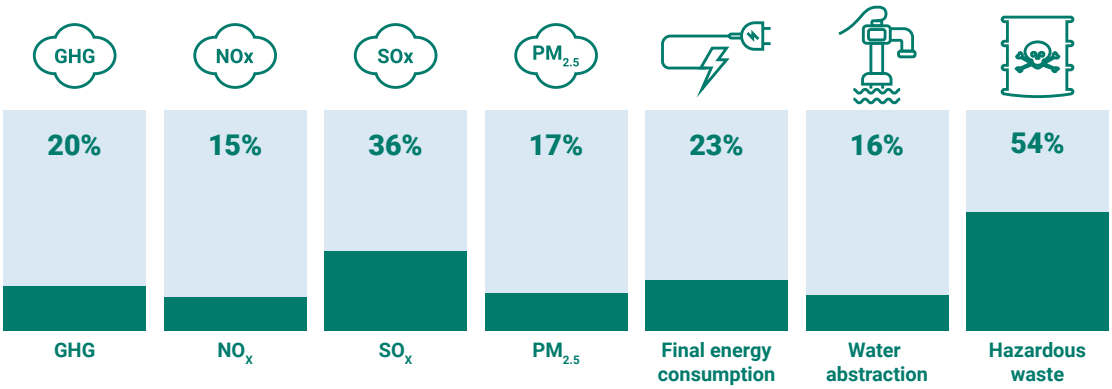
Strengthening the evidence base does not necessarily require additional reporting obligations. Greater benefits may come from better-designed reporting requirements, improved interoperability of datasets and the use of digital tools and emerging technologies to collect, verify and analyse information more efficiently. These changes could support better assessments of industrial transformation in the future, while helping to minimise reporting burdens for industry.

1 Introduction

Europe has demonstrated significant leadership in environmental and climate policy over the last three decades. Despite significant achievements, climate change and environmental degradation continue to intensify. Their impacts increasingly interact across systems and accumulate over time. This raises growing concerns about the capacity of natural systems to continue providing essential life-support functions, long-term competitiveness and resilience (EEA, 2025a).

Within this context, industry plays a vital role. Europe's historically ambitious environmental policies have already paid off, driving substantial reductions in industrial emissions of pollutants and improving environmental performance across sectors. However, despite signs of both relative and absolute economic decoupling in some areas, industrial activities continue to contribute substantially to climate and environmental pressures. In several areas, industry's share of these impacts is significant (Figure 1.1).

Figure 1.1 **Share of selected environmental and climate pressures caused by industry in Europe**



Notes: 'Industry' in this figure refers to the sectors listed in Table 1.1, with a few exceptions. For a full breakdown of sub-sectors and a sector-to-figure coverage matrix see Annex.
GHG, greenhouse gas; NO_x, nitrogen oxides; SO_x, sulphur oxides; $PM_{2.5}$, particulate matter ≤ 2.5µm.

Sources: European Environment Agency (EEA) elaboration based on multiple sources (see Annex).

Industry plays a central role in Europe's economy. The manufacturing sector alone employed around 30 million people and generated approximately EUR 2.5 trillion in value added in 2023 (Eurostat, 2026b). A transition towards clean, decarbonised, circular and resource-efficient industrial facilities is, therefore, critical for safeguarding Europe's environmental baseline — as well as future-proofing its economy. Moreover, as the pressures for global resources intensify, higher resource productivity provides a significant competitive edge for European industry.

The European Union's (EU's) strategic policy frameworks reinforce this direction:

- The zero pollution action plan (ZPAP) highlights the need to reduce industrial emissions.
- The Fit for 55 package and Clean Industrial Deal (CID) aim to accelerate industrial decarbonisation through stronger carbon pricing, affordable energy and the deployment of clean technology.
- The water resilience strategy and the forthcoming Circular Economy Act emphasise the role of industry in strengthening EU resilience and strategic autonomy through more efficient and sustainable management of water and material resources.

A combination of incremental improvements and deeper shifts in production processes, material choices and value chains is necessary to address the remaining interlinked challenges. Achieving this in specific sectors may require major reorientations in systems goals, incentives, social practices and norms.

Policymakers designing Europe's industrial and economic strategy no longer need to question whether transformation is necessary. The issue now is whether current developments are aligned with the pace and scale needed to achieve a sustainable, clean, circular, resource-efficient and climate-neutral economy by 2050, as set out in Directive 2010/75/EU (the Industrial Emissions Directive, IED). A further challenge lies in facilitating a transition that maximises long-term competitiveness.

Many of the sectors central to these pressures — in particular energy-intensive industries — are at a critical juncture. Economic strain is slowing or delaying the investment decisions needed to support deep transformation. Each year of delay risks further lock-in of long-lived unsustainable assets and value chains or a loss of crucial industrial capacity.

Moreover, structural decline in industrial capacity would erode a cornerstone of Europe's social and economic fabric. It would also risk displacing environmental and climate impacts beyond EU borders. Although the pressures differ across sectors and Member States, many industries face similar challenges:

- insufficient infrastructures for clean technologies;
- high investment needs;
- elevated energy and labour costs relative to global competitors;
- weak domestic demand and structural overcapacity for products such as steel.

The dynamic outlined above has sharpened the policy debate on how to better reconcile environmental ambition with economic resilience. In response, EU-level initiatives such as the CID frame circularity and industrial decarbonisation not as a cost but as a strategic pathway to sustain competitiveness, strengthen resilience and secure Europe's social and economic foundations in the long term.

Against this background, this report assesses industry's environmental and climate performance over the past 10-15 years. In doing so, it aims to highlight drivers of change and areas that require further attention. The report also examines progress in establishing the enabling conditions for transformation, including access to clean energy, the development and uptake of technology, clean manufacturing capabilities as well as finance and market conditions. It identifies a number of high-level signal

indicators [1] which together offer a framework to regularly monitor and evaluate progress towards a clean industrial transformation.

The challenges facing European industry are increasingly well documented; however, there is less clarity on the strategic pathways available for simultaneously advancing sustainability, resilience and competitiveness. As such, a key objective of this report is to identify strategic options that can help guide industrial transformation in the years ahead. The report also explores how transforming Europe's industrial facilities generates opportunities for competitiveness in an increasingly complex geopolitical and policy landscape.

This report is structured as follows:

- **Chapter 2** provides an overview of the policy landscape shaping industrial transformation at the EU and Member State levels; it maps key legislative frameworks, strategies and governance arrangements that set out the context for assessing industry's environmental and climate performance.

- **Chapter 3** presents evidence relating to industry's environmental and climate performance in the last 10-15 years [2]; it groups the information according to sectors across extractive industries, the manufacturing sector and utilities (Table 1.1).

- **Chapter 4** assesses progress on the enabling conditions supporting or hindering industrial transformation, analysing factors such as access to clean energy, the development and uptake of technology, clean manufacturing capabilities as well as finance and market conditions.

- **Chapter 5** examines the broader conditions required to sustain industrial transformation over the long term; it explores the roles of culture, people and places, the contribution of destabilisation and phase-out policies in driving structural change, and the importance of transformative resilience in enabling industry to adapt to future environmental, economic and geopolitical challenges.

- **Chapter 6** examines the benefits of a clean industrial transformation for competitiveness; it explores strategic priorities towards the dual objectives of industrial competitiveness and sustainability, with a focus on energy-intensive industries.

(1) In this report, a 'signal' refers to an observable development that may indicate progress, stagnation or emerging challenges in the transition towards a clean, circular and competitive industrial system. Signals should be interpreted in the context of their scale, pace and potential to drive structural change.

(2) In order to balance a sufficiently long timeframe for identifying structural trends with the need to reflect recent developments in industrial transformation, this report focuses on the 2010-2024 period. This also corresponds to the period for which consistent and comparable data are available across most indicators analysed in this report.

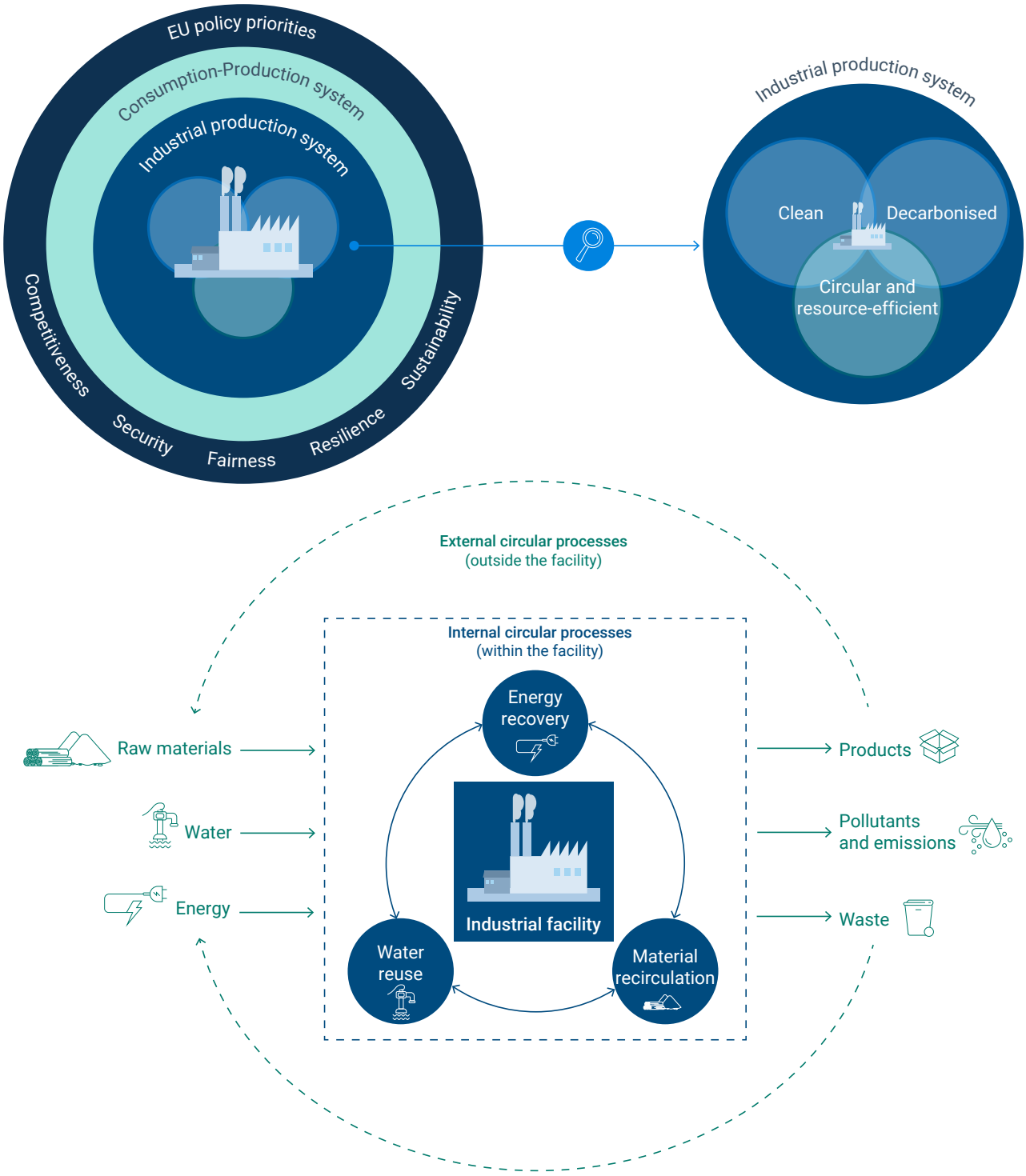
In this report, **competitiveness** is understood not simply as a measure of cost but as a key strategic goal embedded in EU industrial policy; it refers to the aim to compete through innovative products and address decarbonisation and strategic autonomy while enhancing sustainability and social cohesion (Draghi, 2024b; JRC, 2026a; EC, 2025n). Enhancing industrial competitiveness has become a policy priority in the face of:

- rapid technological advancements;
- escalating economic competition;
- competition for control of key enabling infrastructures and value chains;
- trade protectionism.

Thus, there is a growing consensus that a major shift is needed from an industrial policy focused on industry protectionism and correcting market failures towards integrated policy strategies that transform industry (EP, 2026a; Nilsson et al., 2021). This report further identifies opportunities for competitive clean industrial transformation to avoid losses, strengthen resilience and create new economic and social opportunities.

Industrial transformation is a complex process of change involving many stakeholders, activities and value chains. The revision of the IED frames transformation as industry's contribution 'to the emergence of a sustainable, clean, circular, resource-efficient and climate-neutral economy by 2050'. Based on this definition, this report uses the term industrial transformation broadly; it is understood as a shift in industrial systems towards these objectives, supported by the wider socio-economic and governance conditions that enable such change. Throughout the report, the term 'clean industrial transformation' will be used to illustrate this concept.

Figure 1.2 **Conceptual framework for the report**



Source: EEA elaboration.

Industry can be classified in multiple ways, including as value-chain based industrial ecosystems (EC, 2026a) or aggregated thematic groups of industry such as energy-intensive industries or the clean tech sector. As this report centres on the transformation of industrial facilities, it uses a sectoral classification based on the main industrial activities covered by the scope of the European Pollutant Release and Transfer Register (E-PRTR) [(3)].

Underlying datasets across impact categories use different sectoral classifications; as such, the granularity and scope of information varies across data sources. To ensure consistency, we have harmonised sector groupings as far as possible. Throughout the report, the term 'industry' refers to these harmonised groupings (Table 1.1) unless otherwise specified.

The chosen groupings aim to strike a balance between maintaining comparability across EU-level datasets and preserving granularity where the data allow. Where relevant and possible, the report highlights climate and environmental performance at a more detailed level for sub-sectors such as iron and steel, cement and basic chemicals.

Table 1.1 Sectoral classification of industry used in this report

Extractive industries	Manufacturing industries	Energy and utilities
Mining	Metals	Water- and wastewater treatment
	Minerals (excluding mining)	Waste management
	Chemicals	Energy [(a)]
	Pulp, paper and wood	
	Food and drink	
	Other manufacturing (including textiles)	

Notes: 'Metals' include ferrous and non-ferrous metals. For a full breakdown of sub-sectors and a sector-to-figure coverage matrix, see Annex.

(a) The energy sector (herein including activities such as electricity and heat generation, coke manufacturing and refineries) is generally treated separately from industry in statistical classifications. However, in selected parts of this report, data on the energy sector are included where they reflect relevant environmental pressures arising from associated industrial activities. This approach aims to provide a more comprehensive picture of pressures from large point sources across the industrial system.

Source: EEA elaboration.

(3) Replaced by the Industrial Emissions Portal Regulation (IEPR) from the 2028 reporting cycle.

2 Policy drivers of clean industrial transformation

Key messages

- The EU policy framework for industrial transformation has evolved; it began with a focus on environmental protection but now encompasses an increasingly integrated agenda combining competitiveness, resilience and sustainability objectives.
- Policy ambition is increasingly comprehensive, but there are implementation bottlenecks which represent a major constraint for the scale and pace of industrial transformation.
- Achieving climate neutrality, zero pollution and circularity objectives require greater attention to the enabling conditions for transformation, policy coherence and more integrated planning across governance levels.

This chapter begins by providing an overview of the EU policy landscape for a clean industrial transformation across environmental and climate objectives. It then explores how these objectives are reflected in national planning documents and strategies for industrial transformation. Finally, it provides illustrative examples of how Member States go beyond EU-mandated planning instruments to develop industry- and sector-specific transformation plans and roadmaps.

2.1 The EU policy landscape shaping industrial transformation

The European Green Deal presented the strategic framework for a green transition of the European economy. It set out the EU's ambition to achieve net climate neutrality by 2050, by:

- ensuring a clean, affordable and secure energy supply;
- moving towards zero pollution for a toxic-free environment;
- mobilising industry for a clean and circular economy.

Building on this, the Eighth Environment Action Programme (8th EAP) — the EU's strategic framework for environment policy up to 2030 — aims to reduce key environmental and climate pressures linked to economic activities, including industry. As part of this agenda, the zero pollution action plan (ZPAP) sets out a vision whereby air, water and soil pollution will be reduced to levels no longer considered harmful by 2050.

More recently, the competitiveness compass has situated competitiveness and strategic autonomy more prominently in the EU's policy agenda. Meanwhile, the Clean Industrial Deal (CID), launched in February 2025, sets out concrete actions to turn decarbonisation into a driver of growth for European industries.

Table 2.1 presents a non-exhaustive list of key EU strategies and instruments for clean industrial transformation. It indicates progressive strengthening of the policy landscape towards the EU's ambitions for a climate-neutral, circular and zero-pollution economy. The progression can be broadly categorised into three waves:

- Wave 1: pollution control and environmental protection (1980s-2000s);
- Wave 2: decarbonisation and resource efficiency (2010-2020);
- Wave 3: industrial transformation, resilience and competitiveness (2021-today).

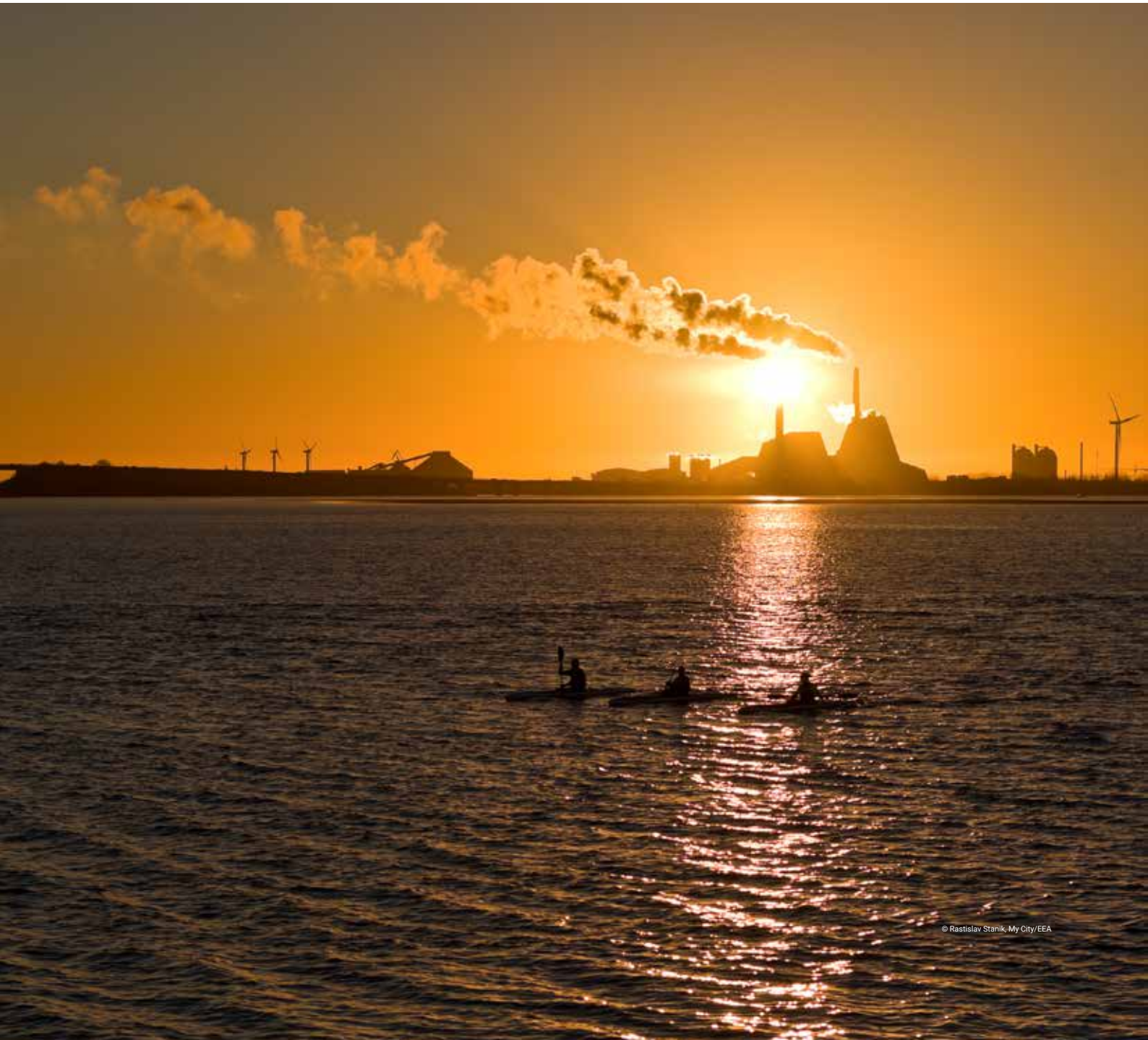


Table 2.1 Overview of EU policy instruments supporting decarbonisation, pollution prevention and circularity for industrial transformation

	Wave 1: pollution control and environmental protection (1980s-2000s)	Wave 2: decarbonisation and resource efficiency (2010-2020)	Wave 3: industrial transformation, resilience and competitiveness (2021-today)
Legislative instruments	Seveso (1982) Environmental Impact Assessment Directive (1985) UWWTD (1991) Water Framework Directive (2000) NECD (2001) EU ETS (2003) Energy Taxation Directive (2003) Environmental Liability Directive (2004) REACH Regulation (2006) Ambient Air Quality Directive (2008) Waste Framework Directive (2008)	IED (2010) Seveso (2012) EED (2012) Environmental Impact Assessment Directive (2014) NECD (2016) Waste Framework Directive (2018)	EU ETS (2023) RED III (2023) EED (2023) UWWTD (2024) IED (2024) Ambient Air Quality Directive (2024) CRMA (2024) Ecodesign for Sustainable Products Regulation (2024)
Economic and financial instruments		Modernisation Fund (2018) Innovation Fund (2020)	Just Transition Mechanism (2021) InvestEU (2021) Horizon Europe (2021) CBAM (2023) CISAF (2025) Competitiveness Fund (forthcoming) EU Decarbonisation Bank (forthcoming)
Strategic direction	5th EAP (1993) Lisbon Strategy (2000) Sustainable Development Strategy (2001) 6th EAP (2002)	7th EAP (2013) CEAP (2015) European Green Deal (2019) EU industrial strategy (2020) Chemicals strategy for sustainability (2020) New CEAP (2020) European Climate Law (2020)	Fit for 55 package (2021) ZPAP (2021) 8th EAP (2022) REPowerEU (2022) EU grids package (2023) CID (2025) Affordable energy action plan (2025) Water resilience strategy (2025) EU electrification action plan (2026) Industrial Accelerator Act (forthcoming) Circular Economy Act (forthcoming)

Notes: Several EU instruments relevant for industrial transformation do not fit neatly into a single category; initiatives such as the Industrial Accelerator Act combine strategic direction with regulatory, economic and enabling elements. Sector-/product-specific instruments, such as the Packaging and Packaging Waste Regulation and the End-of-Life-Vehicles Regulation, are not included in the table.

8th EAP, Eighth Environment Action Programme; CBAM, Carbon Border Adjustment Mechanism; CEAP, circular economy action plan; CID, Clean Industrial Deal; CISAF, clean industrial state aid framework; CRMA, Critical Raw Materials Act; EED, Energy Efficiency Directive; EU ETS, European Union Emissions Trading System; IED, Industrial Emissions Directive; NECD, National Emission reduction Commitments Directive; REACH, registration, evaluation, authorisation and restriction of chemicals; RED III, Renewable Energy Directive (recast, 2023); UWWTD, Urban Wastewater Treatment Directive; ZPAP, zero pollution action plan.

Source: EEA elaboration.

Key EU instruments across policy objectives

While EU policy frameworks increasingly address industrial transformation in an integrated manner, this section presents key legislative instruments across decarbonisation, zero pollution and circularity as distinct policy objectives. The focus is on instruments that directly affect industrial facilities and economic activity.

Decarbonisation and climate neutrality. The EU's net climate neutrality objective — defined in the European Climate Law — drives a robust set of policies for industrial decarbonisation.

The EU Emissions Trading System (EU ETS) sets out a carbon price signal to reduce greenhouse gas (GHG) emissions from power and industry; an emissions cap decreases annually on a trajectory in line with meeting 2030 emissions targets. Revenues from the EU ETS partly feed into the Innovation Fund, which supports innovative low-carbon projects in energy-intensive industries.

The Net-Zero Industry Act (NZIA) complements these aims by targeting domestic industrial capacity for clean technologies. For example, it sets out an aim for 40% of key net-zero technology components to be made in the EU by 2030. It also outlines the need for the EU to have at least 50 million tonnes (Mt) of annual carbon dioxide (CO_2) injection capacity [4] by 2030.

The Renewable Energy Directive (RED) and Energy Efficiency Directive (EED) — updated under the Fit for 55 climate package — set binding targets to boost the share of final energy consumption derived from renewable energy sources (with a target of 42.5% by 2030) and improve energy efficiency, thereby enabling industry to be able to access clean and affordable energy. In addition, the EED requires industrial installations to carry out independent energy audits and Member States to monitor and report the energy performance of data centres.

In March 2026, the European Commission (EC) adopted a legislative proposal for an Industrial Accelerator Act. It is designed to boost demand for low-carbon industrial outputs and will cover strategic sectors such as steel and cement.

Adopted in July 2026, the EU Electrification Action Plan proposes a new, indicative EU electrification target of 46% by 2040, referring to the share of electricity in final energy consumption. This is part of the post-2030 energy union package and will facilitate the decarbonisation of end-use sectors, including industry.

These measures create important incentives and pathways for industry to shift to low-carbon energy sources and processes, aligning with the EU's mid-century climate neutrality goal. They also directly support key enabling conditions: accelerating renewables and electrification improves access to clean energy, while carbon pricing and technology mandates spur industrial innovation and adoption.

Zero pollution and emissions control. Achieving a toxic-free environment and clean air and water is another pillar of the EU industrial transformation agenda.

The IED, revised in 2024, is a central instrument for this. It defines strict emission and environmental performance levels for industrial installations. It also requires industrial operators to adopt best available techniques (BATs) to reduce — among other things — emissions to air, water and soil. The revision introduces provisions

(4) Injection capacity is the amount of CO_2 that can be injected annually into operational geological storage sites for permanent storage.

to better integrate resource efficiency, circularity and decarbonisation within the BAT framework.

The 2024 revised Ambient Air Quality Directive sets stricter air quality standards and — in cases where the 2030 limit values are at risk of not being achieved — requires Member States to establish air quality roadmaps.

Meanwhile, the National Emissions reduction Commitments Directive (NECD) imposes national caps on key pollutants (e.g. nitrogen oxides (NO_x), sulphur dioxide (SO_2) and particulate matter ≤ 10µm (PM_{10}). The 2030 reduction targets push Member States and industries to implement measures consistent with the ZPAP (aiming to drastically cut the health impacts of pollution by 2030 and reach near-zero pollution by 2050).

The (recast) Urban Wastewater Treatment Directive (UWWTD) provides additional steer for wastewater management. The Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) Regulation — and, to some extent, the Seveso III Directive — is one of the main policies directly impacting industry in terms of managing chemical risks.

These instruments collectively ensure industry adopts cleaner processes, thereby promoting industrial innovation as companies must implement new technologies to meet stricter emission standards. Importantly, as air pollutants and GHG emissions often originate from the same source, policies for preventing industrial pollution deliver important co-benefits for climate change mitigation (EEA, 2022b).

Circular economy and resource efficiency. Critical raw materials (CRMs) must be secured to scale up industry's use of renewables, electrification and digitalisation. The Critical Raw Materials Act (CRMA) was adopted in 2024 to reduce Europe's supply risks. It includes benchmarks for domestic capacity. By 2030:

- At least 10% of the EU's annual consumption of strategic raw materials must be extracted domestically;
- At least 40% of annual consumption must be processed domestically;
- At least 25% of annual consumption must be recycled within the EU.

Meanwhile, the circular economy action plan targets resource-intensive sectors and drives product design and waste legislation to increase reuse and recycling. It is complemented by broader sector initiatives. The EU monitors progress through indicators such as the circular material use rate (with a goal to raise it from around 12% in 2024 to 24% by 2030); this represents a key performance indicator.

Targets for recycling apply for certain types of waste — such as packaging waste, end-of-life vehicles and waste electrical and electronic equipment — rather than by industrial sector. The Circular Economy Act — expected in late 2026 — is envisaged to increase the supply of high-quality recycled materials and further strengthen secondary raw materials markets which currently only function well for a few materials (EEA, 2022c).

Circular economy considerations are also increasingly integrated into the IED — including through the conclusions on BATs for resource efficiency and material use. While many installations have made progress, the IED has had a limited role in advancing circularity thus far (Wood, 2021). There is potential to positively impact the accelerated uptake of circularity and resource efficiency measures at industrial

facilities by shifting from performance ranges and qualitative benchmarks towards more quantitative standards similar to BAT-associated emission levels [5].

2.2 National plans and strategies for industrial transformation

Member States use a range of EU-mandated strategy and planning tools across sectors to support industrial decarbonisation, pollution reduction and circularity; there is currently no single plan dedicated to this sector of the economy. Table 2.2 highlights the range of plans and programmes prepared by national governments under various policy frameworks. They each address distinct but complementary objectives linked to clean industrial transformation.

Table 2.2 Key EU-mandated national planning instruments relevant for clean industrial transformation

National planning instrument	EU policy framework/legal basis	Key industry-relevant objectives
NAPCPs	NECD (EU) 2016/2284	Reduction of SO_2, NO_x, NMVOCs, $PM_{2.5}$ from industrial processes and combustion; technology upgrades
National and regional air quality plans and roadmaps [a]	Ambient Air Quality Directive (EU) 2024/2881	May include measures to reduce air pollution from industrial sources under the IED and through the use of economic instruments such as taxes, charges or emission trading
NECPs	Governance Regulation (EU) 2018/1999 EU Climate Law	Industrial decarbonisation pathways; energy efficiency improvements; fuel switching; electrification, hydrogen and carbon capture and storage (CCS) deployment
LTSs	Governance Regulation (EU) 2018/1999 EU Climate Law	Structural transformation of energy-intensive industries; investment signals for low-carbon technologies; infrastructure planning
NEEAPs	EED	Reduction of industrial energy demand; mandatory audits and energy management systems; efficiency investments
RBMPs	Water Framework Directive	Limits on industrial water abstraction and discharges; control of priority substances; water efficiency and reuse
Waste management plans, waste prevention programmes and circular economy strategies	Waste Framework Directive	Resource efficiency; reduced material use and waste generation in processes and products; turning waste into secondary raw materials

Notes: Circular economy strategies are not mandated under the Waste Framework Directive but are voluntary national plans that guide efforts towards the development of a circular economy.

(a) An air quality plan sets out measures to achieve compliance after limit or target values have been exceeded. An air quality roadmap is adopted before the compliance deadline and identifies the actions needed to meet the limit and target values. Furthermore, Member States may need to establish short-term action plans with emergency measures to reduce an immediate risk or limit the amount of time an alert threshold is being exceeded.

NAPCPs, national air pollution control programmes; NECPs, national energy and climate plans; SO_2, sulphur dioxide; NO_x, nitrogen oxides; NMVOCs, non-methane volatile organic compounds; $PM_{2.5}$, particulate matter ≤ 2.5µm; LTSs, long-term climate strategies; NEEAPs, national energy efficiency action plans; EED, Energy Efficiency Directive; RBMPs, river basin management plans.

Source: EEA elaboration.

(5) The pollutant concentration ranges that industrial installations must meet when applying Best Available Techniques under EU Directive 2010/75/EU.

Key policies and measures (PaMs) in Member States' national plans

The national planning instruments listed in Table 2.2 set out relevant strategies, priorities and targets. A review of implemented and planned PaMs — drawing on the EEA-hosted GHG PaMs database, the NECD PaMs database and other sources — highlights several cross-cutting observations discussed in the sections below.

Decarbonisation and climate neutrality

Member States have been reporting for well over a decade on PaMs that limit and/or reduce GHG emissions. National energy and climate plans (NECPs) first took shape in 2020. They are strategic planning tools that enable countries to outline actions and policies to achieve their 2030 climate and energy targets.

NECPs vary in terms of how much detail they provide on industry-relevant issues. In this context industrial processes are among the least targeted for PaMs. However, while the share of PaMs addressing industrial processes increased only slightly between 2011 and 2025, from 5% to 7%, the absolute number of national PaMs addressing industrial processes has more than tripled from approximately 70 in 2011, to approximately 245 in 2025. While these numbers may not capture the full picture, it does indicate that industrial decarbonisation is receiving more attention.

An EU-wide assessment of the latest NECPs reveals that the plans show an increased focus on the competitiveness of industry, resilience of supply chains, innovation and skills development. Most countries outline clear measures to promote clean technologies and net-zero projects — including through investment and accelerating the issuance of permits. Several plans refer to the need to develop CO_2 pipeline networks; in some Member States regulatory and enabling frameworks for carbon management have progressed.

However, the plans often lack detail on actionable objectives. They commonly outline targets (e.g. renewable shares, emissions cuts) without fully detailing the (timebound) policy instruments and measures required to achieve them in industry-relevant sectors (EC, 2025e; ECNO, 2025).

Countries also set out PaMs in the energy sector that are critical for enabling industrial decarbonisation. These include measures to improve interconnectivity in electricity grids and setting up energy efficiency standards. Around 27% of all reported PaMs relate to the energy supply sector; of these a majority had already been implemented at the time of writing this report.

The Governance Regulation required Member States to submit national long-term strategies (LTSs) by 2020. These include long-term plans for achieving the EU's climate-neutrality objective, expected progress on decarbonisation and expected socio-economic effects of the transition, among other objectives.

The next strategies are due in 2029, presenting an important opportunity to improve policy coherence across climate and environmental objectives. Various actors, including the European Renewable Energies Federation, have called for these strategies to be updated sooner to ensure that they align with the latest regulatory frameworks and new geopolitical realities.

Zero emissions and pollution control

In the PaMs reported under the national air pollution control programmes (NAPCPs), countries primarily prioritise regulatory measures such as the implementation of BATs, updates to industrial permit conditions and the tightening of emission limit

values for IED installations. This reflects the important role of the IED and increased regulatory ambition in achieving targets set out under the NECD — including for pollutants such as NO_x, SO_2 and $PM_{2.5}$ (EC, 2024d).

The OECD-PINE policy database further indicates that 10 Member States have adopted various taxes and fees. These include air pollution charges, non-compliance charges and, conversely, tax exemptions or relief for less polluting activities and fuels.

Measures to address water pollutants from industry — reported or identified under the river basin management plans (RBMPs) and the OECD-PINE database — mainly relate to:

- authorisation and permitting systems to reduce or stop the release of certain pollutants into water;
- reducing pressures from wastewater treatment plants and chemicals;
- the remediation of contaminated sites.

Most Member States have reported basic measures related to constructing or upgrading urban wastewater treatment plants, acknowledging that additional efforts are needed to comply with the UWWTD.

Circular economy and resource efficiency

Most Member States have national circular economy strategies and action plans either in place or planned (EEA, 2024i). However, the EEA country profiles on waste prevention indicate that few measures have been proposed for reducing waste generation in processes related to industrial production, extracting minerals and manufacturing. Implementation of circularity measures at the facility level happens mainly through permitting or sector-specific regulations.

Among the existing policy proposals, several focus on stimulating behavioural change, for example by:

- raising awareness during inspections about resource efficiency and waste prevention using BATs (Sweden);
- supporting increased implementation of cost accounting systems for waste generation to incentivise resource efficiency in production processes (Iceland).

Meanwhile, Ireland's Circular Economy Programme (2021-2027) explores the integration of circular economy principles within environmental regulatory frameworks and licences to reduce industrial waste generation.

Belgium — more specifically the region of Flanders — has set more ambitious goals through quantitative targets for reducing industrial residual waste by 30% by 2030 compared with the 2018-2020 baseline. This indicates increased ambition following on from an earlier target of a 15% reduction compared to 2013. Belgium also proposes concrete measures to promote reuse and to stimulate industrial symbiosis — the use of by-products from one facility as input at another.

Industry- and sector-specific planning

In addition to national planning instruments mandated by EU policy frameworks, national governments may also choose to develop industry- or sector-specific plans and strategies targeting industry. While overarching policy frameworks, such as climate laws, are important starting points, more detailed plans are necessary to align with the realities and specificities of different sectors (Nilsson et al., 2021). The section below illustrates country examples gathered through the EEA's European Environment Information and Observation Network (Eionet).

France — binding site-level decarbonisation planning

France has introduced sectoral decarbonisation plans for large industrial emitters; the plans go beyond EU-mandated climate and energy frameworks. Through ecological transition agreements and the major industrial decarbonisation projects scheme, the French government has established long-term contractual agreements with the country's 50 highest-emitting industrial sites.

These sites are required to submit company-specific decarbonisation roadmaps, including quantified emissions-reduction trajectories and investment plans. They are supported by long-term public funding commitments — in some cases extending over 15 years — which aim to reduce the investment risk for capital-intensive transformation projects. The approach targets sectors such as steel, cement and chemicals. It also enables coordinated planning of infrastructure needs (electricity, hydrogen, CO_2 transport) at the sector and territorial levels.

Austria — sector-based industrial transformation pathways

Austria has developed sector-based transformation plans that translate national and EU climate targets into concrete transformation pathways under the transform industry framework. These pathways provide a structured assessment of decarbonisation options for energy-intensive industrial sectors, including technology choices, infrastructure requirements and indicative investment needs.

Going beyond EU requirements, Austria complements its high-level strategies (the NECP, hydrogen strategy and carbon management strategy) with analytical work that explicitly identifies technology options, sequencing of investments and financing gaps at the sector level. Competitive funding schemes linked to these pathways support industrial installations in shifting towards climate-neutral processes.

While not legally binding, this approach represents a governance innovation; it systematically links climate objectives, sectoral analysis and public funding decisions, thereby improving the investment value of industrial decarbonisation projects.

Czechia — coordinated planning for the deployment of carbon capture, utilisation and storage (CCUS) in industry

Czechia has focused its industrial decarbonisation efforts on coordinated planning for CCUS rather than sector-specific roadmaps. The action plan for the development of CCUS technologies links emissions-reduction needs in hard-to-abate industrial sectors with assessments of CO_2 transport infrastructure, geological storage capacity and potential funding sources.

The plan addresses technical parameters, spatial planning considerations and financing options, including EU funds. While deployment remains at an early stage and no binding sectoral obligations have currently been defined, the approach goes beyond EU requirements by treating CCUS as an integrated industrial system rather than a collection of individual projects.

Flanders (Belgium) — sectoral roadmaps linked to innovation support

Flanders has adopted a distinctive approach to clean industrial transformation through the Klimaatsprong programme. This focuses on key regional industrial clusters such as steel, chemicals and refineries. Rather than static sectoral plans, Klimaatsprong relies on dynamic roadmaps that are continuously updated.

In parallel, the Flemish moonshot innovation programme provides funding for industrial research and demonstration projects via four pathways:

- biobased chemistry;
- circularity of carbon in materials;
- electrification;
- radical process transformation and energy innovation.

This enables technological progress to be integrated rapidly into industrial planning while maintaining a long-term decarbonisation trajectory. The Flemish approach goes beyond EU mandates by explicitly combining sector-level industrial planning and regional innovation policy, while also integrating emerging concerns related to circularity and hazardous substances.

In parallel, Flanders has begun integrating pollution prevention more explicitly into its industrial transition policy. This is most notable through its response to the per- and polyfluoroalkyl substances (PFAS) crisis, which includes a vision and dynamic action plan for hazardous substances and the establishment of a dedicated knowledge centre.

Policy coherence across plans and objectives

Stronger alignment between national planning processes and EU policy could help reinforce coherent pathways for industrial transformation. While NAPCPs and NECPs broadly contribute to EC's climate change and air pollutant objectives, there is scope for co-benefits for water management and the circular economy to be considered more systematically. The EC also notes the potential for alignment between NAPCPs and NECPs; such as the impacts of energy and climate policies on air pollutant emissions and vice-versa how synergies between air pollution, water and circular economy policies can strengthen NECPs. Yet, many NECPs and NAPCPs do not adequately assess this alignment (EC, 2023b, 2024d).

Beyond EU-mandated plans, industry-specific roadmaps would also benefit from improved vertical policy coherence. For example, circularity measures and their emission-reduction impacts are often poorly captured in countries' climate policy reporting. This is partially due to the disconnect between the strict sectoral reporting structure for GHG emissions and the cross-cutting nature of the circular economy.

Further, there are very few quantifiable data on the climate mitigation potential of circularity measures, and half of the circularity policies and measures reported to the EEA focus on downstream measures with relatively limited climate benefits (EEA, 2024a). National policies could also make better use of bottom-up information from corporate transition plans and disclosures, while ensuring that these are grounded in territorial realities.

EU policy increasingly recognises the co-benefits between decarbonisation, pollution prevention and circularity, including under the revised IED. Similar approaches exist nationally in some cases. For example, Sweden's *Industriklivet* programme gives financial preference to industry projects that deliver climate benefits alongside reduced air pollution or greater circularity.

However, such 'triple integration' remains limited in many national plans that have not been mandated by the EU and in funding schemes for industrial transformation (Eionet, 2026b). Better understanding of the drivers, barriers and opportunities for exploiting these co-benefits could support more integrated policy design.

3 Environmental and climate performance in EU industry

Industry is a key pillar of the EU economy. It drives innovation, productivity and competitiveness across supply chains. There has been progress in decoupling economic growth from environment and climate pressures; however, industry remains a major source of climate and environmental impacts.

This chapter examines industry's environmental and climate performance over the past 10-15 years. It focuses on key indicators as signals of progress towards clean, decarbonised, resource-efficient and circular industrial processes. It also highlights drivers and opportunities for scaling ambition.

3.1 GHG intensity and energy use

Table 3.1 Overview of GHG intensity and energy use in industry in the EU

Indicator	Progress	Description
Share of fossil fuels in energy consumption of EU industry	Limited development	The share of fossil fuels in the final energy consumption mix of EU industry [a] only declined from a 53% share in 2010 to 50% in 2024, while the share of electricity remained constant. Total final energy consumption decreased by 12%.
Total GHG emissions from EU industry	Positive development	In the period 2010-2024, total GHG emission reductions from EU industry fell by 27%; reductions were consistent across sectors.
Carbon intensity trends of industry	Mixed development	Carbon intensity has improved — i.e. declined — across all industrial sectors when defined as kilograms of GHG emissions per euro of GVA. However, when comparing CO_2 emissions over physical output — e.g. tonnes of product — for the highest-emitting sectors, progress has been limited or stagnant.

Robustness of the evidence base: high

Key data limitations:

- Data comparability is limited by fragmented datasets alongside differences in sectoral scope and classification codes — between Eurostat energy balances and air emission accounts, UNFCCC GHG inventories, EU ETS data and GHG emission data.
- Process versus combustion-related emissions are not clearly separable in all datasets. This restricts the identification of appropriate mitigation measures.

Notes: (a) This excludes the waste sector as it only appears as an energy carrier in the relevant dataset

GVA, gross value added; UNFCCC, United Nations Framework Convention on Climate Change.

Source: EEA elaboration.

The composition of the energy mix in EU industry — in particular its share of fossil fuels — is a key determinant of industry's overall climate impact. The share of fossil fuels in the mix of industry's final energy consumption only declined from 53% in 2010 to 50% in 2024. Meanwhile, the share of renewables and biofuels increased from 10% to 11% in the same period [6]. Electricity remained stable at 30% and it

(6) These percentages exclude consumption of fossil fuels for non-energy uses, such as fuel used as feedstock in industrial processes. In sectors such as petrochemicals, the percentage of fossil fuels used as feedstocks can be higher than for final energy consumption.

accounted for a third of the EU manufacturing sector's energy mix. The energy mix varies greatly across sectors, reflecting the specificities of production processes (Table 3.2).

Table 3.2 Final energy consumption across selected sectors by energy carrier category in the 27 EU Member States (EU-27) in 2024

	Sector	Electricity	Fossil fuels	Heat	Non-renewable waste	Renewables and biofuels	Total
	**Mining**	18 TWh (47%)	18 TWh (47%)	2 TWh (4%)	0 TWh (0%)	1 TWh (2%)	**38 TWh (100%)**
	**Metals (iron and steel)**	88 TWh (37%)	148 TWh (61%)	4 TWh (2%)	0 TWh (0%)	0 TWh (0%)	**241 TWh (100%)**
	**Metals (non-ferrous metals)**	39 TWh (48%)	40 TWh (50%)	2 TWh (2%)	0 TWh (0%)	0 TWh (0%)	**81 TWh (100%)**
	**Minerals (excluding mining)**	57 TWh (17%)	207 TWh (62%)	1 TWh (0%)	43 TWh (13%)	24 TWh (7%)	**333 TWh (100%)**
	**Chemicals**	159 TWh (30%)	288 TWh (55%)	72 TWh (14%)	4 TWh (1%)	6 TWh (1%)	**529 TWh (100%)**
	**Pulp, paper and wood**	113 TWh (28%)	88 TWh (22%)	24 TWh (6%)	4 TWh (1%)	168 TWh (42%)	**397 TWh (100%)**
	**Food and drink**	113 TWh (35%)	174 TWh (54%)	13 TWh (4%)	0 TWh (0%)	19 TWh (6%)	**320 TWh (100%)**
	**Other manufacturing (textile and leather)**	14 TWh (43%)	17 TWh (52%)	1 TWh (3%)	0 TWh (0%)	1 TWh (2%)	**32 TWh (100%)**

Notes: The table excludes non-energy uses of fuels, such as natural gas used as feedstock for chemicals or coke used as a reducing agent in blast furnaces. The category 'fossil fuels' includes solid fossil fuels, oil and petroleum products (excluding biofuel), manufactured gases, natural gas, oil shale and oil sands, peat and peat products. The category 'heat' includes both primary and secondary heat. Primary heat is obtained from natural sources such as geothermal and solar thermal power. Secondary heat is obtained from the nuclear fission of nuclear fuels and by burning primary combustible fuels such as coal, natural gas, oil and renewables, and wastes. Heat is also produced by transforming electricity to heat in electric boilers or heat pumps.

TWh, terawatt-hour.

Source: Eurostat, 2026h.

In absolute terms, the most energy-consuming sectors are the chemicals sector, pulp, paper and wood and non-metallic minerals (notably cement). For these sectors, electricity accounts for less than or about a third of final energy consumption. In contrast, electricity accounts for nearly half the energy consumption for non-ferrous metals (notably aluminium), mining and textiles. This partially contributes to their overall lower rates of energy consumption.

The share of non-renewable waste is minimal across all industrial sectors except non-metallic minerals. In fact, the use of waste-derived fuels in cement kilns has increased in the EU over recent decades, from 8% of total energy consumption in 2010 to 18% in 2023 (JRC, 2023). Using waste-derived fuels allows mineral components — like ash-based mineral fractions — to be recycled within the cement production process.

Waste incineration in cement kilns may reduce fossil fuel use and divert waste from landfills. However, some civil society organisations question the practice. They argue that it may compete with waste prevention and recycling objectives while posing environmental and health risks associated with pollutant emissions (Zero Waste Europe, 2020). The benefits depend on how emission levels compare to dedicated waste incinerators.

Finally, the high share of renewables and biofuels used in the pulp, paper and wood sector reflects the intensive use of biomass combustion for industrial heat by factories that are generally situated next to forests and that generate solid biomass by-products (Malico et al., 2019). In the 2010-2024 period, total GHG emissions fell substantially across industrial sectors (Figure 3.1), by:

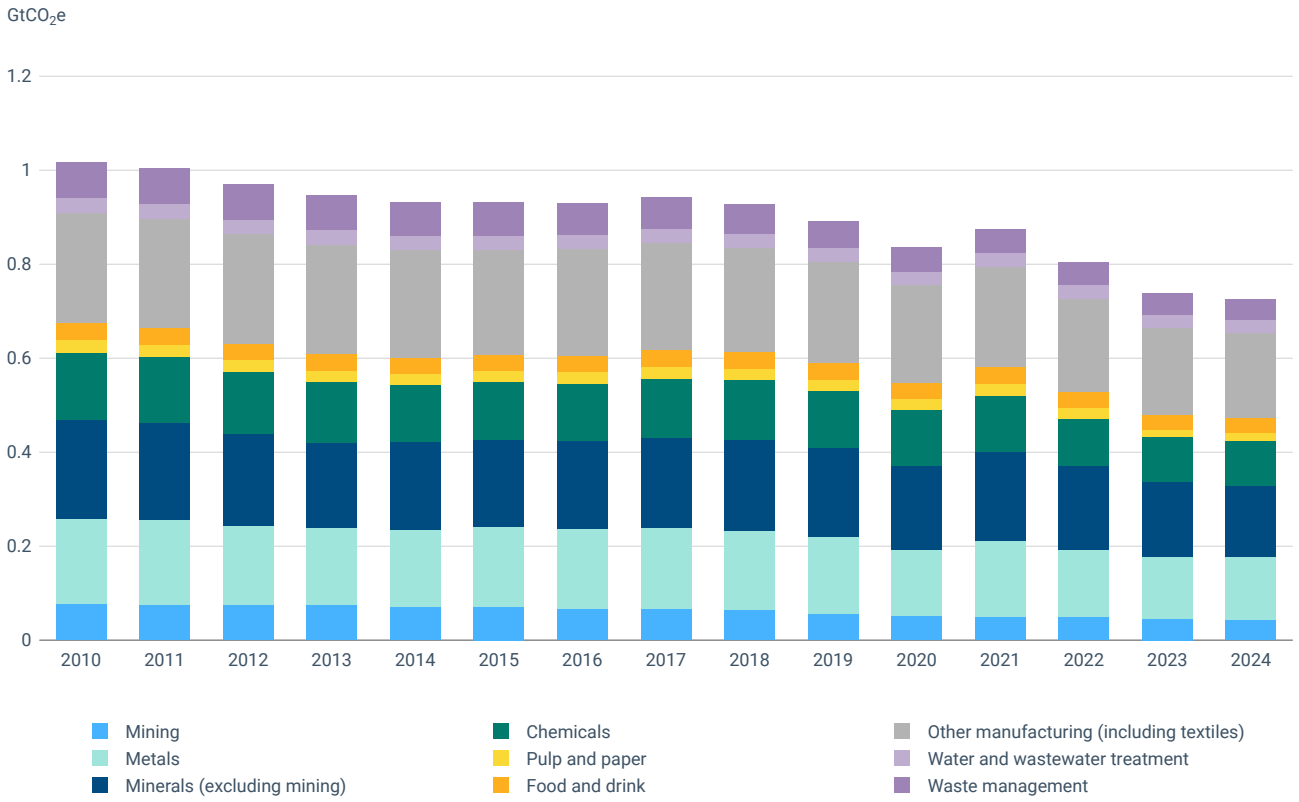
- 43% in the mining sector;
- 33% in the chemicals sector;
- 27% in the metals sector;
- 27% in the minerals sector;
- 25% in other manufacturing sectors;
- 24% in the waste management sector.
- 15% in the food and beverages sector;

The total emission reductions across European industry in the observed period can be explained by a number of drivers: a shift away from heavy industry towards the services sector, lower carbon intensity of the energy system and improved energy efficiency (EEA, 2026i).

Between 2010 and 2022, overall energy consumption in industry decreased by 8% [7]. While this was partially due to structural shifts towards less energy-intensive subsectors, it was mainly driven by improvements in energy intensity (EC, 2026d). Between 2022 and 2023 these trends were likely reinforced by the energy price shock and collective EU measures to reduce gas demand (EEA, 2026l).

(7) Industry here includes the following sub-sectors: food and tobacco (Eurostat (ESTAT) code: B_101830); textiles and leather (ESTAT code: B_101835); wood, paper, etc. (ESTAT code: B_1018851+B_101840); chemicals and petrochemicals (ESTAT code: B_101815); metals and machinery (ESTAT code: B_101847+B_101805+B_101810); non-metallic minerals (ESTAT code: B_101820+B_101853); transport equipment (ESTAT code: B_101846); construction (ESTAT code: B_101852).

Figure 3.1 GHG emission trends by industrial sector in the EU, 2010-2024



Notes: Manufacturing encompasses both energy-related emissions (Intergovernmental Panel on Climate Change (IPCC) Sector 1.A.2) and process-related emissions (IPCC Sector 2). Mining also includes coal mining and handling (IPCC Sector 1.B.1.a), oil and natural gas and other emissions from energy production (IPCC Sector 1.B.2). Waste management encompasses all of IPCC Sector 5 except water and wastewater treatment (IPCC Sector 5.D) which is given here as its own category.

$GtCO_2e$: gigatonnes of carbon dioxide equivalent.

Source: EEA, 2026i.

Beyond data on absolute GHG emissions, it is interesting to assess how emissions have fallen as a measure of gross value added (GVA) — i.e. kg of GHG per euro of value added. This can provide a more comprehensive picture of the evolution of industrial trends, both in terms of growth dynamics and decarbonisation (Figure 3.2).

Figure 3.2 **Carbon intensity trends for industrial sectors defined as kg of GHG emissions per euro of GVA**



Notes: For consistency, the carbon intensity estimates in these graphs were computed using Eurostat data for both GVA (nama_10_a64) and GHG emissions (env_ac_ainah_r2). GVA is in chain-linked volumes (2020), million euros, to neutralise price effects. At the time of the analysis the Eurostat GVA dataset had missing values for: textiles (NACE codes C13-C15) for Poland (2023); oil refining (C19) for Ireland, Lithuania, Malta and Poland (2023); chemicals (C20) for Ireland and Malta (2010) and Sweden (2010-2024); in the basic pharmaceuticals sector (C21) for Ireland, Lithuania, Luxembourg, Malta and Sweden; and rubber and plastic (C22) for Luxemburg and Malta (2010).

$KgCO_2e$, kilograms of carbon dioxide equivalent.

Source: EEA elaboration based on Eurostat, 2026g, 2026a.

Since 2010, GVA-based carbon intensity has decreased across all the sectors considered for this report, most notably in the chemicals sector (including basic pharmaceuticals, as well as rubber and plastics) and in manufacturing overall.

Sectors such as chemicals are large and structurally complex, encompassing diverse outputs and extended value chains. As such, the observed reductions in carbon intensity may reflect both the decarbonisation of specific emission-intensive production processes as well as shifts in the composition of economic activity — including production moving towards less carbon-intensive types of products[8].

The limited progress in mining suggests that emissions have largely declined in line with the sector's contraction. While GVA fell sharply as mining activities were scaled back, this has not translated into substantial improvements in emissions per unit of value added.

GVA-based carbon intensity can improve because of structural changes across activities, offshoring or moves towards higher-value products. The changes do not necessarily reflect facility-level transformations. Assessing carbon intensities based on emissions linked to production volumes — instead of GVA — provides a better reflection of decarbonisation efforts at the plant level.

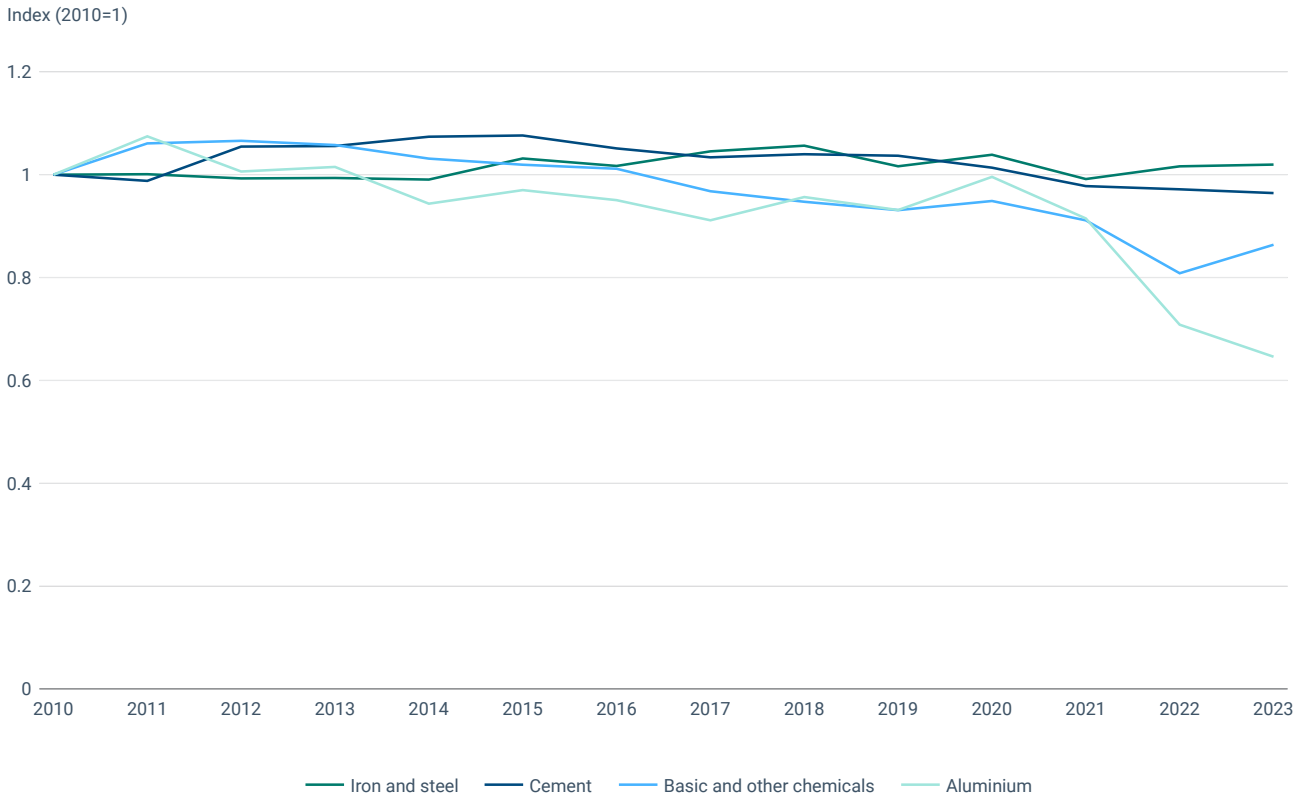
The Joint Research Centre's (JRC's) Integrated Database of the European Energy System (JRC-IDEES) provides a consistent set of disaggregated energy-economy-emissions data for each EU Member State. It covers all sectors of the energy system for the 2000-2023 period (JRC, 2023).

Based on calculations of GHG emissions linked to production volumes, there seems to have been limited progress in decarbonising production processes in the most GHG-emitting industrial sectors (Figure 3.3). This stands in stark contrast to the data on total emission reductions and improvements in GVA-based carbon intensity presented earlier.

This suggests that carbon intensity metrics based on GVA offer a better reflection of structural economic changes than of low-carbon process improvements. The implication is that some of Europe's most emission-intensive sectors remain at an early stage in their journey towards deep industrial transformation.

(8) For example the change in the share of industrial GVA in the EU since 2010 for pharmaceutical products has outpaced that for basic chemicals, which are typically more energy-intensive and with lower value added products (EC, 2026d).

Figure 3.3 Carbon intensity of selected industrial sectors based on physical output



Notes: Emission data from JRC-IDEES only include CO_2 emissions. While CO_2 makes up the vast majority of GHG emissions across the sectors included in this figure, emissions of other GHGs are relevant in some production processes for chemicals and aluminium (e.g. nitrous oxide and F-gases, respectively). For the sectors examined, trends in CO_2 emissions appear consistent with total GHG emission trends. However, emission reductions may be somewhat understated for parts of the chemical industry, where for instance, nitrous oxide (N_2O) emissions related to the production of nitric and adipic acid fell significantly due to implementation of abatement techniques. Due to this report's focus on sector-level analysis, emissions from primary and secondary production routes for steel and aluminium are aggregated. However, it should be noted that the carbon intensity of secondary routes is lower. Industry-reported carbon-intensity estimates sometimes show somewhat larger reductions over the period, reflecting differences in system boundaries and definitions.

Sources: EEA, based on JRC, 2023; Eurostat, 2026g.

For aluminium production and the chemical industry, carbon intensities based on emissions linked to production volume have decreased by 35% and 14% respectively; most of these reductions occurred after 2021. However, the carbon intensities for cement as well as iron and steel production have seen only a marginal decline (and even a small increase for iron and steel since 2021). Cement, together with iron and steel, make up nearly 45% of manufacturing emissions. As such, decarbonising these sectors presents a significant opportunity to accelerate progress towards the EU's emissions targets.

Free allocation of EU allowances — which gives the holder the right to emit a tonne of carbon dioxide equivalent (CO_2e) — has been notably high in the cement sector (Bruegel, 2024). However, free allowances are gradually being phased out and the ETS carbon price is projected to increase. This should incentivise cement producers to decrease their carbon intensity.

Box 3.1

Why are GHG emissions from steel, cement and chemicals difficult to reduce?

GHG emissions in industry arise from two main sources:

- energy-related emissions from fuels and electricity used in production;
- process-related emissions generated directly by industrial reactions.

While energy-related emissions can often be reduced through electrification and the use of cleaner energy sources, process-related emissions require more fundamental technological changes.

Decarbonisation challenges differ by sector. In cement, emissions primarily result from limestone calcination during clinker production ($CaCO_3$ -> $CaO + CO_2$). Reducing the clinker-to-cement ratio is thus a key near-term solution.

Breakthrough technologies include novel cement types and carbon capture technologies. Meanwhile, the technology needed to enable cement electrification is currently at a low level of readiness (JRC, 2026b), although recent testing of industrial-scale electrified pre-calcination of cement raw meal has begun in Sweden.

Similarly, in the iron and steel sector, process emissions are primarily linked to the use of coke to reduce iron ore to iron, generating CO_2 in the process ($Fe_2O_3 + 3CO$ -> $2Fe + 3CO_2$), as well as the use of quick lime (CaO) to remove impurities. In the chemicals sector, process emissions stem from fossil-based feedstocks used as raw materials.

Share of process-based emissions (JRC, 2023)

- Cement: 67%.
- Basic and other chemicals: 42%.
- Iron and steel: 45%.

It is relevant to note that the sectors that are most energy intensive are highly mature industries. Their transformation is not linear. Major efficiency gains have been made in the past. For instance, in the cement sector, 90% of clinker is now made using a more energy-efficient dry clinker-making process rather than with wet kilns.

Thus, the stagnating gains can be viewed as a signal that many of the lower-cost adjustments have already been made. Further progress will increasingly require energy-intensive sectors to adopt transformational technologies and infrastructure. Importantly, these sectors involve high process-related emissions; these cannot be mitigated by shifting to cleaner fuels (Box 3.1).

Despite evidence that reductions in carbon intensity are limited, there are positive signals of transformation. Electric arc furnace (EAF) production — which has a much lower carbon intensity than steel blast furnaces (0.16 vs 1.22 kilotonnes of CO_2 ($ktCO_2$)/kt steel in 2023) — now represents a 44.6% share of steel production (Eurofer, 2025; JRC, 2023). EAFs make use of scrap steel rather than pig iron as input. They also use electricity rather than coke (a carbon-rich fuel derived from coal) as an energy carrier in the production process.

The share of secondary aluminium — made by recycling used or leftover aluminium scrap — vs primary aluminium has also increased since 2010. By 2023, its share had

increased from 61.8% to 76.1% (JRC, 2023). The energy requirement for producing secondary aluminium is much lower than for primary aluminium. At the same time, the increased share of secondary aluminium in part reflects recent closures of sites that produced primary aluminium in Europe.

The EU's dependence on secondary metal has deepened in recent years, in particular following energy price shocks (EC, WSP, 2026). As such, indicators relating to the share of secondary steel and aluminium production should be interpreted alongside consumption and trade data. As global remelting capacity grows, targeted measures may be required to secure the availability and quality of scrap input and thereby ensure the EU's transition towards secondary metal production routes (Box 3.2).

Box 3.2

Accelerating electrification and circularity in the production of steel and aluminium

Electrification is a key pathway for decarbonising steel and aluminium production. For steel, this includes a shift towards EAFs, which can significantly reduce emissions when powered by low-carbon electricity. Compared to conventional production, EAFs also allow for significantly higher shares of scrap input (89% on average (Cullen et al., 2012)).

For steel, EAF's combined with direct reduced iron (DRI) — which replace coke-based iron reduction with hydrogen- or natural gas-based reduction —need to be more widely deployed for deep transformation. This is particularly relevant where the availability of scrap may be limited. EAFs are now capable of meeting the majority of steel application needs. It has long been the case that quality considerations for certain high-grade applications, particularly in transport, prevent scrap-based EAF production from fully replacing primary steelmaking. However, EAF's are now capable of meeting the majority of steel application needs, and the composition of the iron mix is considered a more important determinant of steel quality than the type of furnace (SteelWatch, 2025).

Similar quality implications and input dependencies may influence the extent to which primary aluminium production can be replaced with secondary production.

Improving circularity can help to address these constraints. Scenario analysis shows that maintaining the quality of alloys throughout product life cycles, enabling traceability and improving product design can substantially increase circularity. Ecodesign requirements such as recycled content targets could also improve the quality and availability of secondary materials for use in steel (and aluminium) products (Ciacci et al., 2026).

Continued progress will depend in part on market and regulatory conditions that encourage investment in low-carbon and circular solutions, including carbon pricing mechanisms, public procurement criteria and other price signals. For example, the benefits of electrifying both low-temperature and medium-temperature industrial heat could be unlocked by lowering the relative price of electricity vis-à-vis natural gas from the current 3-5 range to the 1.5-2.8 range; this could be achieved by shifting the tax burden from electricity towards fossil fuels (Agora Industry, 2026c).

Material recycling and recovery targets would be crucial regulatory signals to accelerate investment in circular production routes. Currently, energy-intensive industries lack quantitative targets for material recycling and recovery beyond EU-wide requirements for downstream products (EEA, 2026r).

If these enabling conditions are not provided at speed and scale, there is a significant risk of a lock-in effect as EU industrial actors make investment decisions about

long-lived assets. For example, some studies estimate that existing coal-based blast furnaces accounting for more than 70% of capacity worldwide will reach the end of their asset lives this decade; reinvestment decisions will then need to be made (Agora Industry, 2023).

Importantly, price signals may require complementary regulation to drive significant transformation. Important lessons could be learned from the positive impact of emission limit values on reducing the intensity of key air pollutants in industry (Section 3.2.).

Interestingly, verified emissions data under the EU ETS indicate that 30 manufacturing installations alone accounted for approximately a fifth of all EU industrial emissions in 2024. This is striking when considering that there are 16,400 large manufacturing firms in the EU (Eurostat, 2025a). This suggests that targeted interventions for specific installations can go a long way towards mitigating industry's share of total GHG emissions.

3.2 Pollutants to air and water

Table 3.3 Overview of pollutants to air and water from industry

Indicator	Progress	Description
Industrial pollutant emissions to air	Positive development	Industrial pollutant emissions to air have improved significantly for most sectors in the last 10-15 years.
Industrial pollutant emissions to water	Positive development	While progress has been slower compared to reductions in air pollutants, reported water pollutant emissions from industry have declined, despite a nearly 20% increase in industrial economic output; this suggests improved efficiency and pollution control measures.
Industrial pollutant intensity	Positive development	There are consistent signs of absolute decoupling of pollutants to air and water with economic growth from industry. The same is true when comparing air emissions over production volumes, with significant reductions in pollutant intensity across the main polluting sectors.

Robustness of the evidence base: high (air), medium (water), low (land)

Key data limitations:

- Thresholds under the E-PRTR are relatively high; around 50% of facilities in its scope do not report emissions data. The IEPR, superseding the E-PRTR, has been designed for improved detail via more granular reporting (at the installation level) and includes the option to amend the pollutants and thresholds specified in the regulation via delegated acts.
- While air pollution data are generally more complete and easier to interpret, it is harder to draw conclusions for water pollution. For water emissions, reporting thresholds are higher, meaning that smaller releases are often note captured in the dataset. Further, a lot of pollution is recorded indirectly via urban wastewater treatment plants and diffuse emissions are more difficult to measure and link to specific industrial sectors. Additionally, the number of data points is only representative for a small number of pollutants — such as total nitrogen, total organic carbon, total phosphorus and heavy metals. Other pollutants are not reported with enough frequency to draw clean conclusions.
- Emerging pollutants are not yet within the scope of the IEPR.
- There are currently insufficient data on land emissions/soil pollution.

Source: EEA elaboration.

Progress on industrial pollutant emissions to air

Industrial pollutant emissions to air and water have a significant negative impact on health and the environment. In the 2010-2024 period, there was a marked decrease in releases of all major air pollutants reported by large industrial facilities under the Industrial Emissions Portal.

- Sulphur oxides (SO_X) decreased by 80%.
- NO_X decreased by 58%.
- PM_{10} decreased by 76%.
- Non-methane volatile organic compounds (NMVOCs) decreased by 41%.
- Heavy metals (cadmium (Cd), lead (Pb) and mercury (Hg)) decreased by 80%.

Air quality measured at air quality stations around industrial sites in the EU offer complementary insights; emissions of key pollutants declined between 2005 and 2021. For instance, annual mean levels of sulphur dioxide (SO_2) decreased by 63.5% in this period, NO_2 by 47.1% and PM_{10} by 41.3%. The time series confirms that the rate of decline was highest in the earliest years (2005-2013) compared to more recent years (2013-2021) (ETC HE, 2023).

Table 3.4 presents trends at the sectoral level based on data reported under the NECD inventory. Overall, the trend consistently points to emission reductions across sectors. Similar patterns are also observed in the E-PRTR dataset available under the Industrial Emissions Portal.

Table 3.4 **Changes in emissions of key industrial air pollutants by sector between 2010 and 2024**

	NO_x	NMVOC	PM_{10}	SO_x	Cd	Pb	Hg	$PM_{2.5}$
Mineral industry (excl. mining)								
Mining								
Metals								
Chemicals								
Waste								
Food and drink								
Pulp- paper and wood								
Others								

Table legend

x < -50%	
-50% ≤ x < -20%	
-20% ≤ x < 0	
0 ≤ x ≤ 20%	
x < 20%	

Notes: Cd, cadmium; Hg, mercury; NMVOC, non-methane volatile organic compounds; NO_X, nitrogen oxides; Pb, lead; PM_{10}, particulate matter ≤ 10µm; $PM_{2.5}$, particulate matter ≤ 2.5µm; SO_X, sulphur oxides.

Sources: EEA elaboration based on Member States' submissions in 2026 under the NEC Directive.

The chemicals sector saw the largest progress over the 2010-2024 period, with significant emission reductions across the board (SO_X, -55%; Pb, -52%; Cd, -72%; Hg, -79%). NMVOCs are also significant pollutants in the chemicals sector; these decreased by 37% in the reference period.

There was also substantial progress in emissions from metal production (e.g. $PM_{2.5}$, -53%; Pb, -53%). However, the ongoing absolute emissions remain significant.

In contrast, the minerals industry (excluding mining) — for which cement is a key contributor — shows comparatively good but more limited progress. The mining sector significantly reduced emissions from heavy metals such as Cd (-53%) yet remains a comparatively minor contributor to overall emissions. Heavy metals — which accumulate in ecosystems and damage human health — represent a key environmental impact category from mining with relevance for local environments.

The data also point to a few exceptions to the air pollutant trends. Reductions in emissions of PM_{10} and $PM_{2.5}$ stagnated in the waste-and wastewater sector and there was a 10% increase in Hg emissions in this sector over the period. However, it should be noted that this likely reflects the transfer and concentration of residual Hg into waste streams and that the main source is not the treatment plants themselves (EEA, 2018). Hg has largely been banned as set out in the EU's Regulation on Mercury, which was revised in 2024 to include further restrictions on its use.

The food and drink sector stands out as another exception; here NMVOCs increased by around 15%. The treatment and processing of food and beverage products from vegetable raw materials — likely linked to process-related emissions — largely drove this change. For the same sector, Cd emissions increased by around 39%. However, this is not a major cause for concern as the sector is not a main contributor of this pollutant.

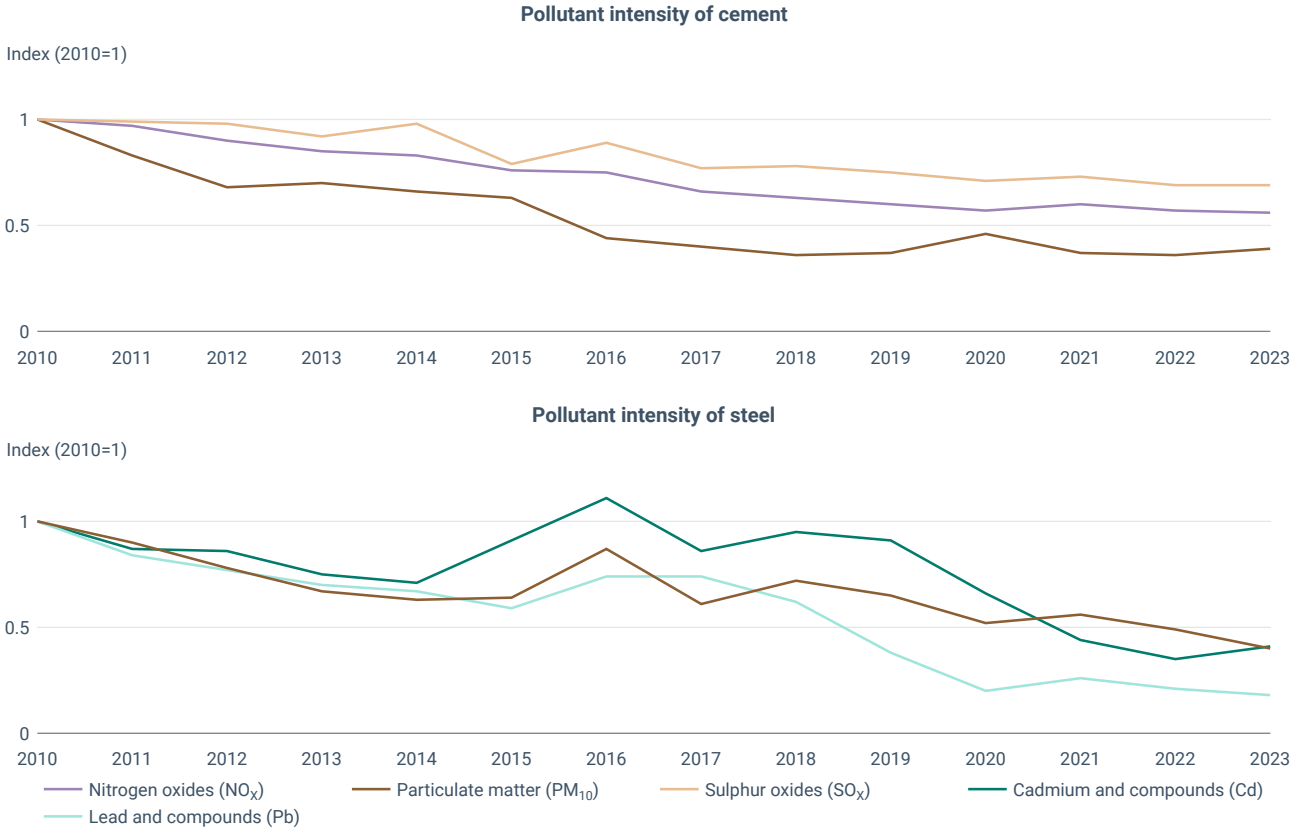
During this period, the value that industry generated for the economy — measured as GVA — increased. While there are sectoral variations, this signifies an overall absolute decoupling of emissions from economic growth (EEA, 2024h). However, as discussed in Section 3.1, intensity calculations based on GVA may not sufficiently explain facility-level changes. Pollutant intensity based on emissions linked to physical output allow for a better analysis of the extent to which the uptake of abatement technology, process efficiencies and other installation-level measures drive emission reductions, as opposed to structural changes in the economy or shifts toward higher-value outputs.

Figure 3.4 demonstrates pollutant intensity trends for steel and cement production, looking at the three pollutants of highest relevance for each sector. The data demonstrate real and significant progress in transforming the sectors towards cleaner production processes since 2010.

The underlying data also indicate that output-based pollutant intensities have dropped more significantly for steel plants that have become electrified. This demonstrates clear co-benefits between decarbonisation, circularity and pollution prevention from this technology [9].

(9) EEA calculation based on Pelckmans et al. (2026) and JRC (2023).

Figure 3.4 **Changes in pollutant intensity (tonnes of pollutant/tonnes of product) for cement and steel, 2010-2023**



Sources: EEA based on JRC, 2023; EEA, 2026h.

Taken together, the trends suggest that EU clean air policy and pollution policy have been highly effective where clear regulatory standards and mature end-of-pipe technologies, process control and solvent management exist. Emissions have also likely reduced as a co-benefit of EU climate policy, in particular policy related to combustion-related emissions such as NO_x, SO_x and PM_{10}. The phase-out of EU ETS allowances and further efforts towards the EU's objective of climate neutrality by 2050 will likely extend these co-benefits.

However, emission reductions across several pollutants and sectors have also stagnated over time (EEA, 2026r). Continued efforts are needed, especially in the context of evidence that there are negative health impacts from pollutants even when they are below the legal limits or below the more stringent World Health Organization (WHO) air quality guideline levels (Box 3.3).

The revision of the IED in 2024 sets out more ambitious rules on emission reductions. Permitting authorities are now required to set the strictest emission limit value achievable by applying BAT at installations.

Box 3.3

Beyond point-source pollution

The IED and the IEPR focus most explicitly on preventing releases of pollutants from industrial installations, as well as managing and monitoring point-source pollution — i.e. classic stack or discharge emissions.

However, data on hot-spot pollution — in other words localised, high-concentration pollution close to specific industrial sites — from the EU Air Quality Directive (2024/2881) illustrate how specific areas can have health-relevant concentrations even when legal limits are not being exceeded. For example, in Taranto, Italy, several studies have linked an excess of mortality with PM_{10} releases from local steel plants (Leogrande et al., 2019).

Similarly, a study commissioned by the Ayuntamiento de Gijón, Spain and conducted by researchers at the Universidad de Oviedo found a statistically significant association of short-term increases in PM_{10} and NO_2 concentrations with higher hospital admissions for respiratory and cardiovascular diseases in Gijón (Martínez Pérez et al., 2025).

Here, pollutant levels remained within legal limit values but above the guidance levels recommended by the WHO (WHO, 2021). The study links observed pollution patterns in relation to proximity to major industrial activities and port operations in the western part of the city, alongside traffic emissions (Martínez Pérez et al., 2025).

Industrial emissions also contribute to diffuse pollution — i.e. pollution released over a wide area, often from numerous sources. In fact, industrial air pollution contributes to widespread pollution of surface waters and can account for more than 25% of the urban background concentration of $PM_{2.5}$ (JRC, 2025f; EEA, 2024f).

However, it is difficult to attribute these emissions to a single installation and such assessments require integrated modelling and source attribution studies. This points to the need for different data sources depending on pollution type and the impact being assessed. These must also capture data about pollutants at higher resolution.

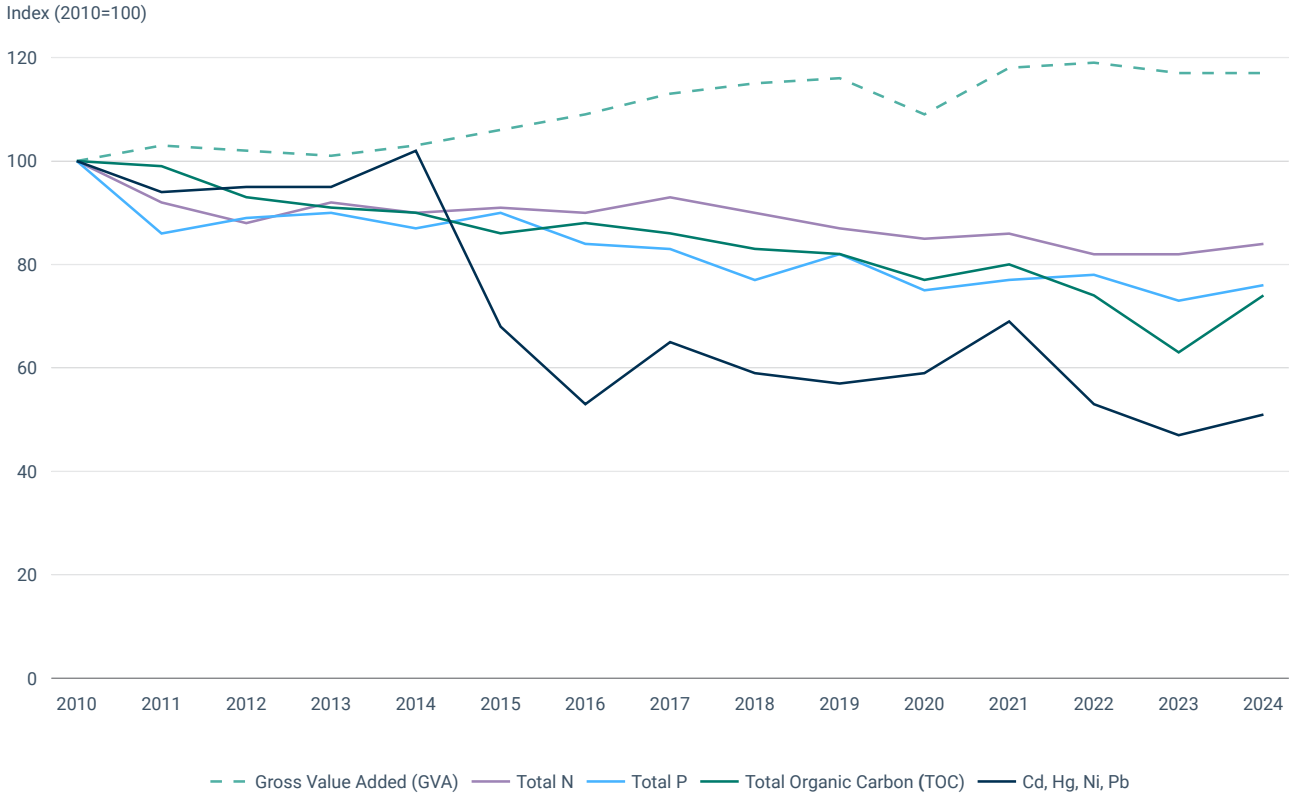
Progress on industrial pollutant emissions to water

Progress in reducing industrial emissions to water has been slower than for air pollutants. Yet, despite a nearly 20% increase in industrial economic output, emissions of pollutants to water declined from 2010 to 2016, followed by a plateau up to 2024 (Figure 3.5). Heavy metal emissions reduced most significantly; nitrogen and phosphorus emissions to a lesser extent. The stagnation is also less pronounced for heavy metals (EEA, 2026g).

Overall, the slower progress or even slightly upward trend across pollutants since 2023 suggests that further reductions may require additional policy measures beyond the current controls. The revised IED strengthens the regulations on industrial emissions to water by reinforcing BAT-based permitting and environmental performance requirements. This enhances its contribution to achieving the EU's water quality objectives under the Water Framework Directive and broader zero-pollution ambitions.

Protecting water quality is not only an environmental objective but also an economic and industrial necessity. Polluted groundwater may not be suitable for industrial use without additional costly treatment. The Water Framework Directive plays a critical role in safeguarding Europe's water resources, thereby supporting Europe's competitiveness and strategic autonomy and reducing long-term risks to industry in a continent that is increasingly water constrained.

Figure 3.5 **Industrial releases of pollutants to water and GVA of industrial activity in the EU-27, 2010-2024**



Notes: The figure is based on reported data under the E-PRTR on direct releases from large industrial facilities in the EU-27. It includes both direct releases from industrial facilities and indirect releases via urban wastewater treatment plants, as many industrial facilities discharge their wastewater for treatment rather than directly into receiving waters. However, releases reported by wastewater treatment plants may also include wastewater from households and other non-industrial sources. As the wastewater treatment sector dominates the statistics, a sectoral breakdown of industrial water pollutant emissions is not presented as it would result in a misleading representation of the actual emission sources. GVA is measured via chain-linked volumes with 2010 as the base year.

Sources: EEA, based on data from Eurostat, 2026g and EEA, 2026h.

Progress in reducing industrial water pollutant emissions is mainly attributed to improved wastewater treatment and more effective industrial emission controls. This partly reflects the positive impact of EU environmental legislation including the IED. Countries now manage industrial water pollutants through authorisation and permitting systems to control point-source discharges of wastewater and to implement other dedicated measures. In particular, the regulations apply to priority substances such as mercury, dioxins and lead as set out in the Water Framework Directive.

Overall, 81% of Europe's urban wastewater is now collected and treated to EU standards under the UWWTD (EEA, 2022a). In most western European countries, urban wastewater treatment is now very effective and treatment in eastern European countries is also improving significantly.

The UWWTD was revised in 2024 to further protect human health and the environment from the effects of untreated urban wastewater. The changes include an extension of the scope to smaller agglomerations, covering more pollutants — including micropollutants — with the aim of contributing to climate neutrality.

Under the Water Framework Directive, if a water body is assessed as failing to achieve good status, Member States identify the pressures causing the failure so that appropriate measures can be taken. Pressures from industrial point and diffuse sources are less significant than other sources such as agriculture.

Nonetheless, the share of European surface water bodies affected by industrial point sources increased from 5.5% to 7.4% between the second and third RBMP reporting cycles [10]. The scope of this data does not include pressures from urban wastewater, although definitions may vary between Member States. While it is possible that this increase partly reflects better reporting, the overall declining ecological status of EU surface waters warrants further action.

While industry is not, on average, responsible for the largest share of pressures, it is essential to manage industrial water pollutants. The EU's surface water bodies continue to have poor ecological status (EEA, 2024f). Local discharges can affect specific rivers and lakes, especially during conditions when there is less water flowing.

Groundwater bodies are also vulnerable to pollution — even small releases can contaminate groundwater for a long time. As such, preventing contamination at the source is an effective way to protect water quality and health (Box 3.4).

Progress on limiting the impact of industry varies greatly between countries. This points to the importance of effective permitting, compliance monitoring and regulatory enforcement in countries which are lagging behind.

Box 3.4

Long-term risks from industrial water pollution

As the fastest warming continent on Earth, Europe can no longer take water for granted. Climate change is reducing the capacity of ecosystems to provide essential services like water purification and flood protection. Human activities further compound these pressures. There are close interdependencies between pollution and over-abstraction (abstraction of water from rivers, lakes, reservoirs, or groundwater aquifers at a faster rate than it is replenished naturally).

For example, in an over-abstracted aquifer, concentrations of nutrients and chemicals may increase where pollutants are less diluted (EEA, 2024f). Groundwater is vulnerable to contamination from a wide range of pollutants, including metals such as arsenic, nickel and lead, as well as persistent, mobile and toxic substances. These pollutants are often linked to geology, mining or other industrial activities.

Importantly, they can remain in aquifers for decades or longer, posing long-term risks to human health and water security. Measures to reduce water pollution can take a long time to improve the quality of groundwater, so preventing pollution is key to protecting groundwater quality (Eionet, Forthcoming).

In the 2022-2027 period, 7.8% of the total area of groundwater bodies was reportedly subject to point-source pollution pressures from contaminated or abandoned industrial sites — up from 6.7% in the previous period (2016-2021). More knowledge is also needed on the extent of and trends in pollution from PFAS, pharmaceuticals and other persistent, emerging contaminants; these are increasingly recognised as systemic risks to groundwater resilience (Eionet, forthcoming).

Several of these pollutants will be more systematically monitored and reported under revised water quality legislation, including the Water Framework Directive.

(10) Across 26 countries included in both reporting cycles (Finland did not report RBMP3 electronically to the EEA). Point sources included: IED and non-IED plants; contaminated sites or abandoned industrial sites; waste disposal sites.

Industrial soil contamination

Limited data on industrial emissions to soil

Data reported under the E-PRTR/IEPR on industrial emissions of pollutants to land are scarce and incomplete. This is because the scope of this reporting only covers waste that is subject to 'land treatment' (D2) or 'deep injection' (D3) disposal operations; these techniques are rarely used in the EU. Consequently, the data need to be interpreted cautiously.

However, the latest assessment on the state of soils by the EEA highlights several contamination hotspots from industrial activities, including high Hg concentrations from:

- mining sites in Spain, Italy, Slovakia and Slovenia;
- waste management in the Western Balkans;
- metallurgy, chemical use and mining in Ukraine.

In a more detailed assessment, mining activities accounted for 42% of the Hg contamination hotspots identified. The remainder were largely linked to coal combustion or local diffuse contamination (Arias-Navarro et al., 2024).

Soil contamination from old industrial sites

Abandoned industrial sites ('brownfields') remain a major and persistent source of soil contamination across Europe. An EEA review found that approximately 60% of recorded contamination is linked to brownfields. Of these, mining sites are a particular concern.

Contaminants in abandoned or orphaned sites often go unmonitored and unreported. Unclear ownership results in public authorities having to take responsibility. In this context, remediation efforts can be delayed — or not addressed at all — due to financial and technical barriers.

Conservative estimates state that the EU has 2.8 million potentially contaminated sites, with at with at least 166,000 sites expected to be in need of risk reduction measures or remediation at a cost of approximately EUR 16.6 billion (EEA, 2024l).

Member States currently report the presence of contaminated sites and the EEA maintains a European indicator on managing them. However, the data do not distinguish between historic and ongoing contamination. Additionally, Member States do not provide georeferencing for the sites, which limits the ability to locate them. While satellite data (e.g. CORINE Land Cover) can help locate old industrial areas such as former mines, the spatial resolution remains coarse and can generally only map land areas that are at least 25 hectares in size. This limits the granularity for targeted assessments.

Under the EU Soil Monitoring Law, Member States are required to establish public registers of potentially contaminated and contaminated sites by 2035. Once a site has been identified, Member States are required to conduct a site investigation and risk assessment. Where a site is found to exceed unacceptable risks to human health and the environment, Member States shall ensure that appropriate risk reduction measures are taken.

Soil remediation is costly. Consequently, preventive approaches that aim to avoid contamination in the first place can often be more cost-effective than remediation.

Existing policy tools include permitting requirements, baseline soil assessments and the application of the polluter-pays principle to assign responsibility for contamination and clean-up.

Progress is being made in developing new methods for understanding the impact of industry and mining on soils and groundwater contamination. For example, new analytical techniques are capable of detecting very low concentrations of flotation chemicals, which are used in mineral processing to separate valuable minerals from ore, in downstream surface waters; this provides a more reliable tool for monitoring their occurrence and risks (IVL, 2026).

3.3 Industrial water usage

Table 3.5 Overview of industry's water usage

Indicator	Progress	Description
Total abstraction: groundwater and surface water abstraction of industrial sectors	Negative development	Manufacturing accounts for 14% of total water abstraction and saw a 3% increase between 2010 and 2023.
Efficiency: water input versus economic value generated by industry	Positive development	Since 2010, manufacturing in the EU has produced the same economic value using 22% less water per euro generated.

Robustness of the evidence base: medium

Key data limitations:

- Progress assessment for specific industrial activities is constrained by data availability, which is often reported only for broad categories (e.g. 'manufacturing' rather than individual sectors).
- Reported data lack details on the environmental and resource costs of water use.
- There is a lack of the kind of up-to-date data required to address acute challenges — particularly related to mining for which only few reported data are available, with large spatial and temporal gaps.

Source: EEA elaboration.

Over-abstraction of water — for irrigation, industrial use and urban development — is one of the main pressures on the EU's water resources. Water currently has a relatively low price; as such, there has been little incentive for industry to manage this valuable resource in a sustainable way compared to energy (AquaSPICE, 2023).

Water abstraction levels must also be viewed in the context of water scarcity conditions in the EU, as almost one third of the EU territory is affected by seasonal water scarcity each year (EEA, 2025e). Water scarcity and drought conditions are increasing in parts of Europe; this is intensifying water stress and putting pressure on energy- and water-intensive industries (EEA, 2024f). Such pressure can affect the reliability of energy systems, influence prices and slow down growth in the deployment of renewables. Projections indicate that water stress will worsen in the future due to increased demand for water and climate change (EEA, 2026q).

Since 2010, total water abstraction in the EU has remained broadly stable, largely because the demand for cooling water from the electricity sector has decreased. This reduction is mainly driven by less nuclear generation and also the transition from fossil to renewable electricity supplies.

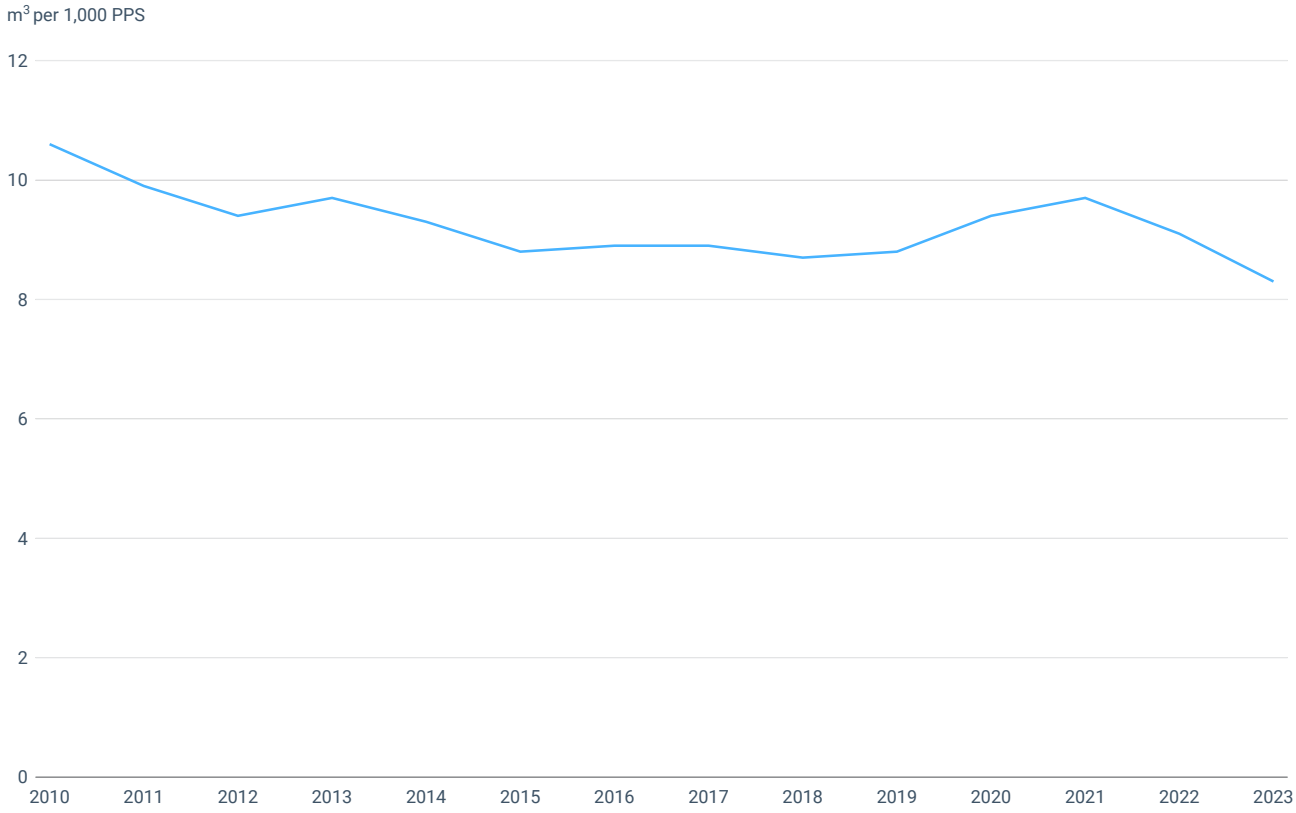
However, there was an increase in demand in all other sectors— including a 3% increase in demand in manufacturing. This highlights the need for enhanced efficiency in water use to meet the EU water resilience strategy's target of enhancing water efficiency by at least 10% by 2030 (EEA, 2024o, 2026q).

The regions most affected by water scarcity will need support to achieve more transformative change towards less water-intensive production systems. In northern Europe, identifying water-saving options in the manufacturing sector is a priority (Wolters et al., 2025). In southern Europe, the leading pressure from water abstraction is not caused by industry but water stress amplifies the risk of local pressures on water resources (EEA, 2024f). On a positive note, the manufacturing industry in southern Europe — which faces the most water scarcity hot spots — has reduced its water abstraction more than any other area, by around half since 2000 (Wolters et al., 2025).

Water abstraction can also be viewed in relation to the generation of economic value — i.e. by assessing water-use intensity. Water-use intensity in the manufacturing sector shows clear progress in this regard. Since 2010, the sector has reduced water input per unit of production by 6.8%. At the same time, it increased the net value added by 19.3% in 2023. This means that the sector generated more economic value for each unit of water used.

Based on EEA calculations, less water is now needed to generate the same amount of value added, i.e. water-use efficiency has increased. More specifically, water use per 1,000 purchasing power standard (PPS) of industrial net value added had decreased to 8.3m^3 in the EU in 2023, down by around half since 2000 and down from 10.6m^3 in 2010 (Figure 3.6).

Figure 3.6 Water-use intensity in the manufacturing sector



Notes: Water intensity of manufacturing production is calculated as the ratio of the volume of water consumed by the manufacturing sector per Member State to the net value added of manufacturing production, expressed in PPS, which adjusts the value of national currency to a common unit according to purchasing power in each country. Net value added is computed as GVA excluding the consumption of fixed capital, all expressed in chain-linked volumes (2010).

Sources: EEA elaboration based on Eurostat (2026m, 2026g).

The divergence between improving water-use efficiency and increasing total abstraction can be interpreted as a signal that efficiency gains alone may not be sufficient to reduce the overall pressure on water resources in the EU.

Despite substantial improvements in water-use intensity at the EU level, large differences remain between Member States. These partly reflect industrial structure, as countries with a larger share of water-intensive manufacturing tend to have higher water use per unit of value added. However, evidence from sectoral BAT reference documents also points to considerable variations between facilities within the same sector. This suggests that there is further potential for efficiency improvements through wider uptake of BATs.

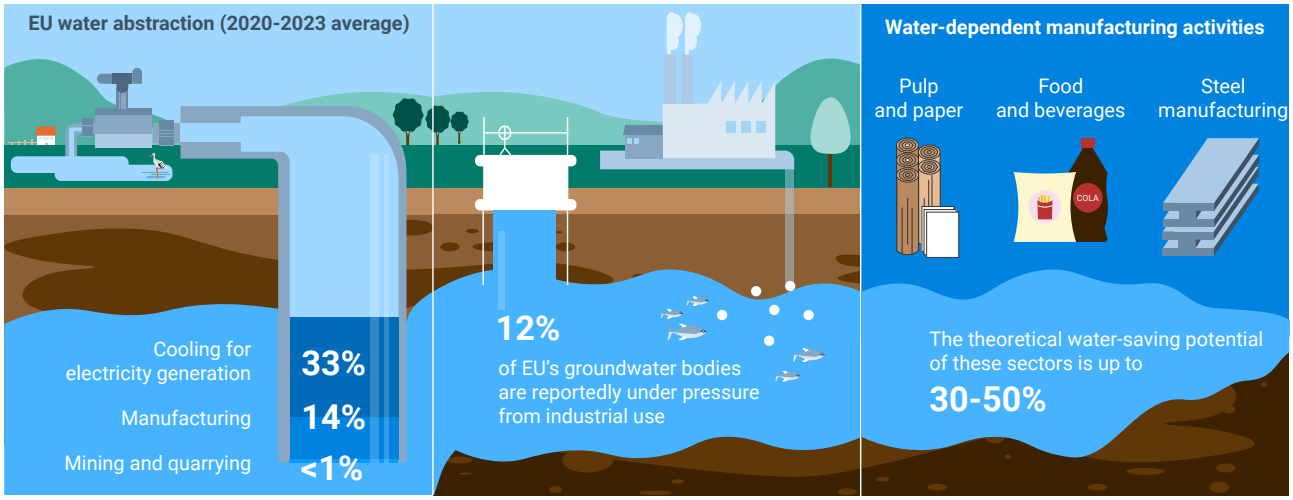
The industry's decreased water-use intensity likely reflects the combined influence of multiple, interrelated drivers rather than a single dominant factor. It is probable that structural changes in the European economy — including a gradual shift away from heavy manufacturing towards more service-oriented and high-tech industries — have reduced the overall intensity of resource use.

At the same time, the implementation of EU environmental legislation has been driving process efficiency and encouraging water reuse. Measures include stricter permitting and the application of BATs. In some sectors and regions, limited water availability and increasing prices for energy and water services have likely been another driver of improved process and technology investments (Wolters et al., 2025).

Current common practices for saving water in the manufacturing sector in Europe include implementing new water-saving technology and/or control processes to treat and recirculate process water and/or wastewater. Yet, technical measures are only effective when complemented by supporting instruments and embedded within a coherent and effective governance framework. Going forward, the revised IED now has specific requirements for competent authorities to set limits for water consumption.

There are certain key challenges, however. These include varied local conditions (meaning solutions cannot be applied uniformly), technical constraints and the need for flexible regulation to enable water reuse.

Figure 3.7 **Industrial water usage in the EU**



Sources: EEA, 2024o; EC, 2025h; Wolters et al., 2025.

Despite high wastewater treatment rates in the EU, wastewater circularity in Europe is still in its early stages; only about 2% of treated urban wastewater is reused directly — far below global best practice. The Water Reuse Regulation provides a harmonised framework for safe water reuse for crop irrigation (from 2028 it may also apply to industry); however, Member States are given discretion about how to apply the regulation and there are several states that don't currently practise any water reuse (EC, 2026k).

The European water resilience strategy calls for improved water-use efficiency, including through demand-side 'water efficiency first' principles, recycling and reduced water-use intensity. A target has been set to achieve at least 10% water efficiency by 2030.

Industry could play an important role in reaching the EU's water efficiency target. Strong policy coherence between the CID and water resilience strategy — with consideration for water use and resilience in industrial planning processes — could amplify the impact of policy across objectives. Further, mitigating water losses and leakages in public water supply systems is a key measure for saving water and improving water resilience (EEA, 2026q).

Significant data gaps remain regarding industrial water use and pollution. This limits the ability to benchmark performance and assess environmental costs. New reporting requirements under the IEPR and Water Reuse Regulation should substantially improve the evidence base on industrial water use and water reuse. This will help to identify where further efficiency gains can be achieved, where circular solutions offer the greatest potential and how emerging industrial activities may affect local water resources.

3.4 Raw material consumption and circularity

Table 3.6 Overview of industry's raw material consumption and circularity

Indicator	Progress	Description
Europe's material footprint	Limited development	The material footprint is stable but above the global average.
Circular materials use rate	Limited development	The circularity rate is almost unchanged since 2010 and has stalled at a low level.
Domestic material input over GVA (manufacturing)	Positive development	The absolute decoupling of direct material input from GVA suggests improved resource efficiency across manufacturing facilities.

Robustness of the evidence base: medium

Key data limitations:

- Data are collected through robust national and international processes, though some methodological constraints can affect accuracy.
- There is a lack of facility-level data on raw material consumption and secondary material use.

Source: EEA elaboration.

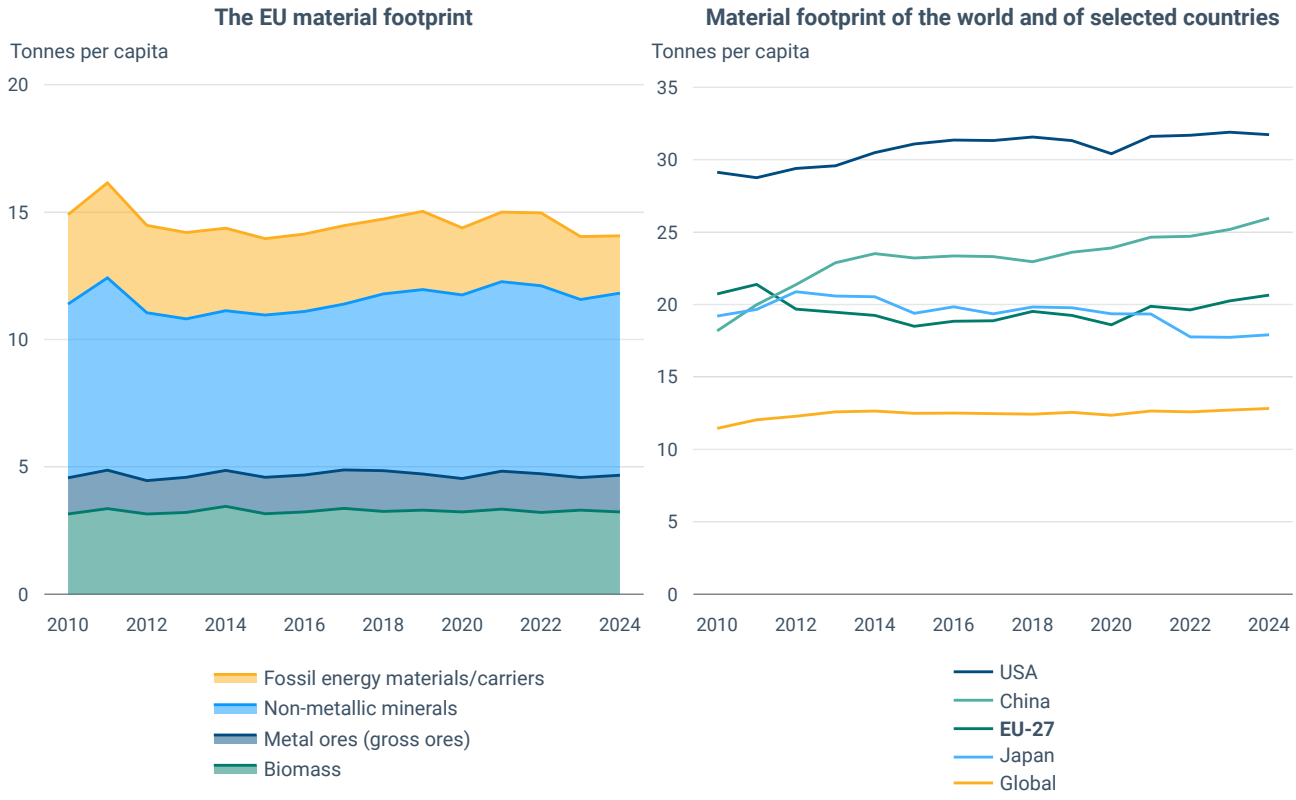
Extraction and the use of raw materials contribute to resource depletion, habitat destruction and pollution. While the material footprint of non-metallic minerals, biomass and metals increased from 2010 to 2024, the EU's overall material footprint has remained relatively stable.

A brief dip was seen in 2020 — likely due to the COVID-19 pandemic — and some more recent fluctuations are likely attributable to Russia's war in Ukraine. This indicator measures the materials extracted globally in order to fulfil consumption demand across the EU. While the indicator is not industry specific, it tracks key intermediate products for use in downstream industrial activities.

The relative stability of the EU's material footprint — despite growing consumption and economic activity — may reflect a combination of factors. There has been a continued shift in economic activity towards service sectors — which are generally less material intensive than manufacturing — and declining fossil fuel consumption; these have likely moderated demand for raw material extraction.

At the same time, gains in material efficiency appear to have been largely offset by increasing levels of consumption. This suggests that improvements in resource efficiency have helped to stabilise, rather than reduce, the EU's overall material footprint (EEA, 2024g).

Figure 3.8 **Material footprint across major components and global comparison**



Note: Due to methodological differences, the two charts should not be compared to each other.

Source: EEA elaboration based on Eurostat, 2026i and UNEP IRP, 2026.

Of the various material groups, consumption of non-metallic minerals is the highest, accounting for 51% of the footprint in 2024; changes in consumption in this group were largely responsible for the overall trend. Biomass was the next largest group (23%), followed by fossil fuels (16%) and metals (10%).

A key consideration is that although non-metallic minerals account for over half of the total material footprint, the type of materials consumed by this sector have less

of an impact on the environment and climate compared to materials extracted and used by metals and fossil fuels. Prioritising measures to make the consumption of metals and fossil fuels more efficient is likely to maximise the environmental benefit.

The EU's current material footprint is higher than the global average and significantly exceeds that of low- and middle-income countries. This level of resource use surpasses the planet's 'safe operating space' for resource extraction; the implication is that, if global resource consumption matched that of the EU, the capacity of the planet to provide these resources sustainably would be exceeded. High material footprints indicate ongoing dependence on primary resources, exposing industry to supply and sustainability risks. This underlines the importance of establishing circular economy solutions.

The circular material use rate (CMUR) refers to the share of the total amount of material used in the economy that comes from recycled waste; it provides a measure of how circular the economy is. The EU's CMUR has increased slightly in recent years, from 10.8% in 2010 to 12.2% in 2024; however, this is still considered low compared to the target of 24% set out in EU policy, including the CID. The improving trend is explained mainly by increases in the amount of waste recycled while domestic material consumption has remained relatively stable.

Stagnation of the CMUR should be interpreted as a signal that progress in circularity remains insufficient relative to the scale of Europe's resource challenge. This is despite advances in recycling and circular economy policy. In other words, for substantial increases in the CMUR, recycling alone is not enough. It needs to be combined with reduced material use.

As the CMUR is based on tonnage, the greatest potential for increasing it lies in reducing the EU's usage of heavier material groups like non-metallic minerals rather than comparable reductions in other material groups, such as metals. However, circularity priorities should not be determined by material quantities alone. Different material groups are associated with different environmental impacts. As such, efforts should also focus on reducing the consumption of metals and fossil energy materials and on improving the sustainability of biomass production.

In a manufacturing context, improving the CMUR is about transforming production systems by turning industrial waste into inputs for new processes and using secondary raw materials instead of virgin materials. Looking beyond material consumption, broader considerations for improved circularity should involve designing products for reuse, repair and recyclability. Extending product lifespans through maintenance and remanufacturing should also be a priority.

Material inputs to the economy serve as an indicator of the resource intensity of economic activity, highlighting the scale of resource demand and the pressures this places on natural resource. In this regard, Direct material input (DMI) measures the total amount of materials directly used by an economy, including metals, minerals, biomass and fossil fuels. Figure 3.9 gives the DMI for each euro of value generated, for mining and various manufacturing activities. These sectors represent approximately 86% of the DMI for all economic activities, including services, trade and transport.

Of all the EU's economic activities, manufacturing — as a predominantly material-consuming economic activity — ranks last in its ability to generate economic value from each kg of material input. However, over the 2010-2022 period, the amount of material input needed for each euro produced decreased by 30% for manufacturing. This indicates substantial improvements in the sector's resource efficiency.

Improving resource efficiency in manufacturing has come about due to a combination of increased value creation and decreased DMI. The sector's DMI decreased by approximately 16% while the GVA increased by around 20% in this period. This signals an absolute decoupling of the sector's economic growth from its material requirements. In other words, the sector is producing more value from fewer materials. The trend may also partly reflect structural changes in the European economy, including a shift towards higher-value-added and more knowledge-intensive manufacturing activities.

Figure 3.9 DMI and GVA across economic activities



Notes: Y-axis represents resource productivity, measured as GVA generated per unit of DMI. The figure excludes the manufacture of coke and refined petroleum products.

Sources: EEA own elaboration.

Looking at DMI/GVA for key manufacturing sub-sectors (Figure 3.9), chemicals manufacturing has made the largest resource efficiency gains (DMI/GVA decreased by 35% between 2010 and 2022), followed by manufacture of mineral products (-25%) and equipment manufacturing (-23%). As expected, there are relatively high inputs per unit of economic value created for sectors focused on high-volume, lower-value products such as wood. While this indicator offers useful insights into the economy-wide or sectoral situation, it is limited in terms of providing insight into process-related transformations taking place at industrial facilities. It should also be noted that DMI accounts for imported materials and products by their actual weight, but does not capture the raw materials extracted abroad to produce those imports, and so tends to underestimate total material requirements.

The raw material equivalent (RME) dataset offers a more comprehensive picture of the material needs of industry in Europe. This is because RMEs also capture materials consumed outside the EU in order to produce the DMI for EU industry. For example, this includes all the material (including energy carriers) needed to extract iron, process it into steel and develop the steel plates that enter a manufacturing plant. In RME terms, industrial sectors were responsible for more than half of all material consumption in the EU-27 in 2015.

Looking more closely at RME data for 2015 (the only year with detailed industry data in RME units), refining petroleum, producing metals and manufacturing motor vehicles were responsible for the highest material consumption, if construction — that consumes huge amounts of mostly inert materials like sand and gravel — is excluded (Table 3.7 below).

Material consumption in RME terms offers important insights into the footprint of EU industry globally, in material terms. For example, although the DMI for the 'manufacture of motor vehicles, trailers and semi-trailers' was 112 million tonnes in 2015, the material needs of that industry in RME terms totalled 593 million tonnes — more than five times higher.

Table 3.7 Top 10 manufacturing sub-sectors with the highest material consumption in RME in 2015 in the EU-27

Sector	MF (kt RME)	Rank
Construction	1,915,975	1
Refining petroleum	859,411	2
Manufacture of fabricated metal products, except machinery and equipment	717,973	3
Copper production	643,909	4
Manufacture of motor vehicles, trailers and semi-trailers	593,090	5
Manufacture of machinery and equipment n.e.c.	449,607	6
Processing of food products n.e.c.	382,049	7
Production of primary plastic materials (plastic resins and polymers)	337,172	8
Manufacture of electrical machinery and apparatus n.e.c.	312,273	9
Manufacture of basic iron and steel and of ferro-alloys and first products thereof	302,638	10

Notes: n.e.c., not elsewhere classified; MF, Material Footprint; kt RME, kilotonnes of raw material equivalent.

Source: EEA own elaboration.

Box 3.5

Circularity in the copper sector

Copper is essential for the EU's green and digital transformation. It plays a vital role in technologies such as wind turbines, solar panels and electric vehicle motors. Since 2023, copper has been included in the EU CRM list as a strategic resource, due to supply risks associated with relying on imports for 48% of supply (EC, 2023f).

As shown in Table 3.7, copper production has a very high material footprint. Since demand for copper is expected to increase significantly in the coming years, attention is needed to mitigate this.

Copper produced from secondary sources has a lower carbon footprint and reduced environmental impact compared to copper sourced from primary extraction (Ekman Nilsson et al., 2017). It is estimated that 44% of EU copper demand is currently met from recycled sources (EuRIC, 2022) clearly indicating that there are substantial further potential gains in this area through an increased focus on circularity:

- The expectation is that around 60% of post-consumer copper scrap will be directed into the formal recycling system globally by 2035 (Spiller, P. et al., 2025). Much of the rest is lost through disposal in landfills or incineration. A further share — especially in consumer goods — is hoarded by end-users. Enhanced collection systems and separation technologies are required to recover this significant loss.

- As products become increasingly complex, the process to extract materials for recycling also becomes more challenging. For example, copper content within printed circuit boards are difficult to recycle because it is embedded with glass fibre and resins (Kim et al., 2021). Incentives or statutory guidelines are needed to ensure that product design is optimised for the end-of-life phase and that items can be disassembled efficiently.

Copper is identified as a strategic raw material, therefore within the scope of the Critical Raw Materials Act, reflecting its importance for electrification, renewable energy systems and other technologies underpinning the EU's green and digital transitions. The Act supports greater use of secondary copper by promoting domestic recycling capacity and improving access to recyclable materials, thereby enhancing the security and resilience of EU supply chains.

3.5 Industrial generation of waste

Table 3.8 Overview of waste generation in industry

Indicator	Progress	Description
Waste generation across industrial sectors	Positive development	Waste generation across industrial activities has decreased by 19%, mainly driven by a decline in mining waste.
Waste generation intensity across industrial sectors	Mixed development	Waste intensity increased in the mining sector but decreased slightly in all other sectors.
Hazardous waste generation across industrial sectors	Mixed development	Trends show strongly different directions for the different sectors.
Waste recovery rates	Inconclusive	The percentage of waste transfer from industrial facilities destined for recovery shows a slightly deteriorating trend since 2010. However, the data only capture a limited part of all industrial waste.

Robustness of the evidence base: limited

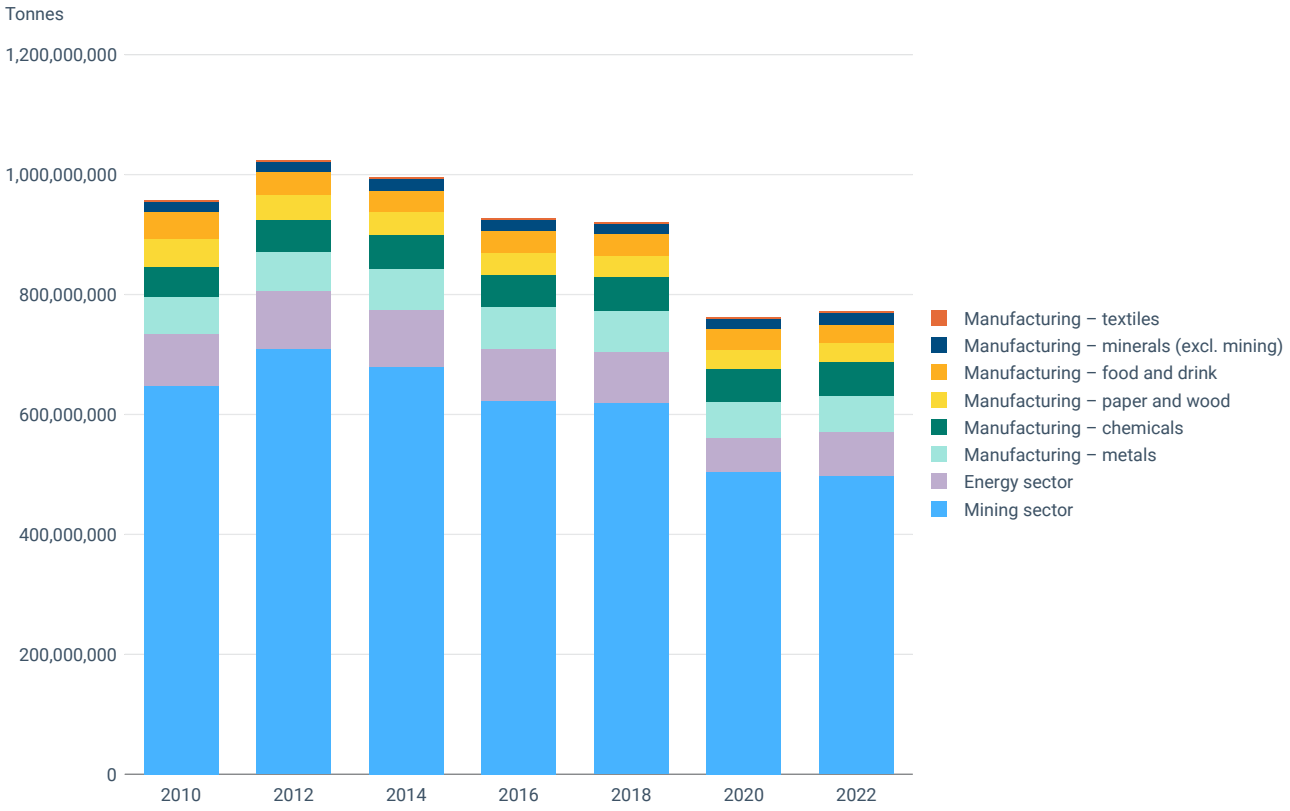
Key data limitations:

- Sector-specific waste destination data are limited.
- There is an incomplete picture from E-PRTR, which only captures offsite waste transfers.
- Reclassification issues for hazardous mining waste hinder trend analysis.
- There is insufficient granularity on hazardous waste streams.

Source: EEA elaboration.

Over the past decade, there has been mixed progress in the area of industrial waste generation and management in the EU. Policies under the EU's Waste Framework Directive and the circular economy agenda emphasise waste prevention and resource efficiency; however, the rates of decline — in terms of absolute volumes of waste generated in industrial sectors — have varied. Since 2010, waste generation across industrial activities — which includes mining, manufacturing and energy sectors — has decreased by 19% (Figure 3.10).

Figure 3.10 Waste generation by industrial sector



Notes: The waste and water sectors have been excluded from this analysis as they are not genuine producers of waste but manage waste from other sectors as well as households and services. The energy sector includes the manufacturing of coke and refined petroleum products.

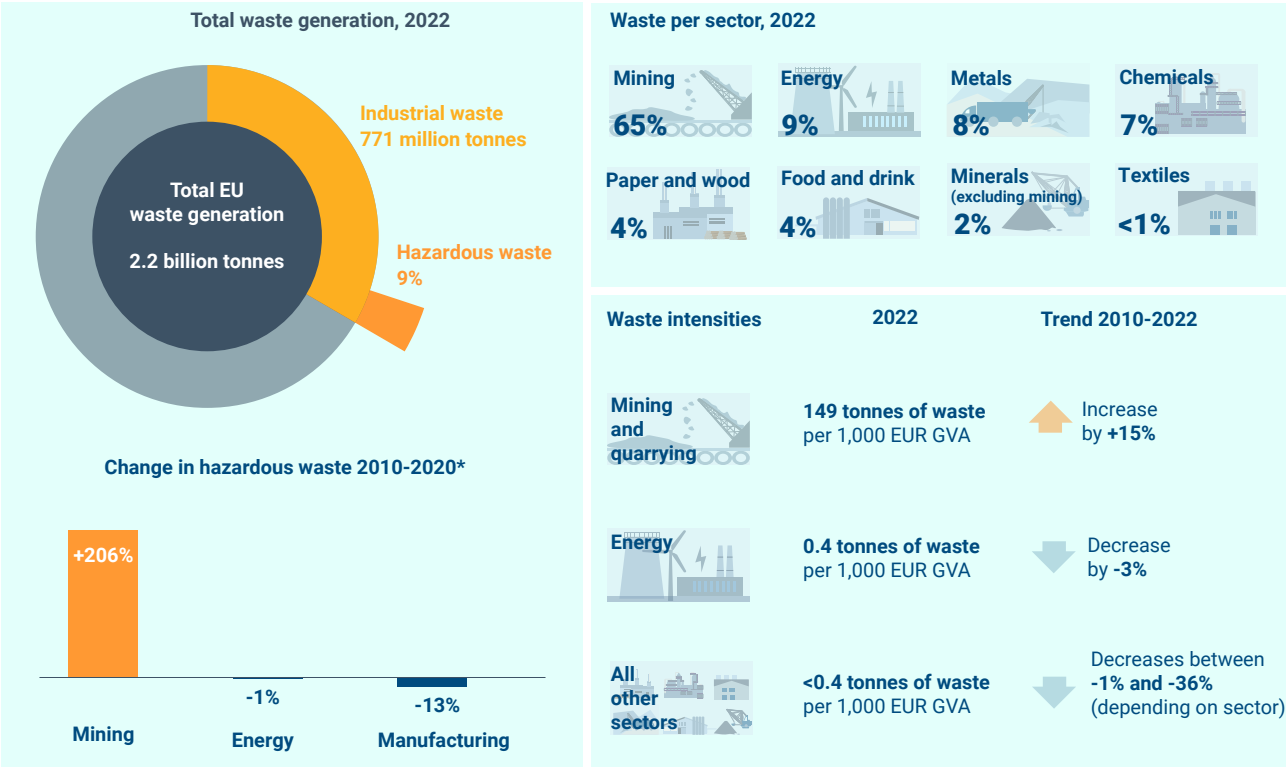
Source: EEA elaboration based on Eurostat, 2025c.

The improvements have mainly been driven by a decrease in waste generated in the mining sector. In 2022 mining was responsible for 65% of waste generated by industry [(11)] (Eurostat, 2025c). The recently adopted CRMA (EU, 2024) on reducing the EU's reliance on (critical) raw material imports is likely to increase the amounts of mining waste in the EU, with a new benchmark of 10% of the EU's consumption of mined materials to be extracted within the EU by 2030. This highlights the relevance of interpreting waste generation data alongside trends in industrial activity, as changes in extraction and manufacturing levels can have a significant influence on aggregate industrial waste indicators.

While total waste volumes from industrial activities decreased between 2010 and 2022, so did waste intensities for all industrial sectors except mining. This signals absolute decoupling of waste generation from economic activity (Figure 3.11). However, it remains unclear whether this decoupling reflects genuine process efficiencies (that reduce total waste-related environmental pressures) or structural economic changes that increase value added per unit of output without reducing waste generation.

(11) All other sectors contribute less than 10% each.

Figure 3.11 Key facts on industrial waste



* Excluding Sweden for the mining sector due to break in time series; excluding Czechia, Estonia and Portugal for the trend in the energy sector due to break in time series.

Notes: The waste and water sectors have been excluded from this analysis as they are not genuine producers of waste but manage waste from other sectors as well as households and services. The energy sector includes the manufacturing of coke and refined petroleum products.

Source: EEA elaboration based on Eurostat, 2025c.

Assessing waste volumes alone provides an incomplete picture of environmental pressures; it does not capture differences in toxicity and risk between waste types. It is therefore essential to consider how hazardous each waste stream is in order to better understand the potential impacts on human health, ecosystems and the effectiveness of waste management policies.

Furthermore, if changes due to breaks in time series — e.g. because of the reclassification of certain wastes from hazardous to non-hazardous wastes in certain countries — are excluded from the analysis, the statistics look very different. For example, in this analysis:

- the mining sector doubled its hazardous waste generation between 2010 and 2022;
- the energy sector's hazardous waste remained relatively stable;
- hazardous waste generation in the manufacturing sector decreased by 13%;
- there were large variations between the different manufacturing sectors.

About 9% of the waste generated by industry (mining, manufacturing and energy industries) in the EU was hazardous in 2022. Based on Eurostat's waste generation and treatment (env_wasgt) dataset, the mining sector was the largest contributor to total hazardous waste, accounting for 71% of all hazardous waste generated by industry. The metals and chemicals sectors accounted for 12% and 9%, respectively.

The disposal of mining tailings — or leftover waste materials — can contain significant levels of toxic substances and is a key challenge for the mining sector. The Mining Waste Directive (2006/21/EC) came into force in 2008 to mitigate the adverse effects of mining waste on the environment. This followed on from the tailing dam failure in Baia Mare, Romania (Mononen et al., 2022).

Currently, EU waste statistics do not provide sector-by-sector information on where the waste generated ends up. However, data from 2024 provided in the E-PRTR — on waste transfers out of industrial facilities within its scope — indicate that around 65% of waste transfers from industrial facilities were destined for recovery (including recycling and energy recovery). This represents a slight decrease from 68% in 2010 (EEA, 2025c).

It is important to note that E-PRTR waste transfer data only cover off-site transfers of waste accounting for 235Mt of waste — equating to 24% of the waste generated by industry according to EU waste statistics [12]. Further, the current data coverage is insufficient to assess progress across the full range of appropriate measures for preventing and managing industrial waste, including:

- waste prevention;
- the management of hazardous waste from industry and potentially harmful by-products of industrial processes;
- the management of tailings;
- control of acid mine drainage;
- wastewater treatment.

There are efforts at the national level to improve the information available (Box 3.6).

Box 3.6

National waste accounts

Waste accounts offer a way to track waste from the point at which it is generated to its final destination. They allow information to be derived on the whereabouts of the waste generated by each industrial sector through several treatment steps towards its final destination.

A methodology for waste accounts has been developed by Eurostat (Eurostat, 2025b) and tested in selected EU Member States. However, the approach is still experimental, and the information is not yet available at the EU level.

(12) The amounts of waste transferred out of industrial facilities are much lower than the total waste generated according to waste statistics for several reasons: some of the waste generated is treated on site and not transferred out of the facility; not all waste-generating facilities are covered by the E-PRTR — waste statistics include aggregated sectors that are not fully covered by E-PRTR and facilities generating waste amounts below certain thresholds do not need to report waste transfers to the E-PRTR. For hazardous waste, the coverage is generally better.

Looking ahead, continued progress will depend on:

- deepening circular economy practices within key industrial sectors;
- enhancing waste prevention measures;
- fostering innovation in waste processing technologies.

Waste reduction efforts in industry must be differentiated according to both waste intensity and waste relevance. A focus on the most waste-intensive industries — especially the mining sector — remains critical for reducing overall waste generation. Progress in this area is directly relevant for the feasibility of reaching the EU's CMUR target.

At the same time, waste management priorities need to become broader: several industries generate small but very environmentally relevant quantities of waste (e.g. chemical waste). These require targeted action to mitigate the risks to ecosystems and human health.

Monitoring progress for both waste intensity and waste relevance is currently constrained by the fragmented and uneven availability of data across sectors and waste types. Initiatives such as Eurostat's waste accounts project, alongside strengthened and more harmonised reporting requirements expected from 2028 onwards — including reporting on facilities' raw material use under the IEPR and new corporate sustainability reporting requirements — have the potential to improve transparency, comparability and policy effectiveness. This is provided that they are fully integrated into industrial transformation strategies.

Emerging waste challenges are increasingly linked to new technologies that are essential for the green transition itself. Waste streams from batteries, wind turbine blades and solar cells all require recycling solutions that are not yet fully mature or deployed at scale. Nonetheless, approaches and policy measures such as eco-design, material-specific recycling targets and extended producer responsibility schemes can help address these burgeoning waste streams (EEA, 2021).

3.6 Synergies, co-benefits and strategic implications

Choosing appropriate technologies, techniques and other measures to support industrial transformation is highly context specific. The requirements vary across sectors and also according to territorial conditions, but transformational measures are not applied in isolation. As such, a broad range of climate and environmental objectives must feed into decisions on industrial transformation to maximise synergies and minimise trade-offs (Box 3.7).

The 8th EAP explicitly calls for systemic approaches across the full life cycle of production processes. The expansion of renewable energy systems and electrification offer substantial potential for synergies, as they massively reduce GHG emissions and other pollutants (including $PM_{2.5}$, SO_2 and NO_x) while improving human health outcomes (Peng et al., 2025).

Such considerations could be translated into strategic indicators for transition planning and prioritising public investment and support, as integrated perspectives can offer broader benefits at the system and community levels. Interventions should also prioritise measures that deliver the most immediate and robust reductions in environmental pressures. This is particularly the case where delays risk triggering irreversible tipping points in climate and ecological systems, thereby limiting future options to design suitable responses.

Single technological shifts — such as electrifying industrial processes — are essential and can deliver substantial emission reductions. In addition, more circular production processes — including measures that optimise the use of energy and water resources — often result in no-regret solutions, delivering multiple co-benefits and few trade-offs across climate and environmental objectives (EEA, 2026r). Based on an average of estimates reported in literature, circular economy measures could reduce industrial GHG emissions by around 26%. However this varies considerably, with most results indicating a mitigation potential between 12-41% (EEA, 2026c).

Importantly, solutions that advance circularity and resource efficiency are strategic. Companies that deplete water resources run a higher risk of facing stranded assets as a result of changes in water regulations, high levels of pollution and local community opposition (CDP, 2022; OECD, 2025a).

Water efficiency, water reuse and closed-loop measures strengthen the resilience of water-dependent sectors in water-scarce regions. Likewise, keeping materials in use for longer and expanding secondary material markets can lower exposure to global supply chain disruptions and price volatility. These measures improve not only resource productivity but also resource security.

This points to the need for a transition away from a traditional linear model of industrial production — where individual processes rely on primary raw materials and generate both products and waste — towards a more integrated industrial ecosystem. Here it is relevant to highlight the significance not only of waste and recycling — which is covered by more than 30 legally binding targets (EEA, 2023c) — but also of reducing the use of raw materials. Currently the EU has no targets for this.

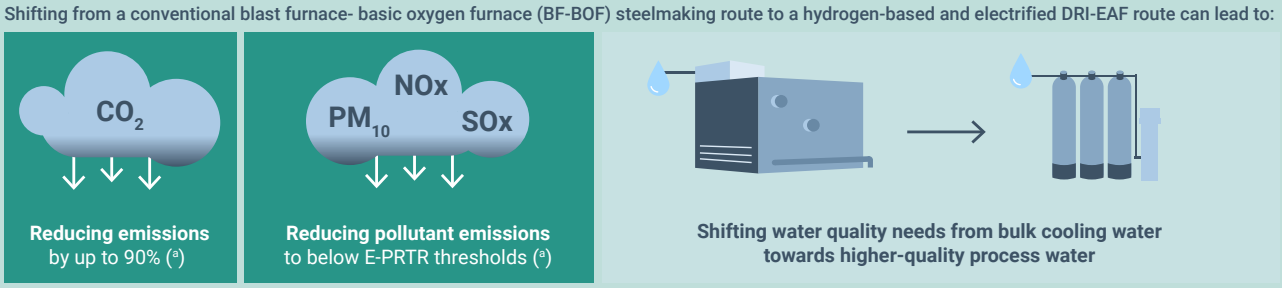
Introducing targets for resource use could be another important measure for achieving policy aims regarding climate, pollution and biodiversity impacts of resource extraction and processing. The Circular Economy Act presents an important opportunity to enable industries to think in terms of life-cycle value rather than linear costs, including by building a stronger market for secondary raw materials and making strategic use of the EU's resources.

Box 3.7

Positive synergistic relationships between green industry measures

- Electrification abates GHG emissions as well as combustion-related air pollutants such as NO_x and SO_x. Depending on the technology and sector, electrification can also reduce water use in thermal systems and enable higher rates of recycling, for example in the case of electrified steel furnaces (Figure 3.12).
- Water-saving measures — including water efficiency, closed-loop systems and leak mitigation — also reduce the energy cost of upstream water treatment and pumping.
- Substitution of raw materials can address both GHG and air pollutant emissions by reducing the need for materials that cause high process-related emissions. This is the case for supplementary cementitious materials (SCMs) used to replace clinker in cement. At the same time, waste-based SCMs improve resource efficiency by making use of by-products from other sectors. Substitution can also be used as a measure to enable downstream circularity by reducing the need for chemicals that are hazardous, difficult to recycle or that hinder the safe reuse of materials.
- Circularity measures such as precision manufacturing, lightweighting [13], recycling and using recycled materials deliver multiple benefits by mitigating the need to extract, process and manufacture primary raw materials. They also reduce associated emissions.
- Energy efficiency and recovery of waste heat mitigate GHG and other air pollutants. Less energy is used to produce the same value.

Figure 3.12 Impact of green steelmaking on emissions and water use



Sources: Aries et al., 2026; Pelckmans et al., 2026.

The benefits of a clean transition in industry significantly outweigh the cost of resources needed for the transition. The additional environmental cost of total raw materials needed for the EU's low-carbon transition represents only around 3.7% of the cost of damages caused by EU's territorial carbon emissions (Arendt et al., 2022).

At the same time, however, changes in materials, technologies and processes may inevitably shift pollution types and other burdens across sectors, domains and geographical boundaries. This would create new types of waste streams and competing demands. Policymakers face the challenge of addressing such tensions and anticipating policy needs — including from new and emerging sectors that

(13) Reducing the amount of material required to deliver the same function.

are expected to increase pressure on local resources or increase competition for electricity.

Data centres are a relevant example (Box 3.8), as they represent a strategic sector for achieving the EU's policy objectives in the digital space. Another example is enhanced mining of strategic minerals; this may address the energy autonomy crisis but create new localised sustainability challenges, as many prospective mineral deposits occur close to protected areas (EC, 2025f).

Box 3.8

Anticipating trade-offs in the EU's twin transition

The EU's installed data centre capacity already uses 4.8% of regional average power output — the third highest share in the world. Going forward, at least eight 500+ megawatt hubs are planned (IEA, 2025a). While estimated projections should be treated with caution, significant increases in capacity are expected (EC, 2025i).

Historical data from Ireland demonstrate how quickly the sector can develop. The percentage share of metered electricity consumption used by data centres there rose from 5% in 2015 to 22% in 2024 (CSO, 2025).

Water demand for cooling at data centres — depending on the technology employed — also has a considerable impact on local water basins. As such, there is a need to better understand whether and how the sector adds stress to Europe's energy and water systems and how this may impact the electrification needs of other industrial sectors (EC, 2025a).

A coherent, cross-sectoral policy approach is required to address tensions across objectives and sectors in relation to transition demands. This must be supported by early identification of potential trade-offs and the development of context-specific and innovative solutions.

Regulatory frameworks are evolving. They now include stricter requirements on sustainability and transparency for batteries and new reporting requirements on energy needs for data centres under the EED. The proposed Cloud and AI Development Act will offer further opportunities for a coherent and sustainable approach to the EU's twin green and digital transition.

4 Supporting a clean industrial transformation

Most industrial transition plans emphasise technological options. There has been far less focus on the enabling conditions that determine whether the outlined pathways can be realised in practice. This chapter examines progress on the enabling environment that supports the transformation of EU industry towards pollution prevention, decarbonisation, circularity and resource efficiency.

4.1 Clean technology innovation and adoption

Key takeaways

Europe's clean industrial innovation base continues to grow:

- Green patent activity is increasing;
- There is a growing number of clean-tech start-ups and scale-ups;
- Public support for industrial innovation projects is expanding;
- Eco-innovation performance is improving.

Yet, there is also evidence of declining output from research and development (R&D). This suggests that generating more patents and research spending does not automatically translate into market-ready solutions.

While industrial firms continue to invest in transformative technologies, investment decisions are increasingly delayed by bottlenecks in electricity networks, hydrogen supply chains, CO_2 transport and storage infrastructure as well as uncertain market conditions. Europe's challenge is therefore becoming less about inventing clean technologies and more about creating the conditions for deploying them at scale.

Growing innovation activity but persistent challenges in commercialisation

Several indicators signal progress in innovation activity related to greening industrial facilities in Europe. For instance, Europe is a significant contributor to advancing clean tech. Between 2017 and 2021, innovators in the EU generated nearly 52,000 international patent families in this field; this represents about 22% of all such inventions globally (EIB and EPO, 2024).

While patent filings are not always a useful proxy for technological innovation (Nagaoka et al., 2010), green and digital patents in the EU have increased significantly — by an average of 14% annually since 2009 (Eurostat, 2026j). Another positive indicator is that the share of green technology start ups and scale ups has increased across several industrial ecosystems (EC, 2026b). This suggests growing entrepreneurial activity.

Progress is also increasingly visible at the level of industrial innovation projects and early deployment. By May 2026, the EU Innovation Fund had supported around 230 projects — mainly in energy-intensive industries — backed by EUR 15.6 billion. In

addition, the European Investment Bank (EIB) steadily increased lending to circular economy projects, rising from EUR 2.3 billion in 2014-2018 to EUR 5.1 billion in 2020-2024 (EEA, 2026d).

The overall growth in innovation projects and public R&D expenditure over the past decade (Section 4.3) is reflected in the fact that Europe's innovation capabilities have gradually been strengthening. Composite indicators such as the eco-innovation index — which has increased by 27.5% from 2014 to 2024, mainly driven by resource efficiency — suggest that there have been improvements in framework conditions, innovation inputs and collaborative capacity in several Member States.

At the same time, a growing body of evidence also points to decreased productivity from R&D in the EU — measured in terms of the ability of R&D expenditure to generate commercially viable innovations, productivity gains or new market opportunities. Some researchers have linked this to Europe's 'middle technology trap' whereby a significant whereby a significant share of private R&D in the EU remains concentrated in established medium-technology industries rather than emerging high-growth, high-technology sectors (EEA, 2025b; ifo Institute, 2024).

While this trend is observed globally, EU-based scoreboards indicate that European firms lag behind competitors in the United States and China, with no clear signs of convergence. This suggests that increasing patenting activity and public R&D expenditure alone are unlikely to be sufficient to close the innovation gap.

Navigating technology uncertainties and transition pathways

Some emerging technologies face uncertainties with regard to cost competitiveness, resource requirements, the availability of infrastructure or scalability. These issues highlight the importance of maintaining a diverse innovation portfolio and regularly reassessing investment priorities as evidence evolves.

For instance, Schmidt (2026) suggests that policymakers can move beyond technology-neutrality principles [14] and identify technologies that deliver both cost competitiveness and domestic economic payoffs. The two main proposed criteria for identifying this kind of technology are:

- its potential for cost reduction (without long-term dependence on subsidies);
- whether it offers early mover advantage (Schmidt, 2026).

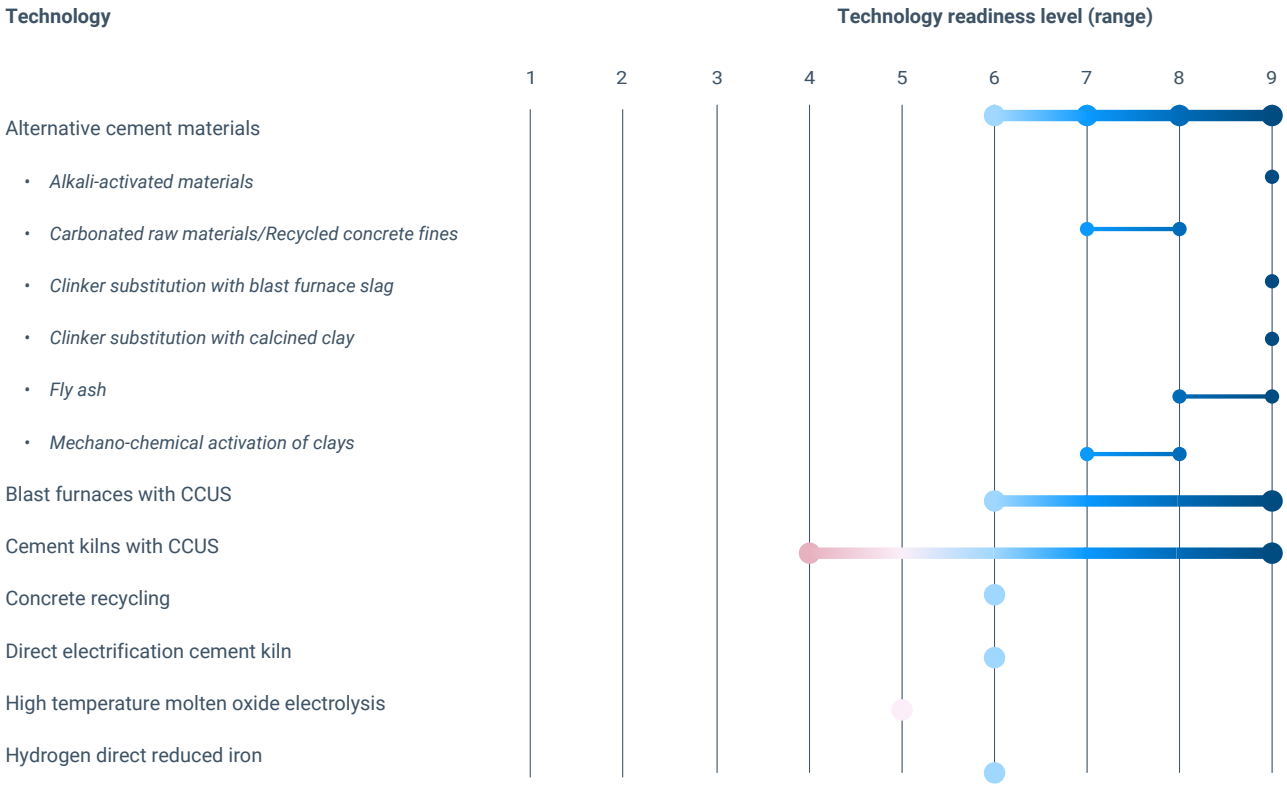
It may also be relevant to identify solutions with the potential to deliver co-benefits in the areas of decarbonisation, pollution prevention and circularity. Such an approach would help to avoid missed opportunities to reduce emissions at the lowest possible cost (EEA, 2026r).

Commercialisation and scale-up remain an important challenge in some sectors and applications, including for high-temperature heat electrification and hydrogen-based steelmaking (Figure 4.1). Attention is increasingly turning towards the need for bridging innovation with deployment. Clean industrial technologies are already available for many applications, particularly low- and medium-temperature heat in sectors such as chemicals, food and beverages, and pulp and paper. For example, evidence suggests that around 40% of industrial heat demand up to 200°C in Germany could be electrified (Agora Industry, 2026c).

(14) Technology neutrality is a principle of EU regulation whereby legislation focuses on outcomes and functions rather than favouring or disadvantaging specific technologies.

However, industrial electrification has stalled across most of the EU. This is due to high upfront capital expenditure (CAPEX) as well as actual or perceived higher operational costs (OPEX) of electricity-based systems. This indicates the need to incentivise uptake and address the gas-to-electricity price ratio at the national and EU levels (Section 4.2).

Figure 4.1 **Technology readiness level (TRL) of selected decarbonisation technologies for cement and steel**



Notes: TRLs provide a standardised measure of technological maturity across a spectrum from TRL 1 (basic principles observed) to TRL 9 (actual system proven in operational environment).

Sources: EEA based on JRC email correspondence with EEA, June 2026; IEA, 2026a.

Regulatory and permitting frameworks will play an increasingly decisive role in determining whether innovative technologies can move from demonstration to deployment. For decarbonisation technologies, the cost competitiveness of breakthrough solutions — such as renewable hydrogen and other electricity-intensive technologies — remains strongly dependent on the price of carbon, access to infrastructure, as well as access to abundant, low-cost, low-carbon electricity. For many technologies, the operating costs — not just CAPEX — present a significant barrier.

Evidence also points to unique obstacles to scaling circular business models beyond local initiatives and early adopter markets in Europe. Barriers include:

- supply chain rigidity;
- technological limitations;
- producer and consumer behaviour;
- linear policy and other lock-ins (EEA, 2026n).

The IED continues to be a key driver of adoption for pollution abatement technologies. For example, fully implementing best available technique measures in energy-intensive industries is expected to result in significant emissions reductions for SO_2 (over 74%) and NO_X (over 70%) by 2050 compared to a business-as-usual scenario (EEA, 2026r).

Previously non-binding BAT-associated emission performance levels will now be binding through BAT reference documents (BREFs) under the revised IED. In this context, it is expected that the uptake of technologies and techniques that also address decarbonisation and circularity objectives will increase in the coming years.

Time series data and benchmarks on technology uptake at the sectoral level are limited; they are only available for selected technologies and sectors. For instance, a 2024 survey of EU companies in energy-intensive sectors assessed technology adoption rates and found that 55% of companies had adopted energy-saving technologies, 40% had adopted waste management technologies and 38% had adopted clean production technologies (EC, 2024b). Box 4.1 identified additional signals of progress related to the uptake of key transformational technologies, with a focus on energy-intensive industries.

Box 4.1

Uptake of key transformation levers in energy-intensive industries

- **Electric Arc Furnaces (EAFs).** EAFs as a share of the EU's total steel production grew by only around 4% between 2014 and 2024. There was a decline of around 9% in crude steel output from the EAF route in this period; however, output from conventional steel production (BOF and other) decreased by approximately 23% in the same period. EAF production now represents a 44.6% share of steel production (Eurofer, 2025). A total of 16 EAF projects are expected to be commissioned in the 2026-2030 period (Aries et al., 2026).

- **Heat pumps.** Heat pump investments increased from EUR 13 billion in 2020 to EUR 23 billion in 2023. Deployment increased from 834,000 units in 2010 to 2.4 million units in 2024. However, these figures refer to the total market and residential heat pumps represent a significant share of this. There is a lack of data on industrial heat pump uptake at the EU level. Overall, high energy prices and cuts to subsidies have been identified as barriers to more accelerated uptake (EC, 2026c).

- **Clinker-to-cement ratio.** 38Mt of Supplementary Cementitious Materials (SCM) is now used with a clinker-to-cement ratio of 0.77. Cement Europe has a stated goal to reach 66Mt of SCM use by 2050 with a clinker-to-cement ratio of 0.6 (Cement Europe, 2025).

- **CC(U)S.** Operational capture capacity reached 64 million tonnes per annum in 2025, in a total of 77 installed facilities — up from 51Mt in 2024. However, most existing CCS plants are deployed in natural gas processing plants and not in energy-intensive industries which may rely on CCS as a key decarbonisation lever in their transition plans (JRC, 2025c). Carbon capture project announcements in the European cement sector rose to a peak of 16 in 2024, before dropping to only 3 in 2025 (Lorea, C. et al., 2025).

- **Hydrogen.** The vast majority of hydrogen in the EU is still made from natural gas; this limits its potential in abating industrial emissions. Hydrogen electrolyser capacity amounted to 308MW in 2024 (ACER, 2025). Globally, growth is expected mainly in Europe, with about 2GW of new capacity expected to come online in 2026, concentrated in a few large projects. Yet, significant progress needs to be made to meet the EU target of 40GW of renewable hydrogen electrolyser capacity by 2030 (IEA, 2026b).

- **Direct reduced iron (DRI).** It is expected that about 17 million tonnes of green and natural gas-based DRI production capacity will be commissioned in the 2026-2030 period. However, at least four projects are currently stalled due to political, market and/or energy-related constraints, including the slow supply of green hydrogen (Aries et al., 2026).

Technology choices of top emitters signal industrial transformation

The technology choices and investments of Europe's top emitters offer another useful signal of progress. Table 4.1 gives examples of planned and implemented technology uptake among the top-10 facilities responsible for the damage or 'external' costs associated with industrial pollution's impacts on human health, ecosystems, infrastructure and climate (EEA, 2024m). Public sources of information, including company websites, were used to gather the information. As energy-intensive industries were of interest here, thermal power stations and refineries have been excluded from the list.

Of the 100 facilities with the highest external damage cost in 2024 (excluding thermal power stations and refineries), the top-10 facilities listed in Table 4.1 accounted for nearly 31% of damage costs. All facilities belong to the steel sector.

The table illustrates how key transformational pathways — such as electrification, hydrogen, and circularity — are actively being explored by Europe's top emitters. However, several projects are at demonstration stage and there are a number of critical delays in projects and investments. These are mainly due to a lack of supporting and enabling infrastructure such as hydrogen supply.

The table also demonstrates that transformation pathways may require the use of interim solutions, such as natural gas-based DRI (NG-DRI) or hybrid energy systems. To prevent carbon lock-in, it is essential that interim solutions are governed to ensure that they remain transitional and do not delay the deployment of fully decarbonised technologies.

Table 4.1 Technology prioritisation among high-emitting industrial facilities in the EU-27

Country	Facility	Sector	Implemented or announced technology prioritisation (including pilots and demonstration sites)
Austria	Voelstapine Stahl (Linz)	Steel	EAF; digitalisation; H-DRI; electric smelting
France	Arcelormittal (Dunkirk)	Steel	EAF; amino-based carbon capture; DRI (final investment decision postponed)
Germany	Salzgitter Flachstahl (Salzgitter)	Steel	H-DRI (partially delayed); alkaline electrolysis plant for hydrogen production; renewable electricity from offshore windfarm
Belgium	ArcelorMittal Belgium (Ghent)	Steel	CCU (recycling of blast furnace gas into ethanol, diverting it from its previous use for power generation); bio-coal from waste wood; EAF+DRI (postponed)
Netherlands	Tata Steel (Ijmuiden)	Steel	NG-DRI (phased shift to hydrogen); EAF; CCS; biomethane
Germany	Thyssenkrupp Werk Schwelgern (Duisburg)	Steel	NG-DRI (phased shift to hydrogen); two electrical smelting furnaces; chemical utilisation of steel mill gases for the production of sustainable chemicals and fuels
Spain	ArcelorMittal Spain, Asturias (Avilés and Gijón)	Steel	EAF; DRI (postponed); CASOH technology: Conversion of blast furnace gas into a hydrogen-rich output and purification of CO_2-rich gas
France	Arcelormittal Méditerranée (Fos-sur-Mer)	Steel	EAF; ladle furnace upgrade (to increase scrap steel use); DRI (awaiting investment decision)
Germany	ROGESA Roheisengesellschaft Saar (Dillinger)	Steel	DRI-EAF (flexible use of natural gas and hydrogen)
Slovakia	U.S. Steel s.r.o (Košice – Šaca)	Steel	EAF; electrolysis plant for hydrogen production or hydrogen production by steam methane reforming

Note: Facilities identified from EEA calculations based on the methodology from EEA, 2024m.

Sources: Aries et al., 2026; INCITE database; JRC's Energy and Industry Geography Lab; company websites and public announcements.

4.2 Access to clean and affordable energy

Key takeaways

The share of electricity in industry's final energy consumption grew by less than 1% between 2010 and 2024. This was despite the expectation that there would be more rapid growth to meet the EU's climate and energy targets. Renewable energy deployment is reducing Europe's exposure to imported fossil fuels. Additionally, upscaling renewable capacity to 2030 benchmark levels could lower day-ahead electricity generation costs [15] by up to 57%.

(15) The day-ahead or spot price/cost is determined by the marginal pricing system, where the most expensive generator needed to meet demand sets the clearing price. This price reflects fuel and operational costs of power plants, carbon pricing, transmission constraints and interconnections. However, it does not include national levies and taxes (e.g. VAT, renewable surcharges, excise duties), which are applied only after the wholesale price and are included in the retail price paid by consumers.

Yet, industrial investments are also being slowed down by high capital costs and policy uncertainty. Faster deployment of grids, interconnectors and flexibility solutions is required in order to realise the benefits of electrification. Additionally, there is a need for market and tax reforms that improve the relative competitiveness of electricity.

Overall context and progress

Conventional EU oil and gas resources are almost fully depleted and unconventional resources like shale gas are technically and economically unfeasible due to complex geologies and high population densities across EU countries (IEA, 2025c). As such, the European Union is navigating a precarious energy landscape.

There is a widening gap between internal oil and gas demand and dwindling domestic supply — culminating in a 98% EU import dependency rate in 2022. This leaves the EU highly exposed to the price volatility and geopolitical instability associated with global fossil fuel commodity chains. This precarity has been highly visible in 2026 with the latest geopolitical tensions in the Middle East (EEA, 2026m).

However, energy costs play an important role in industrial competitiveness; this is particularly true for the EU's energy-intensive sectors. In the cement sector, energy costs accounted for up to 16% of total production in 2023, compared with just over 10% in 2021. In the iron and steel, chemicals, glass, pulp and paper sectors, energy costs represented 5-10% of total production costs over the same period (EC, 2025l).

Between 2005 and 2024, EU renewable energy use more than doubled [16]. Had renewable energy consumption remained at the 2005 level, the EU's fossil fuel consumption in 2024 would have been at least a quarter higher. The benefits for the EU and national energy independence are tangible.

The largest reduction in annual fossil fuel use (over 71%) has occurred in the EU electricity supply; here the use of fossil gas contracted most strongly against rapid expansion in renewable electricity supply (EEA, 2026f). In particular, the costs of solar and wind power decreased by around 90% and 70% respectively between 2010 and 2024 (IRENA, 2026). This means that electrification has become one of the most cost-efficient pathways to decarbonise end-use demand and reduce the EU's high energy import bill associated with fossil fuels [17].

Unlike fossil fuel technologies, the marginal costs for generating solar and wind electricity are close to zero. This results in downward pressure on wholesale electricity prices as these sources replace more expensive fossil fuel combustion plants.

Coupled with heat pumps, low-carbon electricity supply can leverage heat production efficiency by at least three times in industry and in buildings, compared with average gas boilers (EEA, 2025d). Globally, in 2025, renewables continued to be the cheapest source of new electricity; over 90% of the commercial renewable electricity capacity added in the year was cheaper than the lowest-cost new fossil alternative (IRENA, 2026).

(16) At the same time, EU total energy consumption contracted slightly over this period.

(17) The EU is burdened by a structurally high and volatile fossil fuel import bill. In 2022, it soared to approximately 4% of EU gross domestic product (GDP), as gas prices rose due to artificial constraints on supply from Russia (Eurostat, 2026e). While total EU spending on fossil fuel imports has fallen back to 2% of GDP since then, costs are expected to increase again in 2026 due to geopolitical tension in the Middle East.

Prospective electrification trends, uncertainties and challenges

In order to meet key EU climate and energy targets and benchmarks for 2040, electricity must already be the EU's dominant energy carrier by 2030. Accordingly, its share in final energy consumption needs to increase to 32% by 2030 and to 57% by 2050 — compared with roughly a quarter in 2024 (EC, 2024a). This feat will require greater policy coordination and efforts given the stagnation of the historic electrification trend since 2005.

For industry in particular, electrifying industrial heat and processes is a critical decarbonisation pathway. Yet, the share of electricity in final energy consumption for industry grew by less than 1% between 2010 and 2024 (Eurostat, 2026f).

Moreover, as indicated by the latest NECPs from 2025, only five EU Member States expect to reach a nation-wide electrification rate above 32% by 2030 (Bulgaria, France, Portugal, Spain and Sweden) (EMBER, 2025).

Demand also needs to shift significantly across sectors by 2030 — growing by 10% in industry, primarily for low-temperature processes (up to 200°C) with household consumption rising by 19% (due to heat pumps) and transport demand surging by 181% (albeit from a low level) to support a rapid transition to electromobility (EC, 2024a).

Accomplishing this pathway will offer substantial economic and security advantages to the EU and to each Member State. Upscaling renewable capacity to reach the optimal 2030 benchmarks could reduce day-ahead electricity generation costs by up to 57% across all EU countries, compared to the average annual levels in 2023 (EEA, 2025d).

Beyond these direct reductions in cost, accelerating renewable deployment remains a strategic necessity to break the EU's high dependency on imported oil and gas; it would also shield national economies from geopolitical instability and price volatility.

While the transition is technically feasible, potential barriers include:

- permitting delays (currently three to nine years for wind);
- grid congestion (which led to a forced reduction of output from renewable electricity sources worth EUR 4 billion in 2023) (Draghi, 2024a; ACER, 2024b);
- potential primary supply deficits for CRMs like lithium and copper.

At present, gas turbines are important providers of flexibility resources in the electricity system, ensuring that electricity supply and demand are in balance. To integrate growing shares of variable solar and wind, the EU must double its non-fossil flexibility resources by 2030; this would help to manage intermittency and ensure that interconnected national power systems are adequately balanced (EEA and ACER, 2023).

By 2030, cross-border interconnectors could prevent the curtailment of renewable power equivalent to Sweden's total annual electricity consumption today. However, it is not currently taken for granted that they will be deployed, as greater national and EU-level coordination is required to realise this ambition. Additionally, progress in this area needs to complement national efforts to ensure security of electricity supply.

Similarly, realising the full potential of demand response — meaning the active, voluntary shift in electricity consumption by consumers to balance the electricity

grid — is central to stabilising the EU energy system. By 2030, all of these measures could lower the need for backup power generation for solar and wind by an amount equivalent to Spain's current total annual electricity consumption.

However, in order to unlock this potential, dynamic electricity pricing and the removal of unjustified market barriers need to be adopted. This would incentivise consumers to shift their energy use according to the needs of the EU electricity system.

Furthermore, retail electricity prices aim to recuperate the high upfront capital costs of generation and transmission infrastructure through network charges. In this context, electricity is burdened with higher taxes and levies than fossil gas in many EU markets (Rosenow, J. et al., 2024).

As such, the prevailing signals effectively mask the system-wide benefits of switching to electric solutions. In industry, aversion to the high upfront CAPEX of converting to electricity-based systems can be compounded by uncertainty about future electricity and CO_2 prices as well as future political priorities.

There is also considerable uncertainty in national and EU energy planning due to the rapid emergence of artificial intelligence (AI) and electricity-intensive data centres. In a worst-case scenario, their rapid expansion may risk sustaining high electricity prices that hinder broader industrial electrification. The power needs of AI could double data centre demand globally by 2030; this may necessitate even higher shares of wind and solar power generation to sustain new digital loads — a trend already apparent in Ireland (Box 3.8) (EEA, 2025d, 2026b).

There is significant potential for structural improvement from electrification across the EU energy system and for EU competitiveness; however, power prices may remain high for years to come if any of the challenges discussed above are not solved rapidly. In this scenario financing needs across the energy system would continue to rise while slow electrification would translate into higher fixed system costs (EIB, 2026); it is unlikely that these costs would be spread across a sufficiently broad customer base.

4.3 Clean manufacturing capabilities

Key takeaways

- Infrastructure development is accelerating but remains behind projected needs. Grid expansion, hydrogen deployment, carbon management infrastructure and secondary material markets are not developing quickly enough to support the scale of industrial transformation envisaged in EU climate and industrial strategies.

- Clean industrial transformation is increasing the demand for CRMs, secondary materials and alternative feedstocks. At the same time, import dependence, low recycling rates and the declining availability of some materials present growing challenges. Progress in recycling, substitution and supply-chain resilience will be an important signal of future industrial transformation.

- Labour and skills are emerging as critical enabling conditions. Many workers in emissions-intensive industries possess skills that are transferable to cleaner production processes. This points to the increasing importance of labour mobility, place-based transition planning and anticipatory skills planning in enabling industrial transformation.

Progress on infrastructure development

Key industrial transformation pathways depend on rapidly building infrastructure and supply chains across the EU to cater for a range of resources — including electricity, water, hydrogen and CO_2 (Nilsson et al., 2021). There is a risk that slow and poorly coordinated infrastructure developments will constrain facilities' capability to transform towards lower-emitting and circular operations. The pace of infrastructure and network development can therefore be regarded as a leading signal of future industrial transformation.

Table 4.2 Progress on infrastructure development to enable a clean transition in industry

Infrastructure	Progress
Power grids	**Significant gap to meet projected needs.** There is a significant gap between the grid expansion which is required and the current development of grid projects — at both the transmission and distribution grid levels. Annual investment in EU power grids may need to double to around EUR 100 billion per year to accommodate rising electricity demand, integrate renewables and support electrification. Half of the projected cross-border electricity needs by 2030 (32 of 66GW) are not being addressed by the current infrastructure development pipeline. When considering planned capacities, the gap is expected to increase to 37GW by 2040 (ACER, 2024a). Industrial electrification rates remain low. An estimated 1.7TW of renewable and hybrid energy projects are currently waiting for grid connection across Europe (Ember, E3G, IEEFA, BFF, 2025). This is prompting countries to adopt queue-clearing reforms — such as shifting from a first-come-first-served approach to a first-ready-first-served approach to avoid project bottlenecks.
Hydrogen	**Significant gap to meet EU targets.** The vast majority of hydrogen in the EU is still made from natural gas. This limits its potential to abate industrial emissions. The operational hydrogen electrolyser capacity grew to 308MW in 2024 — far behind the EU targets of 6GW for the year and 40GW of renewable hydrogen electrolyser capacity by 2030. As of May 2025, the EU hydrogen network totalled approximately 1,600km of pipeline, concentrated mainly in Belgium, France, Germany and the Netherlands. The EU has five underground storage facilities for hydrogen, including a 500,000m^3 facility commissioned in Germany (ACER, 2025).
CCS pipelines, transport vessels and storage	**Growing deployment but significant gap to meet projected needs.** Faster permitting, further deployment and upscaling of CCS and CCU infrastructure are needed to transport and store CO_2 emissions, in particular emissions from activities with no or limited mitigation alternatives. Commercial transport of CO_2 uses tanks, pipelines and ships for gaseous and liquid CO_2. Pipelines are more cost-effective than liquid transport methods for large volumes over short-to-medium distances (approximately EUR 5-25 versus EUR 10-50 per tCO_2) (JRC, 2025c). The EU's CCS ambitions depend on transport infrastructure that is not yet built. This means that there is likely to be an early reliance on shipping hubs and ports (JRC, 2024). Only a few dedicated transport pipelines exist in Europe today — roughly a few hundred kilometres — mostly connected to specific projects in Croatia, Hungary, Netherlands and Norway. A majority of these projects became operational before 2010 and connect to energy-producing facilities rather than being available to hard-to-abate sectors such as cement. In addition, a few projects are linked to enhanced oil recovery. More recently in 2025, the Northern Lights project — which includes a 100km pipeline in Norway — became operational. It allows for third-party CO_2 transport and storage, including from a cement plant. However, up to 19,000km of additional pipeline may be needed by 2050 to transport roughly 250$MtCO_2$/yr, as foreseen in the EU carbon management strategy (JRC, 2024). The EU's current operational CO_2 storage capacity has not progressed significantly since 2010; it remains underdeveloped despite rapid recent growth in CO_2 injection capacity, especially around the North Sea (JRC, 2024) [18]. The number of storage sites is on the rise with three permitted storage sites, seven more expected to become operational in the next years and dozens under development (EC, 2026i). Yet, the injection capacity of planned projects — approximately 33$MtCO_2$/yr by 2030, as reported by Member States — is not sufficient to achieve the target EU CO_2 injection capacity of at least 50$MtCO_2$/yr by 2030 (EC, 2026j). Beyond the infrastructure development needs, CCS facilities themselves are still not operational on a commercial basis in the EU. Additionally, a lack of fully developed industrial carbon management value chains means there is currently a higher supply of CO_2 than can be used (EC, 2023e; Cavanagh and Lockwood, 2025a). However, there are major potential storage hubs in the North Sea, several countries have made progress on CCS legislation and more projects are expected to apply for permits in the coming years (EC, 2023d).

(18) Based on scenario A1 — CTP 2040 (EU) which is derived from the total capture capacity of announced CCS projects within the EU before 2035.

Infrastructure	Progress
Recycling facilities and secondary raw material markets	**Mixed progress and remaining market barriers.** There has been less than a 2% increase in the EU's total circular material use rate since 2010 and the EU is currently off track to achieve its target of doubling the use rate by 2030 (EEA, 2024b). This indicator, while macro-level, provides an indication of industry's use of recycled materials; in turn, this points to the effectiveness of recycling infrastructure and markets. A small number of recycling facilities with the capability to recycle CRMs — including in Finland (Fortum), Germany (Cylib), Norway (Hydrovolt) and Poland (Elemental Strategic Metals and Ascend Elements pCAM plant) — have been built in Europe in the last 10-15 years. However, for key waste streams — such as scrap steel — significant collection, processing and contamination reduction efforts are already in place. Looking beyond recycling infrastructure, the mechanism that connects recycling facilities to manufacturers — namely the secondary raw material markets — has not yet reached its full potential. While traditional markets, for materials like metals, glass or paper, perform well, emerging markets for materials like plastics, textiles, aggregates, compost or wood struggle to deliver good-quality secondary materials to industry in a cost-competitive manner (EEA, 2022c). As a result, the circularity of industry is impeded and investments in recycling capacity are squeezed. This is partly also due to cheap imports boosted by overcapacity in other world regions — as in the case of plastics (EC, 2025b).
Transport infrastructure	**Growing investment but potential infrastructure constraints.** A clean industrial transformation may also be dependent on strategic development of transport infrastructure such as rail, freight and ports, depending on the sector and location. For instance, the Swedish region of Norrbotten has flagged the need to enhance its capacity of rail- and port infrastructure for a number of industrial decarbonisation initiatives in northern Sweden (Region Norrbotten, 2024). Additionally, the EU's railway system has had decades of underinvestment (although there have been variations between countries). It faces the challenge of fragmentation since it is an amalgamation of separate national systems rather than a single integrated network. The rail network has actually declined slightly over the long term (Eurostat, 2026h) due to closures of secondary lines. However, the financial commitments to rail have grown in recent years as a result of climate policy and modal-shift ambitions. At the EU level, the European Rail Facilities Portal maintains data on last-mile connectivity (private and public sidings) to rail services but the data coverage is incomplete (EC, 2026f). However, in Interreg's assessment, it is essential to revitalise and develop industrial sidings [19] in Europe to halt the decline in EU rail's share of transport and to shift freight from road to rail (Interreg Central Europe, 2024). Further, large-scale industrial uptake of hydrogen will depend on the timely development of port-related hydrogen infrastructure and associated transport systems (Clean Hydrogen Joint Undertaking, 2023).
Water infrastructure	**Progress in service provision but investment needs remain.** There has been significant progress in EU wastewater management, especially in expanding treatment coverage and reducing pollutant loads. However, investments in modernising water infrastructure and reducing leakage need to be prioritised further as EU industry's water needs grow, including for strategic sectors associated with the EU's green and digital transition (EC, 2025d). A clean transformation of industry also includes higher expectations relating to resource recovery from sectors such as wastewater treatment plants. Many existing plants can be upgraded with nutrient recovery modules without rebuilding the entire plant. The revised UWWTD promotes a more circular approach to wastewater management, with Member States preparing national implementation programmes by 2028; these might contain information on planned infrastructure investments. However, no data are currently available on the status of such infrastructure and plant upgrades at the EU level.
District heating and cooling	**Established infrastructure with further expansion potential.** The role of district heating and cooling has been described in most EU countries' national climate plans and strategies. They all highlight the importance of district heating as a factor in the decarbonisation of industrial sectors. Some form of regulation in this area exists in every European country (Munćan et al., 2024). There are more than 19,000 district heating networks in Europe, with more than 40% supplied by renewable and waste heat sources (IIR, 2024; Euroheat & Power, 2024). However, in some countries barriers to implementing and extending district heating networks include tax regulations on utilising excess heat from industrial processes; this lowers incentives and means that heat that could have been used for district heating is now simply cooled away outside (Ramboll, 2020). In addition, it has been assessed that industrial transformation will likely lead to less excess heat which can be used to feed district heating systems (Manz et al., 2023; Billerbeck et al., 2024).

Source: EEA elaboration.

(19) Industrial sidings in Europe refer to the tracks or rail lines that extend from the main railway network to serve industrial facilities such as factories, warehouses, ports and other industrial sites.

Clear and credible demand signals are needed to stimulate investment in supply-side infrastructure and create viable markets for green solutions. Continued and targeted use of the Innovation Fund can help address early-stage investment risks by supporting the deployment of strategic infrastructure (EC, 2025o).

Box 4.2

Is infrastructure development taking place where it is most needed?

Industrial transformation will sharply increase demand for electricity and hydrogen. This will make alignment between infrastructure and industrial needs critical. For example, many carbon capture and storage projects are concentrated around the North Sea; this leaves several emission-intensive regions with limited or costly access to storage (Cavanagh and Lockwood, 2025b).

The challenge is particularly relevant for sectors like cement; building the transport and storage infrastructure required to move the captured CO_2 from cement plants to dedicated storage sites is expensive. This is due to the distributed nature of cement production compared to large centralised production sites for other commodities like steel (JRC, 2025e).

Tools developed by the EC help to assess this alignment. The Energy and Industry Geography Lab is a geospatial data hub, which maps industry, infrastructure and energy systems; it enables industrial decarbonisation clusters and locations where clean energy supply and industrial demand overlap to be identified.

Meanwhile, the EC's JRC is also developing GeoDep, a tool that maps 'geographical dependencies' — external factors that are:

- outside a company's direct control but that can influence its decarbonisation plans and projects;
- sensitive to specific local and regional characteristics.

These can include favourable regulatory frameworks as well as access to decarbonised grids, hydrogen and carbon-capture networks.

By spatially mapping these dependencies, energy-intensive industrial assets and information from corporate transition plans, GeoDep aims to support assessments of how geographical dependencies may impact the implementation of decarbonisation projects in energy-intensive industries. The tool covers five key decarbonisation levers:

- CCS;
- hydrogen;
- electrification;
- circular economy measures;
- biomass for energy purposes.

The tool builds upon a conceptual framework — published in 2024 — and a first technical report, published in late 2025, identifying relevant geographical dependencies for each decarbonisation lever. This methodological basis has been further strengthened with another technical report on key performance indicators for each decarbonisation lever covered in the GeoDep tool (Arranz Padilla, M. et al., in press).

In addition, a pilot version of the tool was tested in summer 2026 by financial institutions. The public launch of the GeoDep tool is planned for 2027, offering companies, investors and policymakers an overview of geographical dependencies at the industrial asset-level. This will inform industrial transition planning, transition risk assessment and investment decisions.

Industry's access to infrastructure can also be enhanced without the need for large-scale physical expansion. Effective grid capacity can be expanded by deploying grid-enhancing technologies; conservative estimates suggest that these could deliver 10-20% additional capacity using existing infrastructure. They could also reduce the need for grid build-out by approximately 35% by 2040 (Compass Lexecon, 2024).

Similarly, a study on the reuse of oil and gas infrastructure for hydrogen and CCS in Europe concluded that there are no insurmountable issues with transporting CO_2 in the gaseous phase in existing onshore and offshore pipelines (Carbon Limits and DNV, 2021). It also concluded that CO_2 transport in dense phase is technically feasible in more than half of offshore pipelines (and in a very small proportion of onshore pipelines). However, it should be noted that there may be practical constraints; conditions may differ, routes may not be well matched and impure CO_2 can prove destructive or corrosive (JRC, 2024).

Access to materials needed for the transition

When monitoring progress on industry's clean transition, it is relevant to consider access to key material resources such as critical and strategic raw materials, secondary materials, as well as sustainable material substitutes and feedstock. This section provides an illustrative snapshot of EU industry's current resource needs and risks.

Table 4.3 Industry's access to materials needed for a clean transition

Sector	Access constraints and risks
Energy	The EU is fully dependent on imports for 10 of the 26 CRMs relevant for the energy transition, including rare earth elements, which are neither mined nor processed domestically. Materials such as lithium, cobalt, nickel and copper are needed to power industry's clean energy, battery and storage needs. High import dependency and growing demand for CRMs mean that access to them is limited and volatile supply chains may become a key transition risk for EU industry. A low share of CRM demand is currently met by recycled materials. End-of-life recycling input rates are about 16% for nickel and 22% for cobalt; the figure is around 1% for many speciality metals (EC, 2023f).
Minerals	The minerals sector, in particular cement production, relies heavily on locally sourced materials. The use of supplementary cementitious materials (SCMs) to reduce clinker-to-cement ratios is a key near-term transformation pathway. Traditional SCM supplies such a blast furnace slag and fly ash are projected to decline sharply in a scenario where coal power and conventional steelmaking decrease in the EU, falling to potentially near zero by 2045 (Johansson et al., 2026). Similarly, Europe's Cement Association predicts that slag consumption in Europe will decline from 13Mt to 4Mt between 2020 and 2050 (representing a reduction from 8% to less than 2% of cement content) and fly ash will reduce by a third by 2050. Other alternatives, such as pozzolana, peaked in use before 2010 when around 4Mt was used; its use has since decreased to less than 1Mt per year in 2021. Dwindling supplies of traditional SCMs point to the need to scale up the use of alternative SCMs — such as natural pozzolans, calcined clay and other industrial by-products — but the current production volumes remain relatively low. There is also research on the use of slag from steel EAFs as a binding material for cement-making but this technique is facing challenges due to the inconsistent chemical composition of slag depending on the type of scrap input (Schneider et al., 2026; Kurecki et al., 2025; Teo et al., 2020).

Table 4.3 Industry's access to materials needed for a clean transition (cont.)

Sector	Access constraints and risks
Metals	There is debate (Recycling Europe, 2023; Eurofer, 2023) about whether or not the EU is facing a shortage of scrap steel for secondary steelmaking — identified as a key decarbonisation pathway for the EU steel sector (EC, 2025h). Scrap steel is a globally traded commodity. Currently, the EU is the world's top exporter of ferrous scrap, exporting around 20% of the ferrous scrap it collects. Additionally, EU extra-regional scrap exports have increased by nearly 50% over a decade. Further, steel outputs from the EAF route saw a 12% decline between 2014 and 2023 (likely due to high electricity prices), reducing demand for scrap as a key feedstock (JRC, 2025b). However, it is expected that measures such as the phase-out of free ETS allowances, as well as requirements for products to be low carbon and made of recycled content will stimulate demand for electrified steel production routes and consequently scrap steel. In this context, it is important that future supply is secured. This could be achieved by improving the quality of scrap and measures that better support sorting and recycling. Yet, increasing the availability of scrap and steel electrification are likely to be insufficient to fully support deep decarbonisation. DRI — in particular H-DRI — is another key transformation pathway, which produces primary iron from virgin iron ore, complementing the conventional ironmaking route. However, there may be limited and declining supplies of iron ore with the high iron content necessary for this technology (IEEFA, 2022; Devlin et al., 2023). Current innovations focus on technological upgrades of lower-quality iron ore. Yet, this material scarcity presents a bottleneck that may influence the pace and geography of the transition. As such, this issue needs further consideration going forward.
Chemicals	The chemicals sector is complex, with different products and process routes facing varied material and resource needs for their clean transformation. For example, in plastics manufacturing, high-quality secondary materials are in high demand, but currently the EU remains dependent on imported fossil-based materials and fossil feedstocks for the chemicals sector. Another challenge for the chemicals sector is that the secondary materials that could replace fossil materials can contain legacy pollutants, reducing their competitiveness with virgin materials in terms of quality. Meanwhile, the EU's bioeconomy strategy promotes increased use of circular and/or sustainably sourced bio-based feedstock, including for pharmaceuticals and plastics products. The EU is largely self-sufficient in the area of biomass production. However, the availability of sustainable biomass is finite and the sector's access to it depends on a careful balance of competing demands and objectives; these include carbon sequestration, land needed for food production, land needed for nature restoration and biomass demand in different economic sectors (EEA, 2023b).
Cross-cutting	Beyond the primary and secondary material needs for greening industrial processes, EU industry is also dependent on third countries for the supply of essential technologies such as batteries, heat pumps and solar panels — and their components (Bruegel, 2026). For instance, while European industry is dominant in the manufacture of industrial heat pumps, manufacturers are dependent on imports for compressors, inverters, synthetic refrigerants and other components (such as expansion valves and four-way valves). These components are largely imported from China, other Southeast Asian countries and the United States and there are currently long lead times. Therefore — even though these technologies and their components are traded globally — boosting domestic manufacturing of clean technologies and the components needed for greening industrial processes would help to shorten supply chains and secure stable supplies.

Source: EEA elaboration.

Managing demand for materials will be critical, including from a global perspective. Swedish researchers have investigated the EU's estimated needs for critical metals in conjunction with global reserves and production capacity. Their research has found that the EU's green transition plans could require up to 60% of the world's supplies of several critical metals (not taking into account the potentially growing role of recycling), despite the EU accounting for only 5.7% of the global population. Such imbalance underscores the risk of unfair distribution and intensifying global competition for scarce resources (Malmaeus et al., 2025).

Supply risk is further exacerbated by high geographic concentration of certain resources; several materials are dominated in supply or firm ownership by single countries such as China. By 2028, the EC will assess whether to establish 2040 and 2050 benchmarks for the extraction, processing and recycling of strategic raw materials — both at EU level and for individual materials — under the CRMA.

Here, long-term benchmarks for CRMs should be aligned with the projected material needs of transforming EU industry towards decarbonisation, circularity and pollution prevention. They should also integrate recycling requirements to enhance supply chain security. In order to achieve this, more detailed mapping of material needs is required at the regional and sectoral levels in order to design more effective policies (ECB, 2024).

Beyond supply chain diversification, resource efficiency and substitution, Europe's demand for materials — and supply risks — can be reduced through circularity measures.

Access to skills and labour needed for the transition

In the last decade, employment in the EU's environmental goods and services sector grew faster than overall employment. The sector's share of employment increased from about 2% in 2010 to just over 3% in 2022; this corresponds to around 6.67 million full-time equivalent employees.

Growth was mainly driven by renewable energy, energy efficiency and waste management (EEA, 2024d; Eurostat, 2026c). At the same time, EU institutions have explicitly identified a growing shortage of appropriately skilled workers as one of the biggest barriers to long-term industrial investments — second only to high energy costs. As such, improved workforce skills are a critical enabler of Europe's clean industrial transformation and overall competitiveness (European Council, 2024; Draghi, 2024b).

Skills development and job quality have become central pillars of EU industrial policy. Under its current budget cycle (2021-2027), the EU Cohesion Fund is investing EUR 44.2 billion to support career guidance and training courses (ICF, 2024).

Upskilling and reskilling programmes are being supported under recent initiatives such as the NZIA; this proposes to establish net-zero industry academies to help address skills shortages in net-zero industries. The quality jobs roadmap under the CID sets out EU priorities to promote quality employment by strengthening skills, social dialogue and worker protections while supporting fair and resilient labour-market transitions.

The union of skills — also launched under the CID — sets out a broader strategy for skills development in the EU. It aims to facilitate a better match between the supply and demand for skills needed for the green transition. The union of skills further addresses the need for labour mobility via the skills portability initiative. This broader framework complements the European skills guarantee launched in November 2025 aiming to support workers to develop skills and transition into strategic industries.

The issues relating to skill and labour gaps specific for greening industrial processes are highly context specific and shaped by territorial and sub-regional conditions. More generally, Draghi's report, *The future of European competitiveness* recommends broadening the range of skills to successfully achieve the EU's twin transition: besides basic numeracy and literacy skills, the report identifies some crucial priorities:

- digital skills;
- skills needed for the green transition;
- science, technology, engineering and maths (STEM) skills.

However, defining the specific skills needed for industry's green transition is challenging; this makes it difficult for policymakers to develop evidence-based policies and programmes. Skill requirements are diverse depending on the sector or occupation; they range from low- to high-skilled requirements and encompass a wide range of competences (OECD, 2023).

As highlighted by the OECD (OECD, 2014), the skills for innovation and adaptability are as important as technical skills in the green transition. This implies a need for both sector-specific skills and transversal skills — for example in management, innovation and communication (OECD, 2023; Cardiff University, 2021; Akyazi et al., 2022). Furthermore, as industrial processes become increasingly automated and digitalised, workers need to be able to perform more complex tasks; this will demand strong skills in areas such as reading, numeracy, information and communications technology (ICT) and problem-solving as well as teamwork, coordination and autonomy (Deming, 2017; OECD, 2017; ESSA, 2023).

This section provides a non-comprehensive overview of EU-level patterns related to the skill and labour needs for greening industry. It covers selected sectors and technologies, drawing on the available literature and industry reports.

Skill gaps for industrial transformation linked to systemic shortages at the EU level

Evidence suggests that the main challenge linked to jobs needed for a clean industrial transformation lies in the systemic weaknesses in the EU's technical skills base — particularly in STEM-related fields. Indeed, challenges for the EU include a gradually weakened performance in the area of basic competences (maths, reading and science, digital skills) and an ageing workforce — for example, more than a third of workers in the electricity sector are 50-74 years old (Gherasim, D-P., 2025).

Despite a 14.4% increase in STEM tertiary graduates between 2015 and 2022, this growth remains insufficient to meet the current and future labour market needs. This is particularly true for ICT and engineering, which are critical, not least for the digitalisation and electrification of industry (EC, 2025c). In spite of the increases, there are signs of marked decline in certain STEM skills, with the EU producing around 850 STEM graduates per million inhabitants per year; by way of contrast, the figure is more than 1,100 per million in the United States (EC, 2025c; Draghi, 2024b).

The low performance in number of workers receiving adult learning and training at the EU level could further impact industry's clean transition. Around 50 million more workers would need to receive training to achieve the 2020 European skills agenda target of having at least 60% of adults participating in training every year (Draghi, 2024b).

Based on a survey of nearly 2,000 organisations in the EU, energy-intensive industries, other manufacturing (herein textiles and clothing) and the renewable energy sector appear to follow similar trends; the highest skill needs were typically identified as *technical skills* (defined in the survey as specialised knowledge and expertise required to perform specific tasks), followed by *green skills* (defined as skills related to green technologies, nature-based solutions etc.) and thirdly advanced *digital skills* (defined as skills related to machine learning, supercomputing and cybersecurity) (EC, 2024c).

Skill gaps across the transformation value chain

Beyond core industrial operations, industry faces a system of interdependent skill and labour demands for greening its processes across manufacturing, construction and services (Table 4.4).

Table 4.4 Examples of skill and labour implications for industry's clean transition

Sector	Skill and labour implications for industry's clean transition
Renewable energy supply	Industrial facilities depend on net-zero technologies for their clean transition, including indirectly through renewable energy supply and grid expansion. The EC has estimated that installations of wind turbines and solar panels to deliver on the EU Green Deal targets would require about 130,000 to 145,000 additional skilled workers in the EU (EC, 2025j). Jobs linked to renewable energy and energy efficiency have expanded rapidly in the past decade — across production, manufacturing and related services — with employment in the renewable energy sector rising to around 1.86 million in 2023. The change has outpaced employment growth in the overall economy (EurObserv'ER, 2025). At the same time, an EEA assessment of EURES data on labour shortages and surpluses shows that all Member States reported shortages in key occupations for clean technologies. This poses a potential threat to industry's access to these technologies and the value they provide (EEA, 2026e). Skill shortages are reportedly higher in countries such as Bulgaria, France, Italy and Malta, while Finland, Portugal and Spain report only one shortage each within the key occupations identified for net-zero technologies (EEA, 2026e). Overall, countries' NECPs have been found to fall short on targeted actions to address the fairness, jobs and skills aspects of the energy transition (EC, 2025m).
Technology manufacturing	Whether facilities are able to transform will depend on adequate renewable energy supplies but also on the direct availability and uptake of net-zero technologies. Overall, the EC has estimated that the investment needs for retraining, reskilling and upskilling in the manufacture of strategic net-zero technologies total EUR 3.1 billion up to 2030 under the NZIA policy proposal to boost domestic manufacturing by 40%. This would correspond to 350,000 additional jobs, depending on factors such as technology choices, the pace of adoption and investment scales (EC, 2023c). Significant skill shortages have, for instance, been identified in the heat pump industry and the battery industry. This poses barriers to innovation, self-sufficiency and the sectors' capacity to meet policy targets for production and uptake (EEA, 2026e). For hydrogen, the EU has set an ambitious target to install at least 40GW of renewable hydrogen electrolyser capacity by 2030, with an estimated 1 million jobs to be created by the hydrogen value chain by 2030. The occupational profiles facing significant demand are mainly within technical domains; in particular, there is an urgent need for engineers and technicians specialising in chemical processes, industrial engineering, health and safety and high-voltage electricity (Green Skills for Hydrogen Project, 2023c).
Infrastructure	Additional skilled workers will also be needed to construct electricity infrastructure (including specialised skills for the construction of sea cables to connect offshore wind parks), hydrogen and CCS infrastructure. For instance, Pickard et al. (2025) found that, depending on the project stage, the construction of CCS facilities can involve up to hundreds or thousands of workers. Meanwhile, the operation of CCS facilities typically only requires a small permanent workforce (i.e. around 20 for a capture plant). It is essential to manage these temporary workforce peaks through anticipatory skills planning, worker mobility and coordination across projects and regions to avoid labour bottlenecks.
Engineering, services and system operation	Electrification of processes such as low- and medium-temperature heat is one of the most important cross-cutting decarbonisation levers. The pace and effectiveness of industrial electrification is not determined by technology availability alone but also by access to specialised service providers. For instance, industrial heat pumps and other electrification solutions often require custom design and installation solutions; this involves highly skilled workers such as energy performance services contractors (JRC, 2025d).
Circular economy and downstream activities	The CID estimates that the European remanufacturing market has the potential to generate 500,000 new jobs by 2030. For the steel sector alone, an estimated 35,000 people are needed to meet the scrap steel supply needs in view of the EU's planned capacity for steel electrification (Klimek et al., 2024). However, the broader evidence base for circular labour-market dynamics is fragmented and only provides a partial picture (Eionet, 2026a).

Source: EEA elaboration.

Progress on reskilling

An important challenge for a clean transformation across industries is accelerating upskilling and reskilling (Cedefop, 2021). There is a slightly increasing trend in participation rates in training and education across most sectors undergoing transformation, with some sectoral variation.

Participation rates across the energy-intensive industries [20] increased to 10.9% in 2023. However, this remains below the average for the economy as a whole in the EU (12.7%). The rates of training for workers in mining and construction are also below average. The energy sector sees higher rates of participation compared to mining and manufacturing. Yet, there still needs to be an increased focus on reskilling and upskilling for energy production and distribution to avoid future skill shortages (EC, 2025g).

It is worth noting that there are differing training and education participation rates between countries. For energy supply services and manufacturing, the highest rates are found in Sweden, Netherlands, Denmark and Finland (20-40%). Meanwhile, countries such as Bulgaria, Greece and Hungary have much lower rates (1-5%) (EC, 2025g). Targeted skills policies are needed to address these gaps. These must reflect differing national industrial bases. Additionally, incentives and guarantees should be provided for workers to stimulate a willingness to reskill.

In some sectors, workers already employed in emission-intensive industries possess the core competencies needed for greener production. For instance, one study has found that existing staff from integrated steelworks could likely fill 95% of all jobs required by facilities that switch to greener steelmaking (EC, 2025g) [21]. However, the study also suggests that the total number of jobs could be reduced by 75% given changes in production processes and mechanisms.

This pattern is reflected in the United States, where electrified steelmaking has become the dominant production route since its introduction in the 1960s and 1970s. Between 1972 and 2002, the US steel industry experienced 28% growth in production despite an 80% decrease in the workforce (Collard-Wexler and De Loecker, 2015; Stabile et al., 2025).

These trends underline the importance of reskilling, compensation and planning for a just phase-out of polluting practices. As such, transition strategies must also consider the uneven geographical distribution of risks and benefits associated with industrial change; this is particularly the case for regions dependent on carbon-intensive activities.

Beyond employment levels, there should also be a focus on job quality, including working conditions, wages and broader aspects of job security. The Just Transition Mechanism and the Just Transition Fund are designed to provide guarantees for retraining and job protection, in anticipation of large-scale lay-offs caused by the move away from fossil fuels.

(20) Covering mining and quarrying (B05-09), manufacture of chemicals and chemical products (C20), manufacture of other non-metallic mineral products (C23), manufacture of basic metals (C24), manufacture of motor vehicles, trailers and semi-trailers (C24).
(21) Greener steelmaking refers here to those facilities that adopt the green DRI and EAF route (DRI/EAF).

Box 4.3

The need for workforce mobility

The clean transformation of industry also requires the workforce to be mobile, to enable workers to transition from polluting sectors or activities being phased out towards less polluting sectors. Here, geographical considerations are paramount and pose a potential barrier.

For instance, fossil fuel industries are not necessarily located close to green energy infrastructure, making it harder for workers to bring their transferable skills (Lim et al., 2023). This challenge, including personal moving costs, is potentially exacerbated in larger countries (EC, 2025g). The issue highlights the importance of place-based transition planning and policies that align reskilling programmes with local labour market opportunities and mobility support.

The OECD has recognised the importance of supporting attractiveness of regions for workers needed in the green transitions. It proposes a set of 67 regional attractiveness indicators at the level of large regions, across environmental social and economic domains (OECD, 2026).

Industrial clusters — as proposed in the EC's Industrial Accelerator Act — could also help to facilitate occupational mobility. Geographic proximity between related industries can enable workers to transfer their existing skills across firms and occupations without needing to relocate (Delgado et al., 2014).

The EU's union of skills addresses the need for labour mobility via the skills portability initiative. This is designed to enhance the portability of skills and qualifications across the EU, independently of where they were acquired — as well as other related initiatives to help free up the movement of workers.

4.3 Financing the industrial transformation

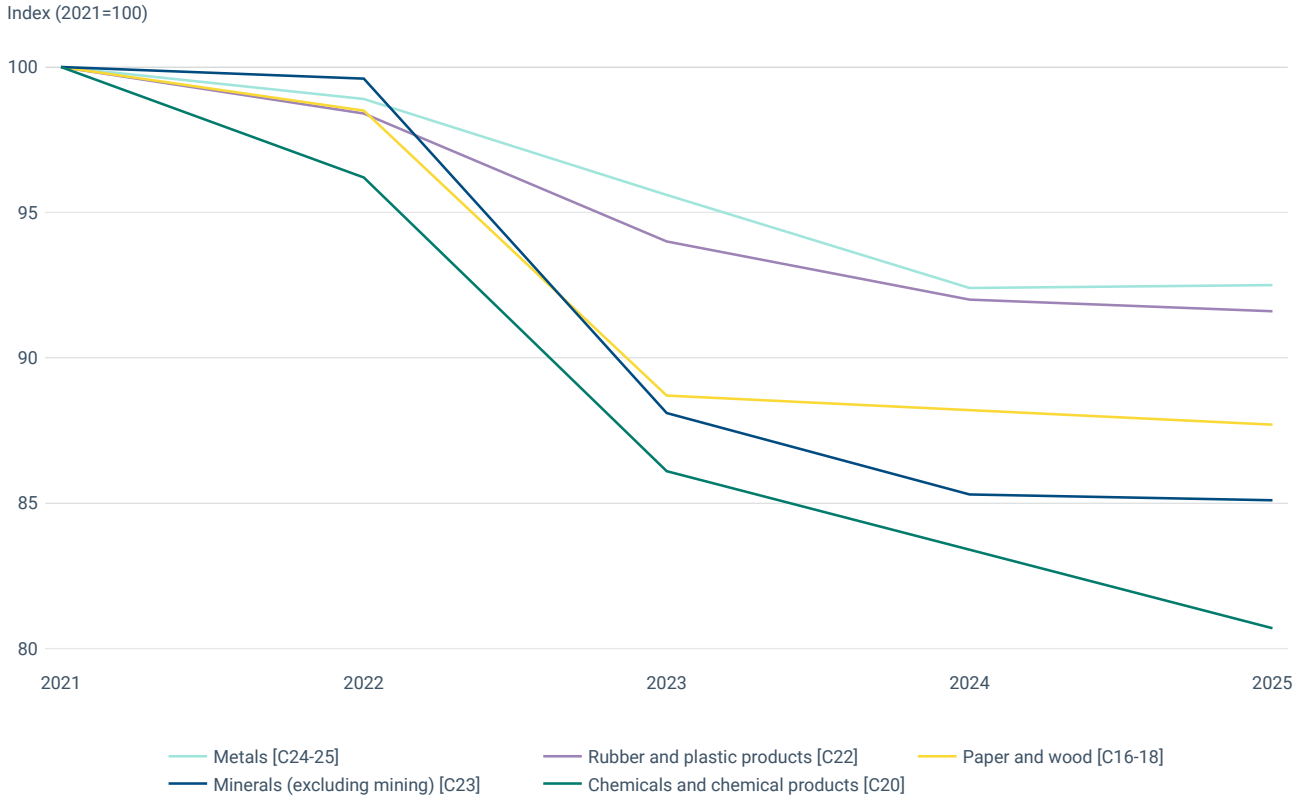
Key takeaways

The EU is expanding its financial support for a clean industrial transformation. At the same time, public financial support to industry is substantially higher in China and other competing regions, and operating costs of industry's clean transition are expected to exceed capital costs. Delayed investments, growing investment gaps and global competition signal that access to capital alone is insufficient for a successful transition. Industrial transformation increasingly depends not only on mobilising funding but also on reducing investment risk and creating predictable demand for cleaner industrial outputs.

Mobilising financial support amid global competition and geopolitical instability

While value added from EU manufacturing has generally been maintained in absolute terms, the EU's share of global manufacturing value added has declined over recent decades as demand has shifted. Manufacturing activity has expanded more rapidly in emerging economies, particularly China. This trend is also evident in the decreasing production levels in EU energy-intensive industries since 2021 (Figure 4.2).

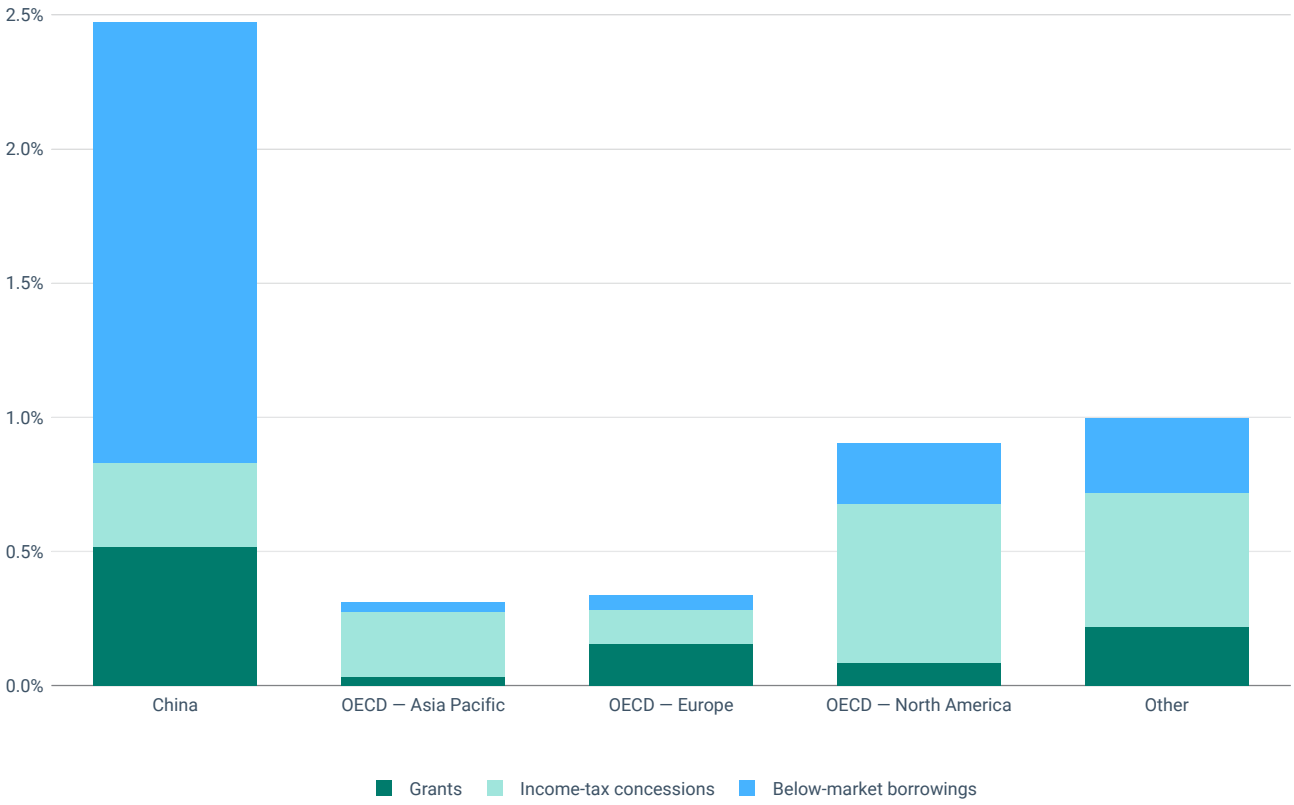
Figure 4.2 **EU total production (volume) from energy-intensive industries, indexed to 100 in January 2021**



Source: EEA, based on Eurostat, 2026k.

While government support for R&D is similar in both the United States and the EU, business expenditure on R&D in the EU represents 1.2% of GDP — about half that of the United States (2.3% of GDP) (ifo Institute, 2024). Meanwhile, state support for China-based firms corresponded to an average of 3% of revenues between 2005 and 2024 (compared to less than 0.5% in Europe). Some capital-intensive firms in China (e.g. producing semiconductors, metals) received funding corresponding to more than 15% of revenues in the same period (OECD, 2025b) (Figure 4.3). As a result, Chinese industry has been able to expand production at scale despite low margins. This has led to persistent global supply-demand imbalances and overcapacities. The EU is increasingly becoming a target market for these overcapacities (EP, 2026b).

Figure 4.3 State support for firms



Note: Data are presented as percentages of revenues by region.

Source: OECD, 2025b.

This uneven playing field is further reflected in foreign direct investment patterns. Data assessed within the framework of the EC's European Monitor of Industrial Ecosystems project indicate that between 2010 and 2022, investment projects in EU energy-intensive industries were dominated by outward flows. This suggests that European companies increasingly sought growth opportunities in third countries where operating conditions may have been more favourable.

Consequently, funding the clean transformation of industry is no longer merely an environmental objective; it is also a strategic measure to restore European industrial leadership. The CID has set out a path towards a decarbonised and competitive industry. It sets a target of mobilising over EUR 100 billion in the coming years [22] — up from EUR 52.7 billion [23] — to support manufacturing for EU-made clean technology and to decarbonise heavy industry. By scaling effective and well-designed direct public support — including through the CID — the EU aims to mitigate global imbalances and support European firms in securing a foothold in emerging lucrative value chains.

(22) An exact implementation period has not been specified.
(23) An earlier estimate based on https://investeu.europa.eu/investeu-programme/investeu-fund/investeu-indicators_en#key-indicators-selection.

Investment needs and funding gaps for industrial transformation

It is challenging to assess the financing needs to transform industrial facilities towards decarbonisation, pollution prevention and circularity. Estimates depend on evolving technologies, uncertain cost trajectories and system boundaries (Box 4.4).

Box 4.4

Funding gaps for industrial transformation

A recent estimate by the Platform on Sustainable Finance found that achieving Paris-aligned transition pathways in key energy-intensive industries — chemicals, steel, aluminium and other non-ferrous metals, non-metallic minerals and paper — would require average annual investments of around EUR 30 billion between 2030 and 2040 (Platform on Sustainable Finance, 2026).

According to internal EC analysis (not publicly available), a similar estimate is provided, covering a broader range of industrial sectors [24]. Average annual capital investment needs were estimated at EUR 30 billion between 2026 and 2030. However, this was expected to increase to EUR 58 billion per year between 2031 and 2040 and EUR 61 billion per year between 2041 and 2050 as key technologies reach commercial readiness.

This EC study assessed the capital investment and operational costs, as well as funding gaps, associated with deploying the technologies needed to transform industry in support of the EU's zero pollution, climate-neutral and circular economy objectives. OPEX were expected to significantly exceed CAPEX — largely due to the continued reliance on clean energy inputs — reaching averages of EUR 82 billion per year between 2026 and 2030, EUR 210 billion per year between 2031 and 2040 and EUR 272 billion per year between 2041 and 2050.

When compared to the total amount of funding available for industry, the study suggests a funding gap of around EUR 70-80 billion per annum in 2030, increasing to EUR 240-250 billion by 2040 and EUR 330-340 billion by 2050 if the funding landscape remains the same as it is now.

It is important to note that the funding gap identified in Box 4.4 represents a baseline estimate; it is derived primarily from estimates for technological pathways that transform core industrial processes. Furthermore, the underlying technology pathways focus more on decarbonisation than broader environmental objectives. As such, it is likely a conservative estimate of the investment gap for industrial transformation.

It does not take into account the additional capital requirements for essential enabling infrastructure, including renewable energy technologies, grid infrastructure and hydrogen or CCS networks. For instance, beyond direct facility-level investments, it is necessary to provide direct support and create markets for strategic net-zero technologies such as wind, solar photovoltaics, heat pumps, batteries and electrolysers.

For the period up to 2030 it is estimated that a cumulative investment of about EUR 120 billion (in constant euros from 2022) would be required to enable the EU to meet the NZIA's domestic manufacturing target for strategic net-zero technologies (EC, 2023a).

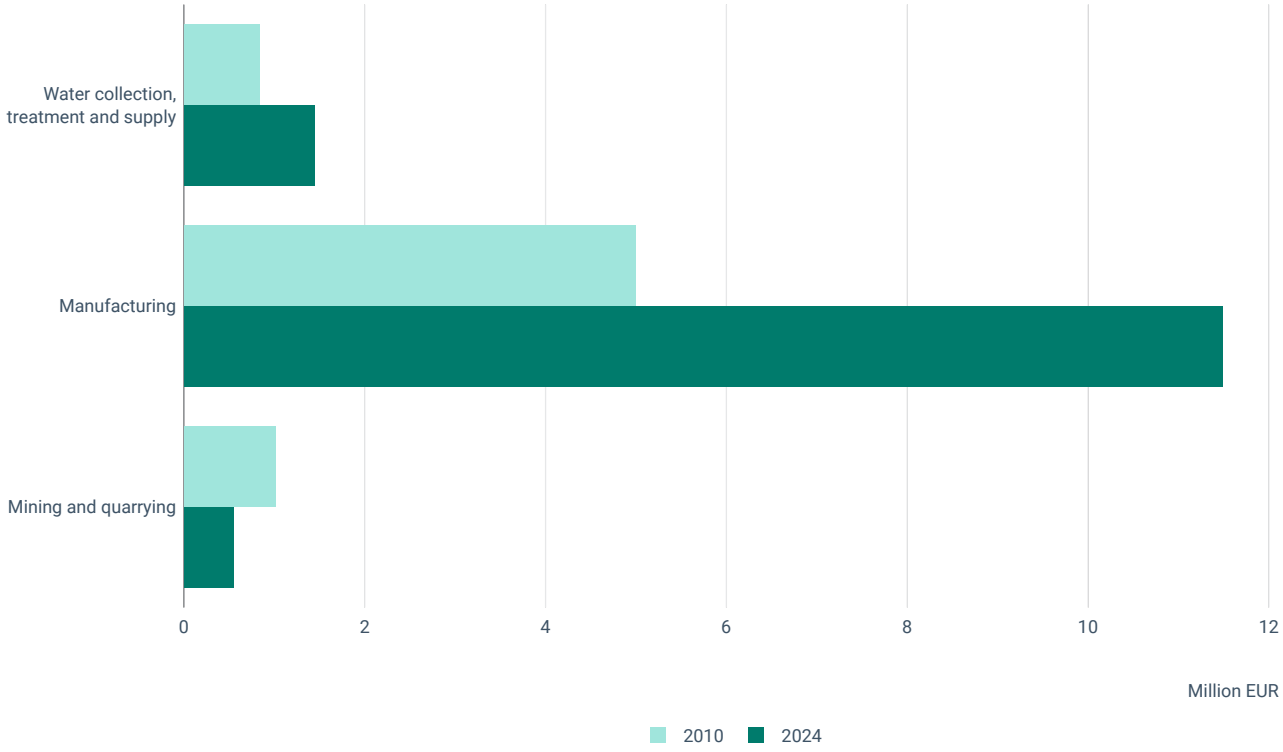
(24) The study included sectors covered by the IED, except intensive rearing of pigs and poultry. It included energy facilities such as refineries and large combustion plants — a sector which accounted for 12% of the total estimated investment gap for industrial transformation.

Private environmental protection expenditure

It is challenging to track private funding and investment into greening industrial facilities. Broader environment- and climate-related expenditure by EU corporations grew by 8.4% in real terms from 2018 to 2024 when it totalled approximately EUR 189 billion (EEA, 2024e).

However, the figure is more modest for expenditure by firms investing in environmental protection for their own use — as opposed to expenditure by firms producing environmental protection services for sale. A detailed breakdown of EU-wide and sector-specific expenditure on environmental protection is provided in Figure 4.4. It should be noted that these figures do not typically account for expenditures related to circular economy, which represent a significant capital flow: annual circular economy investments are around EUR 120 billion, largely driven by the private sector (EIB and EC, 2026).

Figure 4.4 **Breakdown of EU environmental protection expenditure by corporations in the EU-27**



Source: EEA, based on Eurostat, 2026d.

EU funding landscape for clean industrial transformation

The framework for mobilising EU funds is determined according to the multiannual financial framework's (MFF's) seven-year cycles. The current period covers 2021 to 2027. Funds are earmarked for specific climate and environmental objectives (Table 4.5) and the 'do no harm' principle is applied to mitigate the risk of potential adverse effects arising.

In the 2021-2027 programming period, EU funding has increasingly drawn on its own resources; contributions from Member States — calculated based on their gross national incomes — are complemented by revenues from dedicated instruments such as the Innovation Fund and Modernisation Fund financed by EU ETS revenues.

The current MFF proposal for the 2028-2034 period (as of 21 July 2026) will involve a significant structural shift, most notably the discontinuation of the LIFE funding instrument as a standalone programme as its activities are proposed to be mainstreamed into larger, more strategic funds.

Notably, EUR 409 billion has been proposed for competitiveness, research and innovation through the combined budgets of the European Competitiveness Fund (EUR 234 billion) and Horizon Europe (EUR 175 billion). This is almost 2.5 times the EU-level of investment under the programmes ending by 2027; it represents around 21% of the total proposed MFF, compared to 17% of the current MFF. Four priority areas are proposed:

- clean transition and industrial decarbonisation;
- health and biotech, agriculture and bioeconomy;
- digital leadership;
- resilience and security, defence industry and space.

EUR 26.2 billion of the European Competitiveness Fund will potentially be allocated to clean transition and industrial decarbonisation.

Table 4.5 Overview of the EU funding landscape relevant for industry's clean transition

Allocation	Primary EU funding mechanism	Strategic focus	EUR billion reported to date
R&D/innovation	Horizon Europe (Pillar II)	Industrial competitiveness and research and innovation (R&I)	30.3 [a]
Piloting	LIFE Programme	Testing new technologies	4 [b]
Strategic deployment	Invest EU	Mobilising in innovation and job creation	26.2
Infrastructure	Connecting Europe Facility for Energy (CEF Energy)	Strengthening cross-border energy and transport links	5.84
Regional transition	Cohesion Fund	Regional economic cohesion and carbon-intensive industry shifts	67.8 [c]
Large-scale flagship projects	Innovation Fund	High-impact, low-carbon tech and renewable energy	~3 [d]
Infrastructure, regional transition	Modernisation Fund	Low-carbon energy systems and infrastructure development	~1.1 [e]
Cross-cutting	Recovery and Resilience Facility	Economy-wide reforms and green investment programmes	Climate expenditure ~275
Future sources: Industrial Decarbonisation Bank, European Competitiveness Fund			

Notes: (a) Refers to funding available for the cluster 'digital, industry and space' (EUR 15.3 billion) and 'climate, energy and mobility' (EUR 15 billion);
(b) refers to the total funding available for projects in three subprogrammes related to industry, namely 'circular economy and quality of life' (EUR 1.862 billion), 'climate change mitigation and adaptation' (EUR 1.171 billion) and 'clean energy transition' (EUR 970 million);
(c) estimate based on 30% allocation to PO_2 ('greener Europe') of total EUR 226.05 billion (2021-2027);
(d) estimate based on the grants awarded to industrial decarbonisation in the last three rounds of the Innovation Fund;
(e) estimate based on confirmed or disbursed amounts as of May 2026, excluding energy supply-related investments.
Source: EEA elaboration.

The EU is seeking to improve the coherence of its regulatory framework through a range of simplification initiatives; discussion among stakeholders about how to achieve this is ongoing. A comprehensive approach is required to ensure that investments are available in a timely and strategic manner.

Considerations include the need for strong support for innovation and venture capital, agile financial instruments to channel savings into productive investment and an environment that supports business growth. At the same time, there needs to be a bold commitment to and targeted support for promising breakthrough technologies to accelerate their commercialisation and deployment — provided they demonstrate strong potential to contribute to decarbonisation, pollution reduction, circularity, sustainability and long-term economic viability.

The funding landscape is structured to support industry's transition across different stages of technological maturity; however, capital support alone is unlikely to be sufficient, particularly for breakthrough technologies facing high operating costs and uncertain revenues. Ultimately, final investment decisions depend on the existence of viable business opportunities and a supportive regulatory and operating environment.

A key challenge for green industrial innovation lies in bridging the multiple 'valleys of death' from the development and demonstration of technology through to commercial deployment. Dedicated post-pilot funding instruments, risk-sharing mechanisms as well as long-term regulatory certainty and demand signals are all often required to overcome these barriers.

In this context, measures that seek to improve the business case for cleaner production — by reducing operating costs or revenue uncertainty — can complement upfront capital support. These measures include energy compensation schemes, tax incentives, carbon contracts for difference (CCfDs) and fixed premium contracts. Demand-side measures include green public procurement requirements, products standards and eco-design requirements (ESABCC, 2024).

Public finance and market creation

Even when individual projects become technically and economically feasible, market failures, investment risks and weak demand for cleaner industrial products may still hinder large-scale industrial transformation. Public intervention can therefore play a wider role in mobilising private capital, derisking investments in less mature technological options and helping create markets for cleaner industrial products.

Recent European Central Bank (ECB) data show that each euro invested by the EU attracts an equivalent amount of private capital; effectively this doubles the overall impact (ECB, 2025b). Directing such capital towards clean industrial investments, promising innovations and scaling up proven solutions can help accelerate industrial transformation across European value chains.

Public finance is not only about mobilising capital but also about shaping the direction of innovation and industrial development. Relying solely on bottom-up market processes may not sufficiently address long-term societal challenges.

EU funding is therefore increasingly designed not only to support existing innovation trends but to set strategic orientations for R&I, including towards a green and digital transition (EC, 2026e). Mission-oriented approaches (see Box 6.1) can play an important role in directing innovation efforts towards the objectives of clean industrial transformation. In this context, choices regarding which technologies receive support are important (see Section 4.1).

In addition to EU funds, recent EU policy development — notably the CID state aid framework (CISAF) — has broadened the scope and flexibility of Member States' own support; this is regarded as a key instrument to derisk large-scale investments. State aid is being disbursed through a range of instruments, including direct grants, contracts or agreements, guarantees and loans, and tax reliefs.

For instance, in 2025, the EC approved a EUR 5 billion state aid scheme put forward by Germany to support the country's industrial decarbonisation through mechanisms such as CCfDs. Under this mechanism, the state pays companies the difference between the actual cost of a low-carbon technology and the current carbon (ETS) price. This provides long-term price certainty for companies switching, for instance, to green hydrogen or electrification.

Meanwhile, France has also placed particular emphasis on large-scale direct grants and long-term contracts with the most carbon-intensive industrial sites. Here, conditional public funding is tied to decarbonisation of the sites (Box 4.5).

Box 4.5

Long-term public investment in and contractual commitments to industrial decarbonisation in France

France provides long term public support to derisk the decarbonisation of its most emission intensive industrial sites. In early 2026, seven large projects were selected for support under the major industrial decarbonisation projects scheme. They will benefit from support over a period of up to 15 years with a total of around EUR 1.6 billion available in public funding in 2026.

In parallel, 'ecological transition agreements' have been concluded with around 50 of the highest emitting industrial sites in the country, which currently produce around 55% of all industrial GHG emissions in the country. Through these contracts, the companies have committed to reducing their GHG emissions by 50% by 2032, with an intermediate target of around 45% by 2030. The total investment associated with these commitments is estimated at EUR 50-70 billion; this funding is largely directed towards low carbon technologies, energy transition and process innovation.

Sectoral roadmaps further aim to identify levers and investment needs to extend decarbonisation across the wider industrial base (Eionet, 2026b).

Beyond supply side support and project level derisking, recent EU initiatives focus increasingly on strengthening demand conditions and providing clearer market signals to support industrial investment. The proposed Industrial Accelerator Act will introduce 'made in EU' and low-carbon requirements in public procurement and public support schemes for strategic sectors. The aim is to strengthen demand for European-made products in energy-intensive industries, the automotive value chain and clean technology sectors. There are potential benefits from this initiative which extend beyond the targeted sectors; including diffusion of knowledge and accelerated innovation.

It is important to note that while this section of the report focuses on financing the transformation, there is a growing understanding that the challenge of building a sustainable and competitive industry goes beyond the availability of capital. For instance, market logics and firm ownership influence investment decisions with subsequent impacts on decarbonisation and competitiveness.

By way of example, Jerneck (2017) argues that after large conglomerates in the United States acquired solar cell manufacturers in the 1970s, they increasingly focused on the prospect of a future utility-scale market rather than expanding existing consumer applications (as opposed to Japanese competitors). This weakened the US solar industry in the 1980s, eventually leading the conglomerates to dismantle their solar divisions and sell them off to foreign firms.

Multinational ownership also means that decision centres are not always in the EU. While policies that help to shape demand and strengthen the market for a clean industry can create new incentives, they can also introduce uncertainty, regulatory risks and potential losses in established business models.

Policymakers need to better understand and anticipate how multinational firms adjust their strategies globally in response to industrial policy and that they may relocate or shift investments across jurisdictions. One approach is to work together with more proactive firms that aim to go beyond compliance (Benito and Meyer, 2024).

5 Social and systemic dimensions of transformation

Industry's access to clean energy and technologies, skills, infrastructure, materials and finance provide an essential foundation for a clean industrial transformation. However, findings from Chapter 4 suggest that even when technologies are available and investment conditions improve, transformation can still stall. This can be due to various factors including those rooted in cultural and territorial contexts, institutional lock-in, fragmented governance and entrenched economic and governance structures.

This motivates a deeper look at the wider system conditions that enable socially legitimate, strategically coherent and resilient industrial transformation. This chapter points to three overarching insights:

- **Technological readiness is insufficient.** Successful industrial transformation depends also on social legitimacy, effective governance and place-based implementation. At the same time, transformation creates winners and losers. Credible mechanisms to ensure (quality) jobs and distribute tangible regional benefits are essential for maintaining political and societal support throughout the transition.

- **Innovation must be accompanied by a deliberate phase-out of unsustainable technologies or practices.** Supporting the development and diffusion of clean technologies is necessary but not sufficient. Industrial transformation also requires unsustainable technologies, techniques and business models to be deliberately phased out in a timely way. This is necessary to avoid the risk of further entrenching incumbent systems.

- **Resilience requires transformation, not only protection.** Long-term competitiveness and resilience depend on the capacity of firms, regions and institutions to anticipate change, reconfigure production systems, diversify supply chains and develop new industrial capabilities in response to emerging societal needs.

The analysis in this chapter draws on various literature — including recent work by the European Topic Centre on Sustainability Transitions — to assess transformative change in EU industry. This study by the European Topic Centre applied analytical lenses from a broad range of academic literature to identify under-acknowledged enablers of transformative change. It illustrates these with practical cases. Further details on the methodology are provided by Diercks et al. (2026).

5.1 Culture, people and places

The Clean Industrial Deal recognises the value of ensuring that workers and local communities are at the centre of the industrial transformation. Alongside measures to strengthen access to clean energy, infrastructure and finance, it emphasises actions to address skill shortages, including:

- the rollout of the union of skills;

- reinforcing sectoral skills initiatives;

- expanding vocational education and training (VET).

These measures provide an essential foundation for the transition. Yet, industrial transformation also depends on broader human, cultural and territorial factors that shape how change is implemented and unfolds in practice.

Public perception and social acceptance play a critical role in the pace and success of industrial transformation. This is particularly evident for infrastructure projects essential to the clean transition, including electricity transmission networks, renewable energy installations and the extraction of CRMs, where local opposition or concerns about environmental and social impacts can slow or even halt deployment.

Transparent decision-making, early engagement with local communities and environmental groups as well as meaningful opportunities for participation can help build trust by ensuring that local concerns and needs are recognised and addressed. Targeted communication about environmental benefits and local economic opportunities can further mitigate the risk of delays or opposition (Muñoz and Tormos, 2025).

However, inclusive dialogue and procedural legitimacy alone do not guarantee successful outcomes. The case from Finland (Box 5.1) highlights the need for a balanced approach that addresses the risk of deepening structural inequalities, recognises the cultural significance of land and establishes robust legal environmental and social safeguards to respond to local concerns in a constructive and legitimate way (Diercks et al., 2026).

Box 5.1

Towards responsible mining in Finland

Finland's mining sector in Kainuu, centred on the Talvivaara mine, exposes the challenges faced by high-trust welfare states in the green transition. During the 2000s boom, Talvivaara opened as a nickel bioleaching facility to tackle unemployment in a remote region.

However, in November 2012 there was a breach in a gypsum waste pond; this released wastewater containing nickel and uranium, causing lasting ecological damage and legal prosecutions. The disaster triggered stricter regulations and a sharp loss of trust in state-owned firms. In 2014, the government responded by establishing the Network for Sustainable Mining.

Created under a national sustainability plan, this multi-stakeholder forum united mining companies, ministries, municipalities, Sámi representatives and non-governmental organisations (NGOs). To strengthen transparency and bolster Finland's image as a responsible battery metal producer, the network introduced performance scores, engagement guidelines and dispute procedures.

However, the initiative soon faced challenges when Sámi representatives and NGOs withdrew, arguing that participation risked normalising mining on culturally significant lands without addressing structural inequalities. Today, the region remains dependent on mining jobs despite ongoing remediation. This illustrates how consensus orientation can improve accountability yet struggle to resolve deeper conflicts.

For EU policy, this underscores that the push for strategic autonomy in CRMs requires deliberative governance but also legally robust social safeguards to deal with local resistance and needs. Additionally, these must be paired with an expanded focus on the interplay of mining and environmental goals.

Trust and collaboration across society are critical enablers of industrial transformation, particularly during periods of crisis, disruption and accelerated change. Participatory processes such as the EU's clean transition dialogues provide an important platform for structured engagement on decarbonisation pathways and competitiveness challenges. Engagement can be further strengthened by systematically involving broader groups — such as local communities, citizens, consumers and civil society organisations — alongside established stakeholders.

Broader participation helps ensure that industrial transformation reflects the realities of places and communities that extend beyond the factory gate. It can improve understanding of how industrial change affects employment, land use, energy costs, environmental quality and local development.

At the same time, it can enable potential conflicts and trade-offs to be identified and addressed at an earlier stage. Without such engagement, the impacts of transformation may be poorly anticipated, contested late in the process or framed as external constraints rather than shared challenges (Diercks et al., 2026).

Participation is particularly valuable at the strategic regional level; this is where decisions about industrial development, infrastructure and innovation ecosystems are often made. For example, the knowledge regions programme — coordinated by the Directorate-General for Knowledge Transfer in Catalonia, Spain — promotes collaboration between universities and research organisations. It focuses on the development of shared visions for systemic transformation — including for sustainable and competitive industry — and the design, testing and replication of solutions to address complex problems (Generalitat de Catalunya, 2024).

While challenging in practice, broader public participation can improve the quality, legitimacy and long-term effectiveness of governance arrangements. It is helpful in many areas including the development of more strategic initiatives such as smart specialisation strategies and regional priority-setting (Diercks et al., 2026; JRC, 2022; ECA, 2025).

These considerations are particularly relevant for ensuring the success of large infrastructure developments. This is evident in the example of data centre governance in the Netherlands, discussed in Box 5.2.

Box 5.2

Negotiating data centre development in the Netherlands

The Netherlands' growing status as Europe's 'digital gateway' over the last two decades has turned Amsterdam and Noord-Holland into dense data-centre clusters for Google, Microsoft and Meta. Permissive policies enabled their growth throughout the 2000s and 2010s. From 2018, warnings grew about energy demand from the data centres, while increasing water demand also raised questions about their impact on local well-being.

When Microsoft's Hollands Kroon site was in the spotlight due to its water consumption levels and tensions between energy users, Amsterdam and Haarlemmermeer froze the development of new centres in 2019 to open dialogue with residents, unions and firms.

Consultations led to new rules on energy efficiency, heat reuse and non-potable water sourcing. At the same time, provinces introduced tiered permits and new hyperscale projects were redirected to the north.

Since then, one major construction has been cancelled, while other new sites involved greater investments in water infrastructure. Industry groups also contributed to better coordination of data centre development and transparency around their impacts.

Together, these efforts have reframed data centres as infrastructures with environmental and social impacts. This, in turn, is enabling enhanced planning and governance (Diercks et al., 2026).

While this section has focused on participatory processes in the clean industrial transformation, it is important to highlight that dialogue and inclusive governance must be complemented by tangible economic opportunities in order to be effective and durable. These opportunities must include job creation, income security and adequate financial compensation for affected workers and communities.

In order to sustain trust and support, it is essential to ensure that the benefits of transformation are visible and fairly distributed. This is particularly the case where policies involve the managed phase-out of unsustainable industrial activities.

5.2 Destabilisation and phase-out policies as catalysts of transformative change

It is necessary to simultaneously scale up new industries and technologies while taking a deliberate approach to phasing out unsustainable or increasingly uncompetitive activities and practices (Kivimaa and Kern, 2016). Without a balanced strategy it will be hard to achieve successful policy mixes to foster deep transformation.

Taking the energy transition as an example, this approach includes the phase-out of fossil-based sectors. However, the energy transition involves different dynamics compared to industry's clean transition, where phase-out policies are more likely to target specific technologies, substances, production processes or business models within sectors. A prominent example is the successful global phase-out of ozone-depleting substances under the Montreal Protocol; here, binding phase-out schedules were combined with the coordinated scale-up of viable alternatives (Solomon et al., 2020).

Recent analysis points to an imbalance between phase-in and phase-out policies in the global steel market (Algers and Åhman, 2024). Over half of steel blast furnaces are due for reinvestment or retirement by 2035 (E3G, 2025) and the long operational lifetimes of these industrial assets present a lock-in risk — without

concerted action, decisions may be taken which reinforce carbon-intensive capacity (Janipour et al., 2020).

Timely deployment of low-carbon technologies is a significant determinant of emission reductions in the steel sector but continued reliance on blast furnaces would consume a growing share of the remaining carbon budget. As such, planned relining of existing blast furnaces and new steel production capacity need to be monitored closely and there needs to be a broad and balanced policy mix to enable unmitigated blast furnaces to be phased out (Vogl et al., 2021).

However, the key issue for Europe is not simply phasing out carbon-intensive assets but actively managing industrial restructuring in a way that:

- preserves strategically important production capacity;
- avoids disorderly decline;
- supports decarbonisation.

Some countries have been experimenting with mechanisms to coordinate industrial restructuring. In China, for example, a 'capacity swap mechanism' aims to reduce excess steel capacity by requiring 1.5 tonnes of existing capacity to be decommissioned for every tonne added. The mechanism further incentivises environmentally friendly steelmaking facilities, including secondary steelmaking (EAFs) and the hydrogen-based route (Reuters, 2025).

The EU context is different, however. It is characterised by declining domestic production capacity and increasing exposure to international competition. As such, there is a need for more strategic and coordinated consolidation; decarbonisation objectives must be balanced with the requirement to maintain internationally competitive production capacity, while taking into account regional and social impacts.

Complementary instruments — such as targeted state aid for low-carbon production, carbon pricing through the EU ETS and effective implementation of the Carbon Border Adjustment Mechanism (CBAM) — could support this transition if priced at the right level (Algers and Åhman, 2024). Implementation of a targeted and administratively feasible CBAM alongside a strengthened ETS could reduce the risk of carbon leakage and anti-competitive distortions (ECB, 2023).

In this context, policy sequencing can help avoid political and economic lock-ins. Early support for innovation, industrial investment and coalition building can help reduce the costs of clean technologies and build political support for change. As low-carbon alternatives become commercially viable, carbon pricing can progressively increase and free allowances can be phased out, while ETS revenues are reinvested in industry's transition (Meckling et al., 2017).

Failure to plan for the discontinuation of unsustainable practices and activities further risks creating structural lock-ins that delay or obstruct change; this would undermine the competitiveness of sustainable alternatives (Turnheim and Geels, 2012).

Failures can occur through counterproductive market distortions, inefficient allocation of public resources and inconsistent policy signals. For example, policies that stimulate additional green production without simultaneously reducing conventional production may simply expand overall supply; this would risk depressing prices and create excess capacity rather than accelerate structural change towards cleaner production systems (Diercks et al., 2026).

One example is the plastics sector, where consumption has grown significantly over recent decades while recycling rates remain relatively low. A key challenge in this sector is the low cost of primary fossil-based plastics relative to recycled materials (EEA, 2024k). Despite growing evidence pointing to the need for upstream measures (Baztan et al., 2024), policy interventions have largely focused on downstream waste management rather than reducing primary production — through, for instance, product standards, the promotion of longer product lifespans or reduced fossil fuel subsidies. Progress on upstream measures has been slow, partly reflecting resistance from countries with vested interests in plastic production (Dreyer et al., 2025).

Poorly designed phase-out processes also carry risks. Short-term stabilisation policies — such as subsidies or bailouts — may preserve jobs temporarily but can also entrench outdated industrial models and delay necessary restructuring. Conversely, abrupt phase-outs that neglect social impacts risk triggering political backlash, eroding public trust and slowing industrial decarbonisation efforts.

Coupling the managed phase-out of unsustainable industrial practices with well-designed just transition measures — including retraining workers, income support and regional development programmes — helps align social, environmental and industrial objectives. Such measures not only cushion the social and economic impacts of industrial transformation but also strengthen the political legitimacy of ambitious industrial transformation (Diercks et al., 2026).

Historical examples show how phase-outs can be navigated in the long term to create new opportunities for innovation, investment and economic diversification. Genk, a former coal-mining region in northern Belgium, illustrates these dynamics. It has reinvented itself as a thriving knowledge- and innovation-driven economy following the economic decline of coal (Box 5.3).

Box 5.3

Genk's managed industrial transition — from coal to a diversified regional economy

Following the first mine closures in the 1960s, the city of Genk, Belgium, replaced coal with car manufacturing. While this secured economic stability over the following decades, the city remained dependent on a single industrial sector. A more fundamental transition began after Ford's closure in 2014; this marked a shift toward a diversified, knowledge- and innovation-driven economy.

A key strategy was the adaptive reuse of Genk's mining infrastructure, with each former mining site given a distinct focus — such as clean technology, cultural and leisure activities or energy-related innovation. This thematic differentiation formed part of a coordinated regional strategy to avoid internal competition for the same resources, facilitate new regional identities at the same time as enabling targeted innovation and investment.

A binary governance strategy, combining top-down measures — including a nationally funded investment plan — and bottom-up approaches — including social innovations — aligned local needs and ideas with regional economic goals. From coal to cars, from cars to creative hubs, clean-tech clusters and community-led regeneration, Genk offers an inspiring example of clear phase-out strategies enabling long-term regional industrial transformation (Diercks et al., 2026).

5.3 Transformative industrial resilience

EU industry has faced a succession of shocks in recent years, including energy price volatility, supply chain disruptions, global oversupply and weak domestic demand. In response, the CID recognises the need to strengthen Europe's industrial base against external disruptions — primarily through measures aimed at enhancing competitiveness.

'Resilience' is commonly understood as the capacity of a system to absorb shocks, adapt to changing conditions and recover or reorganise while maintaining its essential functions. However, resilience — in the context of industrial transformation — may also require more fundamental change. This includes the capacity to fundamentally transform production systems, business models and value chains when existing structures are no longer viable and 'business as usual' is no longer an option (EEA, 2024n).

A narrow, instrumental interpretation of resilience risks reinforcing existing vulnerabilities. When resilience is reduced to short-term efficiency, risk management or the ability to 'bounce back', policy responses such as subsidies, deregulation or trade protection may help stabilise industries temporarily. However, they can mean that underlying structural weaknesses are not addressed. Such approaches can also overlook opportunities to use periods of disruption as windows for experimentation, innovation and industrial renewal by supporting emerging niche activities that may become the basis for future competitiveness (Diercks et al., 2026).

Industrial resilience can be strengthened through proactive strategic restructuring. This can involve rethinking production methods, material choices, business models or even territorial planning in terms of where to locate industries. The examples below illustrate how resilience can emerge through business transformation (Box 5.4) and through supply-chain diversification and circularity (Box 5.5).

Box 5.4

The two transitions to alternative fuels in the Norwegian maritime industry

Shipbuilding is a major industry in the Norwegian economy. This industry faced collapse in the 1970s due to an oil crisis and global competition from Japan, then South Korea and, more recently, China — with the development and subsequent global dominance of shipbuilding in Asian countries.

Following the discovery of oil in the North Sea in this period, the industry survived by developing novel, complex designs to meet a new growth market in platform supply vehicles (PSVs) and ferries. This industrial capability for advanced technology in ship design and shipbuilding influenced national policy to support technology development to reduce NO_x — which was becoming a growing environmental concern — through the use of liquefied natural gas (LNG) systems. This enabled the Norwegian shipbuilding industry to become a world leader in LNG for PSVs and ferries.

Following a change in national climate policy (Hansen et al., 2024), the Norwegian government initiated a second transition through R&D support, switching to battery and hydrogen technologies, complemented by government procurement of new battery and hydrogen ferries.

Norway's technology capability has been strong enough to move from being a world leader in LNG maritime technologies to being a world leader in battery and hydrogen technologies. The mobilisation of diverse stakeholders — including the Norwegian shipbuilding industry and a very strong R&D innovation system at universities and maritime research institutes — has been key to these two transitions. Green public procurement and state policy were other crucial drivers (Bach et al., 2020). This case shows how Norway's maritime industry strengthened both its long-term position and its immediate competitiveness by reorienting toward a highly specialised and sustainable market niche.

Box 5.5

Resilience in the context of geopolitical shocks — Japan's electronics industry during the 2010 rare earth crisis

In 2010, China allegedly slowed or suspended rare earth exports to Japan following an incident involving the arrest of the captain of a Chinese fishing trawler that sailed near the Japanese-administered Senkaku/Diaoyu Islands. The incident reflected long-term structural tensions, with China targeting materials essential for high-tech industries such as magnets, electric vehicles and renewable energy technologies. The crisis revealed the systemic risks of concentrated supply chains and prompted coordinated action by Japanese industry and government to strengthen their strategic autonomy and long-term supply chain resilience.

Before the crisis, Japanese policymakers and firms had proactively begun to restructure the rare earth sector to mitigate potential supply disruptions. The measures included:

- enhanced resource diplomacy and strategic use of official development assistance to support overseas resource development and mutual investment;
- recycling and stockpiling rare metals;
- exploring seabed resources;
- fostering innovation to lower material intensity;
- substituting rare earth elements in industrial applications.

These measures aimed to diversify supply sources and reduce dependency on rare materials and single suppliers of these materials. The result was a dramatic, permanent reduction in rare earth demand: from 2010 to 2013, overall consumption fell by roughly 60%. This mitigated immediate supply risks and increased the economy's flexibility and adaptive capacity for future shocks. This illustrates how proactive and concerted efforts to address a geopolitical crisis can transform a highly vulnerable supply chain into a more resilient system.

As demonstrated above, resilience responses are not a one-size-fits-all concept. They are shaped by the specific risks, shocks and structural dependencies that regions or sectors seek to hedge against. This in turn makes sector-specific and place-based strategies central to transformative resilience.

Industrial clustering represents one such strategy. By concentrating firms, suppliers, specialised skills and innovation ecosystems, clusters can:

- facilitate knowledge diffusion;
- improve resource efficiency;
- strengthen coordination across value chains.

The Verbund system and development of Verbund sites by chemical company BASF — in locations such as Antwerp and Ludwigshafen — illustrate this approach. Through the co-location of interconnected chemical production processes, by-products from one facility become feedstocks for another, reducing material and energy losses while increasing both resource efficiency and supply-chain resilience.

In other sectors, resilience may instead require greater decentralisation and territorial diversification in order to reduce exposure to localised disruptions, geopolitical risks or infrastructure bottlenecks. For example, for the battery sector, safety requirements may mean that 70% of recycling costs are spent on transporting used batteries.

A decentralised engineered network consisting of regional pretreatment facilities could help reduce transport distances, costs and improve scalability. This would involve discharging, dismantling and shredding the batteries close to where they are collected and shipping only the non-hazardous recycled material to large centralised hydrometallurgical hubs (Soldan Cattani et al., 2025).

Place-based approaches are embedded in EU cohesion policy instruments and initiatives such as the Just Transition Fund and smart specialisation strategies. These aim to align industrial transformation with regional socio-economic realities and set out priorities for research and innovation that build on the competitive advantage of each region.

More recently, the Industrial Accelerator Act and the establishment of industrial accelerator areas represent a more centrally designed approach. The aim is to align competitiveness, regional development and transformative resilience through geographically targeted interventions.

For policymakers, the key challenge is not simply to strengthen resilience, but to determine what type of resilience is needed, where and for whom. Successfully navigating industrial transformation requires balancing resilience, competitiveness, territorial cohesion and environmental objectives, while managing the trade-offs between them.

6 Towards long-term competitive transformation

The Clean Industrial Deal (CID) marked a pivotal shift in the EU's industrial policy architecture. It aims to support Europe's industry through a period of highly competitive pressure while strategically leveraging the long-term competitive advantages offered by decarbonisation and enhanced resource productivity.

This chapter examines competitiveness from two complementary perspectives. The first is the competitiveness of Europe as a whole: its capacity to generate sustainable prosperity, resilience, innovation and high-quality employment. The second is the competitiveness of individual sectors and firms, which underpin Europe's broader economic performance and ability to compete in global markets.

The relationship between these perspectives is central to industrial transformation; measures that strengthen long-term socio-economic competitiveness may create adjustment challenges for sectors and firms in the short term.

This chapter is therefore structured in two parts. Section 6.1 examines how the clean transformation of industrial facilities contributes to avoiding losses, strengthening resilience and creating new economic and social opportunities. Section 6.2 then explores strategic options that build on the path set by the EU's recent industrial policy initiatives by aiming to align industrial competitiveness with environmental and climate objectives, in support of a more resilient and forward-looking European industrial base.

6.1 Clean industrial transformation — key opportunities for competitiveness

Environmental pressures and climate change can undermine competitiveness at multiple levels — from individual industrial installations to Europe's position in global markets. In this section we examine how the clean transformation of industrial facilities can support competitiveness by avoiding losses, reducing risk, strengthening resilience and creating new economic and social opportunities (Table 6.1). Understanding these pathways and externalities helps clarify the costs and benefits of transformation versus business-as-usual — not only for society but also for industry itself.

Table 6.1 The contributions of clean industrial transformation to competitiveness and resilience

Short term	Medium term	Long term
Avoiding losses	**Reducing risk and strengthening resilience**	**New economic and social opportunities**
• Improving productivity and cost savings at the facility level • Impact on GDP • Preventing ecosystem service degradation • Lowering healthcare expenditure • Lowering disaster recovery risk • Reducing remediation costs	• Increasing resilience against constrained material and water supplies • Reducing import dependency and exposure to price volatility and global supply chain disruptions • Energy system resilience through a diversified fuel mix • Reducing risk exposure (transition risk, stranded assets, insurance and litigation risk) and enhancing bankability	• Strengthening global export competitiveness and new green lead markets • Enhancing technological and innovation capacity • New innovative and circular business models • Higher-quality jobs, skills development and workforce resilience • Contributing to public revenues and broader societal welfare

Source: EEA elaboration.

Strengthening productivity and avoiding costs to society and industry

The links between environmental degradation, climate change and the global economy are well established. Climate mitigation and resilience are therefore essential for Europe's economic competitiveness rather than being simple cost trade-offs.

Economic losses from weather- and climate-related extremes in Europe have been felt more frequently and acutely over the last few years (EEA, 2024c). There are also direct consequences for industry. For EU industry's critical infrastructure, the annual damage from climate change impacts is expected to increase 10-fold by the 2080s, up from EUR 1.5 billion in 2018 (Forzieri et al., 2018).

These impacts have the potential to consume large shares of future profits. Globally, it is estimated that companies' fixed asset losses per year as a proportion of their operating profits will average 6-7% and over 20% for utilities, in both low- and high-emission scenarios by 2035 (WEF, 2024).

Compliance, treatment and remediation costs are another important cost category for society, as well as for industry, under the 'polluter pays principle'. It is estimated that over 60% of soils in the EU are currently in an unhealthy state; this currently costs our economy and society EUR 40-70 billion every year (JRC, 2025a).

One important component of this challenge is soil contamination. Remediation of potentially contaminated sites alone is conservatively estimated to require EUR 16.6 billion across the EU (EEA, 2024l), which highlights the cost-effectiveness of pollution prevention measures.

An EC study focusing on PFAS alone estimated annual remediation and treatment costs at about EUR 3.8 billion per year. Meanwhile, total societal costs under continued pollution could reach hundreds of billions or even trillions by 2050 depending on the scenario (EC, 2026h).

The full extent of the economic impact of pollution on various sectors — such as agrifood systems, healthcare and tourism — is only beginning to be understood. For instance ozone — with methane, NMVOCs and NO_x as the main precursors — caused billions of euros of damage due to crop losses in the EU in 2023 (EEA, 2026a).

Assessing the external damage cost specifically from industrial activities can reveal how clean industrial transformation contributes to EU competitiveness by reducing costs and externalities to society. Sources can be highly concentrated; data on the external damage cost of industrial air pollutant emissions in the EU show how only 129 facilities were responsible for more than 50% of industry's modelled damage costs to society, representing a significant health burden (EEA, 2024m).

The good news is that managing these risks pays off. A study on the long-term economic benefits of air pollution regulation found that every euro spent on air pollution control could return an estimated EUR 30 in economic benefits (US EPA, 2011).

The benefits to industry can also be more direct. Increasingly, clean production is a competitive advantage due to pricing, regulation and market preference. For example, growing evidence shows how industrial heat electrification — in particular combined with thermal energy storage — can outperform fossil-based alternatives if supported by competitive electricity prices, effective carbon pricing and the right policy frameworks (Agora Industry, 2026c).

A clean transformation can also support productivity — including resource productivity which is increasingly recognised as a key competitiveness indicator (EC, 2024e; Porter and Cembrero, 2024; EEA, 2026r). Particularly within the European context, material use levels and economic output are intricately linked (Malatyinszki et al., 2025).

Shifting towards circular production processes with more efficient use of materials, water and energy has already delivered cost savings for industry. Compared to two decades ago, EU manufacturers now generate 50% more value added while using 25% less energy (IEA, 2025b). This represents a significant advantage in the face of higher energy costs.

The European steel sector provides a notable example, reflecting decades of process optimisation and innovation that have contributed to high levels of energy an resource productivity. In fact, EU-27 facilities have decreased the costs of producing hot rolled coil by EUR 59-152 per tonne relative to baseline production costs (JRC, 2016). This decrease partly compensates for potentially higher energy, labour and material costs relative to competitors.

At the same time, there is a wide disparity in firms' energy productivity, signifying great untapped potential. Typically, aggregate energy consumption could be almost halved if the least productive firms would raise their energy productivity to that of the 25th percentile firm in their industry (OECD, 2025c).

Reducing risk and strengthening industrial resilience

The European steel, chemical and cement industries remain heavily dependent on fossil fuels and fossil-based feedstocks. Around 75% of their energy and feedstock needs are still met by fossil sources (Agora Industry, 2026a) rendering them vulnerable to volatile commodity and energy prices.

Recent gas price spikes in 2026 demonstrate that even limited physical dependence on supply routes such as the Strait of Hormuz can translate into significant economic impacts for industry through exposure to global benchmark prices. This reinforces the strategic case for reducing fossil fuel dependence through energy efficiency, electrification and home-grown renewable energy. It also reinforces the need for more stable and diversified supply chains in planning for a clean industrial transition.

Sustainable production processes — including through better management of resources — further reduce the EU's exposure to import dependency, price volatility and global supply chain disruptions. Since 2010, there has been a nearly seven-fold increase in trade restrictions against the EU for CRMs needed for the green transition (EEA, 2026p).

Clean industrial transformation can reduce risk exposure at multiple other levels, including companies' climate transition risk. This refers to the financial risks that companies face as economies transition towards lower-carbon and more environmentally sustainable models. Such losses could be brought on by abrupt regulatory changes, technological progress or shifts in market or consumer preferences. Firms with lower climate transition risk exposures have often been found to perform better financially (Reboredo and Ugolini, 2022).

Businesses must also mitigate and adapt operations to the impacts of physical climate risks. Water scarcity threatens industries of central interest to the EU — such as the production of semiconductors, data centres, renewable hydrogen production and the manufacture of electric vehicle batteries.

In the coming decades, droughts and heatwaves are likely to become the dominant sources of damage, with impacts including higher costs for water and water treatment. Industry in the south of Europe is expected to be particularly vulnerable to increasing drought-induced damage Meanwhile, floods and windstorms currently account for most hazard losses in industry. These kinds of losses are primarily caused by damage to infrastructure, machinery and equipment (Forzieri et al., 2018).

Finally, businesses increasingly face insurance and litigation risks as evidence of the health and environmental impacts of certain chemicals continues to emerge. Preventive approaches — including 'safe and sustainable by design' and the substitution of hazardous substances with safer materials — can reduce exposure to such risks. There have been recent court cases involving PFAS, which are highly persistent 'forever chemicals' that spread widely through water, air, soil and food, posing risks to human health and ecosystems (EEA, 2024j).

In Italy, for example, a landmark court ruling in the Veneto region in 2025 held a chemical company criminally liable for intentional PFAS contamination, after around 350,000 residents in the region had been drinking water contaminated with PFAS for at least two decades. Many still carry high concentrations in their blood today.

Eleven former managers and employees of the chemical company were sentenced to a combined 141 years in prison for serious offences including intentional environmental disaster, water poisoning and fraudulent bankruptcy. In addition, the court awarded several million in damages (Warren, A., 2025).

This highlights how contaminants such as PFAS are not only a waste concern but a societal challenge and litigation risk. They can be mitigated through:

- PFAS restrictions;
- the development and deployment of safer and more sustainable alternatives;
- innovations in treatment and monitoring.

Leading chemical companies have begun to phase out the production of 'forever chemicals' as the risk of litigation grows and the EU looks set to impose broad restrictions on their use (ChemSec, 2026).

New economic and social opportunities

Overall, environmental regulation has been found to have a positive impact on innovation and competitiveness. A policy framework that supports clean industrial transformation can open up new economic opportunities for EU industry by strengthening innovation, productivity and global competitiveness (Li et al., 2022; Zhang et al., 2024).

Producing green industrial outputs can be viewed as a vertical differentiation strategy — whereby products are differentiated from those of competitors. It can take advantage of the price premium on greener goods and intermediate products (Altenburg, T. and Assmann, C., 2017). To support such a premium, policy attention is increasingly focused on creating lead markets for low-emission materials. Measures include carbon-intensity standards, environmental product declarations, public procurement criteria and future product requirements related to the Ecodesign for Sustainable Products Regulation and the Construction Products Regulation.

Industrial transformation also enables the emergence of innovative and circular business models that improve resource efficiency and value retention. Progress on the safe and sustainable design of chemicals can help to remove technical and innovation barriers to circularity, while also reducing long-term compliance costs and environmental risks.

A study of more than 860,000 EU procurement tenders confirms how companies leverage higher environmental, social and governance (ESG) scores to gain competitive advantage when sustainability considerations are included in a tender. The use of sustainability considerations is expected to grow under recent EU policy frameworks and planned revisions of public procurement rules (Sieber, J., 2025).

Firms undergoing clean industrial transformation may also be better positioned to attract investment and financing, as investors, banks and insurance companies are increasingly sensitive to environmental risk. Evidence based on large industrial facilities reporting pollutant emission data under the Industrial Emissions Portal shows that banks appear to reduce credit availability and increase borrowing costs for firms with higher biodiversity-related pollution risks. In this policy context, banks are increasingly factoring in the risk of litigation, fines and regulatory non-compliance when making lending decisions (ECB, 2025a).

Beyond economic performance, clean industrial transformation can deliver important social and societal benefits. Cleaner production processes and reduced pollution can contribute to higher-quality jobs — for example, through lower occupational exposure to hazardous substances — contributing to better health outcomes for workers and surrounding communities. A healthier industrial environment can also increase how attractive EU regions are for skilled labour, innovation and investment; this, in turn, can support the availability of talent needed for industrial renewal.

Emerging evidence from Member States further demonstrate the impact of industrial transformation on public revenues and broader societal welfare. For instance, in Sweden, a recent assessment estimates that industrial transformation would increase Sweden's GDP by 2-3% — equivalent to Sweden's annual defence budget — as well as raising an additional EUR 1.2-3.2 billion in tax revenue (Region Norrbotten, 2024).

6.2 A portfolio of strategic options for a clean and competitive industry

Industry remains a significant contributor to Europe's environmental and climate pressures. Yet, further progress towards a clean industrial transformation is increasingly constrained. Many of the more straightforward efficiency improvements and pollution reduction measures have already been implemented. Shifting towards deep decarbonisation, zero pollution and circular industrial value chains requires fundamental changes to production processes and the deployment of capital-intensive technologies. It also depends on policy certainty and the development of markets that reward lower-emission and more circular products. As such, it is unlikely that environmental and climate regulation alone will enable this transformation to be scaled up sufficiently. This is particularly the case in view of the competitiveness pressures faced by EU businesses.

Traditional economic approaches have largely framed the role of the state in terms of fixing market failures (Mazzucato, 2018). Yet, there is growing recognition that public policy must also play a more proactive role in shaping and steering markets towards collectively defined societal objectives — including climate neutrality, resource security and long-term resilience (Mazzucato, Mariana, 2021). A mission-oriented policy approach provides such a framework. This kind of approach has gained prominence as a response to complex, interconnected challenges that cannot be addressed through market correction alone (OECD, 2021) (Box 6.1).

Box 6.1

A mission-oriented approach to industrial transformation

A mission-oriented approach can be understood as a policy framework that sets clear, time-bound and societally relevant goals and mobilises a broad range of actors and instruments to achieve them (Borrás and Edler, 2020). Rather than targeting individual technologies or sectors, missions define a direction of change — such as climate neutrality or circularity — and support multiple innovation pathways that contribute to that goal.

This involves:

- combining different types of policy instruments (regulatory, financial and market-based);
- fostering experimentation and coordination across sectors, value chains and governance levels;
- enabling collaboration between public and private actors.

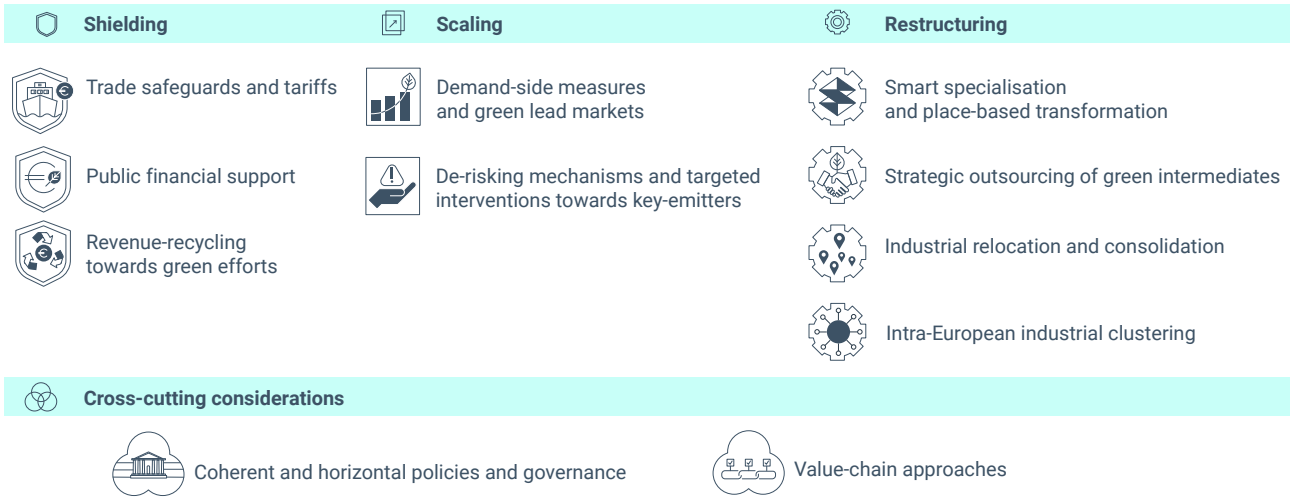
This is particularly relevant for industrial transformation, where change rarely occurs within single sectors. Industrial decarbonisation and circularity depend on interactions across energy, mobility, materials, digital technologies and infrastructure. This requires policy approaches that can address multi-system dynamics and value-chain interdependencies (Steen, Markus et al., 2026).

These characteristics imply the need for a balanced and coherent policy mix. Targeted measures — including support for innovation, infrastructure, market creation and skills — are needed to derisk investment and accelerate transformation. At the same time, conditions can be attached to public support to ensure that public-private partnerships remain aligned with societal objectives, including sustainability, inclusion and long-term public value creation. A mission-oriented framework helps align these instruments, enhancing policy coherence and effectiveness across domains (Steen, Markus et al., 2026).

The EU does not face a binary choice between competitiveness and sustainability nor is there a single optimal pathway for industrial transformation. Instead, it faces a portfolio of strategic options with different strengths and trade-offs. These differ in terms of the time they would take to implement, their depth and their implications for geography and competitiveness. A mission-oriented approach provides a framework to navigate these choices by aligning long-term objectives with policy, investment and innovation.

Chapter 4 of this report outlined the progress made on enabling conditions for EU industry to contribute to a sustainable, clean, circular, resource-efficient and climate-neutral economy by 2050. Building on the findings throughout this report, as well as inputs from external experts, this section presents a list of strategic options for achieving these objectives, while strengthening the competitiveness of EU industry. They include approaches already pursued by the EU, as well as proposals put forward in the academic literature and by industry experts. The options have been classified according to policy function and they are discussed below.

Table 6.2 Strategic options for a clean and competitive EU industry



Source: EEA elaboration.

Shielding — protecting industry during transition

Trade safeguards and tariffs

Trade-defence instruments, tariffs and safeguards are being pursued as options by the EU to manage transition risk and protect EU industrial sectors against unfair competition from countries not subject to the EU's carbon pricing under the EU ETS. These measures include:

- import restrictions;
- tariff-rate quotas;
- European-preference criteria;
- the recently rolled out CBAM.

The CBAM is aimed at managing the risk of carbon leakage as free allowances under the EU ETS are phased out — particularly in sectors such as iron and steel, cement and aluminium. In practice, it means that for producers outside the EU, EU importers have to buy CBAM certificates to cover the carbon price difference with EU-made products covered under the EU ETS.

While such trade instruments can buy time, protect jobs and maintain social cohesion, they do not fully address underlying competitiveness challenges on their own. Cost disadvantages for EU industry arise not only from carbon pricing but also from broader industrial policies in countries such as China and the United States; these can include subsidies, state support and preferential market conditions.

Addressing these imbalances would require a more comprehensive approach to tackling competitiveness beyond climate policy alone (Nilsson et al., 2021). Further, trade measures like tariffs are most effective against 'anchored' industries such as steel and cement, which cannot easily move their heavy infrastructure. In contrast, they are less effective against industries like solar manufacturing, where production can quickly shift to other countries to avoid the extra costs (NBER, 2025).

Importantly, care is needed to ensure that protective policies do not delay the investments, structural shifts and trade necessary to achieve clean, decarbonised and circular industrial objectives.

Public financial support

Public financial support — in the form of measures like state aid subsidies and tax breaks — is considered a key strategy to enable a clean and competitive transformation of industrial processes. Although such short-term stabilisation policies may preserve jobs temporarily, they must not be allowed to entrench outdated industrial models and postpone necessary restructuring.

While broad subsidies are often considered fiscally and politically unsustainable (Di Bella et al., 2025), targeted public support can bridge the gap between demonstration and commercial deployment of large first-of-a-kind industrial plants — such as those required to decarbonise steel and cement production. This is particularly the case given the high risks associated with change and weak early markets (Nilsson et al., 2021). This kind of intervention ideally involves targeted support linked to a clearly defined mission (e.g. climate neutrality).

To maximise public value, such support may also be linked to explicit conditions on recipient firms, ensuring that public resources contribute to agreed societal objectives rather than merely supporting private returns. Conditionalities can help align public-private partnerships with broader goals such as industrial decarbonisation, innovation and long-term resilience (Mazzucato, M. and Rodrik, D., 2026).

Further, large industrial plants such as waste-to-energy, cement and chemical plants are complex, non-standardised systems. As such, it may not be sufficient simply to subsidise the frontrunners in the transformation. The transferability of learning across sites is generally limited. In this context, policy support should allow for technological learning across a diversity of plant configurations, in particular for complex technologies such as CCS (Hansen et al., 2025). Simultaneously, it is essential to phase out fossil-fuel subsidies to avoid counteracting such efforts and to ensure consistent price signals.

Revenue recycling towards green efforts

Recycling EU revenues — in particular targeting trade-exposed sectors — is increasingly recognised as a strategic tool to support both competitiveness and sustainability. The EU ETS represents a significant opportunity. It raised over EUR 258 billion in revenues between 2013 and 2025. Nearly 77% of this income benefited Member States directly; the rest was channelled through EU funds, including the Innovation Fund and the Modernisation Fund (EC, 2026l).

Since July 2023, all revenues generated by the EU ETS must be spent on climate actions. However, at present, only a limited share of the money is allocated to industrial decarbonisation. As such, there is scope to increase this contribution. More targeted use of these funds could accelerate the transition in these sectors by supporting the uptake of low-carbon technologies while strengthening the competitiveness of early movers (EEA, 2026o).

Beyond ETS revenues, phasing out environmentally harmful subsidies, including fossil fuel subsidies, could free up public resources that can be redirected towards a clean and circular industry.

Channelling these revenues into targeted support — such as CCfDs, clean energy and hydrogen infrastructure or innovation funding for deep decarbonisation or circular production processes — can derisk capital-intensive investments while preserving incentives to cut emissions. Revenues could also be directed towards measures that deliver co-benefits across environmental objectives while avoiding unintended cross-media trade-offs.

Scaling — creating markets and accelerating investment

Demand-side measures and green lead markets

In order to achieve the political goal of near-zero emissions in the industrial sector not only must new technologies, products and social practices be developed but existing markets must also be reshaped to align with green ambitions. This places renewed emphasis on demand-side measures and the creation of green lead markets.

The CID has framed the creation of green lead markets as a strategic opportunity to align industrial competitiveness with sustainability objectives. This approach seeks to create early and predictable markets for low-carbon industrial outputs. This would shift cost curves so that cleaner options can compete with fossil-based ones.

The EU has begun to operationalise this approach through a combination of demand-side instruments. These include:

- green public procurement;
- product standards and labelling;
- targeted derisking mechanisms such as CCfDs.

Green public procurement and other mechanisms can help create a pull-effect and steer investment and innovation towards green production and consumption systems (Nilsson et al., 2021; Wesseling et al., 2017). The Industrial Accelerator Act aims to introduce low-carbon and made-in-EU criteria in public procurement and public support schemes. Combining the two criteria can anchor value creation

in green lead markets and improve the commercial viability of low-carbon cement. It does, however, require careful coordination across standards, procurement rules and trade policy to avoid market fragmentation, excessive costs for downstream users or protectionist outcomes that could undermine broader industrial efficiency (EEA, 2023a; EPRS, 2024).

It has also been argued that a robust approach to lead markets could build on Europe's existing industrial ecosystems — in areas where Europe is not lagging behind its competitors — from advanced manufacturing and chemicals to clean energy and aerospace. By leveraging new technologies such as digitalisation, AI and automation to upgrade and reinvent sectors in a place-sensitive way, the EU can enhance its competitiveness and resilience while avoiding the economic and political risks of one-size-fits-all convergence (JRC, 2026a).

While new green markets should be explored, successful regional transformation also requires a pragmatic approach to established industry players. Rather than sidelining them, the EU should collaborate with 'willing incumbents' who are ready to diversify. These firms possess the essential scale and resources needed for a rapid transition.

Derisking mechanisms and targeted interventions towards key emitters

As shown in this report, a small share of industrial facilities accounts for a disproportionate share of environmental and health damage costs in Europe. This concentration of emissions provides a strong rationale for targeted interventions rather than diffuse policy approaches, as they can offer a cost-competitive opportunity to mitigate impacts (Miklin et al., 2025).

EU policies pursue this approach to industrial decarbonisation and pollution to some extent — most notably through the EU ETS and the IED. These instruments only apply to large high-emitting industrial facilities above certain capacity or emission thresholds. However, these instruments primarily regulate or price emissions ex-post and do not, on their own, address the investment risk associated with transforming production processes.

Additional targeted instruments involve derisking mechanisms for green investments; they include long-term public contracts such as CCfDs and power purchase agreements to provide access to lower and more stable energy prices. These and other types of derisking mechanisms, long-term conditional agreements and technology-specific decarbonisation plans for the highest emitters (Janipour et al., 2020) are being explored by various Member States (Section 2.2).

Targeted public grants can further support capital-intensive retrofits or first-of-a-kind deployments at the facility level. In sectors with significant public or state ownership, governments can go further by explicitly sharing first-of-a-kind and scale-up risks, accelerating deployment where private actors alone may be unwilling to invest.

However, it should be noted that the price of carbon is likely to be the main driver of a firm's investment decisions and that targeted instruments such as CCfDs for specific high-cost, high-emission projects would not replace the ETS but rather reinforce its effectiveness (Gerres and Linares, 2020).

Restructuring — changing Europe's industrial model

Smart specialisation and place-based transformation

An important opportunity for a clean and competitive industrial transformation lies in the ability of countries and regions to identify and build on their unique strengths for innovation and structural change. Smart specialisation is a place-based approach that encourages regions to prioritise a limited number of activities aligned with local assets, comparative advantages and innovation capacities — rather than attempting to transform or compete across the full industrial spectrum (JRC, 2017; EPRS, 2016).

Smart specialisation strategies are already embedded in EU cohesion policy; they must be in place for countries to be allowed to access support under the European Regional Development Fund. This aims to guide public and private investment towards targeted domains that support structural change, upgrades in industry and resilience.

In the context of industry's clean transition, this can involve focusing on high-value or strategically important niches for the region that reduce critical dependencies — such as strengthening Europe's comparatively strong position in certain clean-technology supply chains — rather than replicating large-scale production where global competition is intense.

Further, smart specialisation strategies are compatible with the mission-oriented approach described at the start of this chapter; they enable coherent regional priorities, the design of corresponding transformative activities and recognition of the need for experimentation (Foray, 2018).

There are challenges associated with these strategies, however. These include overly broad priority-setting, uneven administrative capacity and fragmentation across regions (EPRS, 2016). As a result, the contribution of smart specialisation to EU-wide competitiveness and sustainability objectives ultimately depends on stronger coordination across Member States and closer alignment with EU-level industrial and climate strategies.

Strategic outsourcing of green intermediates

One option discussed by academia and think tanks (Johnson et al., 2025; Agora Industry, 2025; NDC ASPECTS, 2024; Di Bella et al., 2025) involves achieving cost savings in green manufacturing by sourcing energy-intensive intermediate products — such as hot-briquetted iron (HBI), ammonia and methanol — from regions with abundant and low-cost renewable energy.

Using the steel sector as an example, many EU steel regions are not cost competitive for green H-DRI (considered a key decarbonisation lever for the steel sector) even when carbon prices are very high. Global 'sweet spots' for green hydrogen are located either within or outside the EU, including Australia, Brazil, South Africa and northern coastal areas of Europe (Bilici et al., 2024; Janssen et al., 2022).

Companies seeking greater control over supply chains of these intermediates can invest in dedicated production facilities in regions with favourable energy and resource conditions, rather than relying on merchant suppliers. This approach is illustrated by voestalpine's natural gas-based HBI plant in Texas, which supplies its steel operations in Austria (Perato, M. et al., 2017).

Importing green iron would effectively involve having to decouple ironmaking and higher-value steelmaking in order to reduce the cost of green steel. Evidence

suggests that this may already be taking place for certain intermediaries, with the location of industry likely driven by the 'renewable pull' effect (Samadi and Lechtenböhmer, 2023).

In terms of job protection for the sector as a whole, the majority of jobs are concentrated in steelmaking while ironmaking accounts for an estimated 10% of jobs in the steel value-chain (Agora Industry, 2025).

The approach to outsource green intermediates would require building international partnerships with strategic countries, and trade relationships that ensure supply-chain security. Policy levers include:

- bilateral or multilateral clean trade partnerships;
- rewarding the import of low-carbon intermediates and avoiding localisation criteria on such intermediates;
- long-term purchase agreements (Agora Industry, 2026b).

Under the EU CID, clean trade and investment partnerships are a new initiative; designed as a faster and easier way to foster trade and investment relations in order to bolster competitiveness and support the development of clean industrial value chains. Importantly, moving part of the value chain abroad risks creating new dependencies which must be carefully managed, including through measures that diversify the value-chain such as sourcing from multiple countries and producers, using a mix of trade routes and avoiding supply concentrations in high-risk regions.

Intra-European industrial clustering

European regions where renewables are abundant — such as the Nordic countries, parts of Iberia and some regions in central and eastern Europe — could host new industrial capacity. Similarly, the creation of clean industrial hubs and regional value-chain clusters could leverage coordinated investments towards co-locating industry with grids, hydrogen and CO_2 infrastructure. This would allow them to share infrastructure costs, access skills and suppliers and derisk investment decisions.

This approach aligns with the EU's smart specialisation strategy — discussed above — which explicitly promotes place-based industrial strategies. Such clustering could further enable industrial symbiosis in which value chains are integrated so that the waste or by-products of one company or sector are used as inputs by another. Industrial clustering has been proposed under the recent Industrial Accelerator Act and each Member State has been asked to identify at least one industrial acceleration area.

Industrial relocation and consolidation

Several analyses suggest that selective intra-European relocation or reconfiguration of industrial activity may, in certain circumstances, support a clean and competitive industrial base. Such adjustments can enable access to lower-cost clean energy and strategic resources while maintaining European value chains, employment and regulatory oversight. This may involve shifting production within Europe from legacy, carbon-intensive installations to new or reconfigured sites where state-of-the-art technologies, higher resource efficiency and greater availability of renewable energy can be integrated more effectively.

However, evidence also indicates that the scope for such relocation is highly context-specific and that restructuring is likely to have significant implications

for just transition. Closing or downsizing plants in less competitive regions, including 'one-company towns', can have a significant impact on workers; equally, electrification targets may disadvantage regions with limited access to cheap renewable energy. At the same time, workers may face difficulties transitioning to new employment due to skill mismatches.

Fragmentation within the single market further limits the efficiency of relocation. Thus, the question is not primarily where factories move, but how Europe coordinates the conditions for transformation. The single market could be better leveraged through horizontal measures that reduce national fragmentation (EEA, 2023a) and enhance integrated coordination of infrastructure and investments across borders. This also highlights the need for coordinated policy rather than plant-by-plant relocation (EC, 2026g).

Cross-cutting considerations

Coherent and horizontal policies and governance

Transformational change necessitates coherence across policy domains; diverging national rules can create barriers for sustainable practices. Harmonised standards and consistent regulatory implementation across Member States are therefore critical enabling conditions for a clean and competitive industrial transformation. New types of governance capacities and models are required to move from incremental improvements of industry's environmental and climate performance towards the transformational shifts required to achieve goals such as net zero (Nilsson et al., 2021; Bruegel, 2023).

For instance, an integrated European approach is needed in order to coordinate planning to deploy renewable energy and develop infrastructure in a more cost-optimised way, including for cross-border integrated hydrogen systems (Al-Dabbas et al., 2026). New governance models should utilise both public and private instruments in areas such as industrial decarbonisation, pollution prevention and circularity. They should also promote competitiveness, participation and equity in decision-making.

Value-chain approaches

The EU is pursuing a value-chain approach for certain products, including through the Packaging and Packaging Waste Directive, the Single Use Plastics Directive, Construction Products Regulation and end-of-life vehicle framework. Rather than focusing on isolated sectors or stages, a value-chain perspective can allow competitiveness gains to be made at the system level and across the entire production and consumption chain of a product — from design and raw material extraction through manufacturing, distribution, use and end-of-life management.

Such a systemic perspective means that opportunities for decarbonisation, pollution prevention, circularity and resource productivity are easier to identify. It supports policymakers by helping to avoid problem-shifting. It also helps to pinpoint where interventions such as regulations, funding, innovation or partnerships are most effective or can have the greatest leverage.

A sectoral example is the German-Danish strategic partnership between Salzgitter AG and Ørsted. Through this partnership, the companies make offshore wind energy, renewable hydrogen and low-carbon steel available to each other through closed loops and long-term purchasing agreements. This includes the use of scrap steel from dismantled wind turbines in the steel production process (Winkler, H., 2026).

List of abbreviations

8th EAP	Eighth Environment Action Programme
AI	Artificial intelligence
BAT	Best available technique
BF-BOF	Blast furnace-basic oxygen furnace
CAPEX	Capital expenditure
CBAM	Carbon Border Adjustment Mechanism
CCfDs	Carbon contracts for difference
CEAP	Circular economy action plan
CID	Clean Industrial Deal
CISAF	CID state aid framework
CMUR	Circular material use rate
CRM	Critical raw material
CRMA	Critical Raw Materials Act
CCS	Carbon capture and storage
CCU	Carbon capture and utilisation
CCUS	Carbon capture, utilisation and storage
CO_2	Carbon dioxide
DMI	Direct material input
DRI	Direct reduced iron
EAF	Electric arc furnace
EC	European Commission
ECB	European Central Bank
EED	Energy Efficiency Directive
EIB	European Investment Bank
Eionet	European Environment Information and Observation Network
E-PRTR	European Pollutant Release and Transfer Register
ESG	Environmental, social and governance
ESTAT	Eurostat
EU	European Union
EU-27	27 EU Member States
EU ETS	European Union Emissions Trading System
GDP	Gross domestic product
GHG	Greenhouse gas
$GtCO_2e$	Gigatonnes of carbon dioxide equivalent
GVA	Gross value added
GW	Gigawatt
HBI	Hot-briquetted iron
H-DRI	Hydrogen-based DRI
ICT	Information and communications technology
IED	Industrial Emissions Directive
IEPR	Industrial Emissions Portal Regulation
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre

JRC-IDEES	JRC Integrated Database of the European Energy System
$KgCO_2e$	Kilograms of carbon dioxide equivalent
Kt	Kilotonne
LNG	Liquified natural gas
LTS	Long-term strategy
Mt	Million tonnes
MW	Million watts
NAPCP	National air pollution control programme
NECD	National Emission reduction Commitments Directive
NECP	National energy and climate plan
NEEAP	National energy efficiency action plan
NG-DRI	Natural gas-based DRI
NGO	Non-governmental organisation
NMVOC	Non-methane volatile organic compound
NO_x	Nitrogen oxides
NZIA	Net-Zero Industry Act
OPEX	Operational expenditure
PaMs	Policies and measures
PFAS	Per- and polyfluoroalkyl substances
PPS	Purchasing power standard
PSV	Platform supply vehicle
R&D	Research and development
R&I	Research and innovation
RBMP	River basin management plan
RED III	Renewable Energy Directive (recast, 2023)
REACH Regulation	Registration, Evaluation, Authorisation and Restriction of Chemicals Regulation
RME	Raw material equivalent
SCM	Supplementary cementitious material
Seveso III	Directive 2012/18/EU on the control of major-accident hazards involving dangerous substances
SO_2	Sulphur dioxide
SO_x	Sulphur oxides
STEM	Science, technology, engineering and maths
TRL	Technology readiness level
TW	Terawatt
TWh	Terawatt-hour
UWWTD	Urban Wastewater Treatment Directive
WFD	Water Framework Directive
WFD (Waste)	Waste Framework Directive
WHO	World Health Organization
ZPAP	Zero pollution action plan

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Annex

Differences in data availability and statistical classifications mean that industrial activities are not defined consistently across all indicators and figures used in this report. The tables in this annex show how sector groupings relate to the underlying classifications nomenclature. They also indicate which sectors and sub-activities are included in various figures and indicators presented throughout the report, where such detail may be needed. This information supports comparability and helps readers interpret differences in reported outcomes across datasets.

Table A.1 Sector-to-figure coverage matrix for Figure 1.1

Report sector	Greenhouse gas emissions: IPCC source categories	Air pollutant emissions: NFR source categories	Final energy consumption: Eurostat energy balances activities	Water abstraction: NACE Rev.2	Hazardous waste: NACE Rev.2
Mining	1B1a, 2A5a	1B1a, 2A5a	Mining and quarrying	B	B
Manufacturing				C	
Metals	1A2a, 1A2b, 2C1-7	1A2a, 1A2b, 2C1-7	Iron and steel; Non-ferrous metals	Included within manufacturing aggregate C	C24-C25
Minerals (excluding mining)	1A2f, 2A1, 2A2, 2A3, 2A5c, 2A6	1A2f, 2A1, 2A2, 2A3, 2A5c, 2A6	Non-metallic minerals	Included within manufacturing aggregate C	C23
Chemicals	1A2c, 2B1-3, 2B5-7, 2B10	1A2c, 2B1-3, 2B5-7, 2B10	Chemical and petrochemical	Included within manufacturing aggregate C	C20-C22
Pulp, paper and wood	1A2d, 2H1, 2I,	1A2d, 2H1, 2I	Paper, pulp and printing; Wood and wood products	Included within manufacturing aggregate C	C16-C18
Food and drink	1A2e, 2H2	1A2e, 2H2	Food, beverages and tobacco	Included within manufacturing aggregate C	C10-C12
Other* all activities not allocated to the report's dedicated sector groups	2D3d, 2D3e, 2D3g, 2D3i, 2H	2D3d, 2D3e, 2D3g, 2D3i, 2H3, 2J	Transport equipment; Textile and leather; Machinery, Not elsewhere specified	Included within manufacturing aggregate C	C13-C15
Water and wastewater treatment	5D1-3	5D1-3	(a)	(a)	(a)
Waste management	5A, 5B1, 5B2, 5C1a, 5C1bi-vi, 5C2, 5E	5A, 5B1, 5B2, 5C1a, 5C1bi-vi, 5C2, 5E	(a)	(a)	(a)
Energy	1B1c, 1B2ai, 1B2b	1B1c, 1B2ai, 1B2b, 1B2c	(a)	(a)	C19

Notes: (a) Not included.
The mappings in Table A.1 represent the categories used for the analyses in this report. They do not imply exact equivalence between IPCC, NFR, Eurostat energy-balance and NACE classifications. For water abstraction, manufacturing is generally available only at the aggregate NACE section C level. The energy sector is generally treated separately from industry in statistical classifications. It is included in selected parts of the report where doing so provides a more complete picture of environmental pressures from large industrial point sources, herein emissions from these facilities. Waste and wastewater activities are excluded from the industrial waste-generation analysis because they primarily manage waste generated by other economic sectors and households. The energy sector in that analysis (C19) includes the manufacture of coke and refined petroleum products.

Table A.2 Sector-to-figure coverage matrix for selected figures of this report

Report sector	FIG 3.1 GHG emissions	FIG 3.2 Carbon intensity	TAB 3.4 Air pollutant emissions	FIG 3.5	FIG 3.6	FIG 3.9	3.10
Mining	x	x	x	x aggregated across sectors	(a)	x	x
Metals	x	x	x		x	x	x
Minerals (excluding mining)	x	x	x		x	x	x
Chemicals	x	x	x		x	x	x
Pulp, paper and wood	x	x	x		x	x	x
Food and drink	x	x	x		x	x	x
Other	x	x	x		x	x	x
Water and wastewater	x	x	X		(a)	(a)	(a)
Waste management	x		x		(a)	(a)	(a)
Energy	(a)	(a)	(a)	(a)	(a)	(a)	x

Note: (a) Not included.

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