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THE ROLE OF THE EUROPEAN INDUSTRIAL GASES SECTOR FOR THE EUROPEAN ECONOMY

A study in the context of the evolving Carbon Leakage Protection for the European Industrial Gases Association (EIGA)

24 NOVEMBER 2025

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Executive Summary

Context and objectives

Industrial gases (oxygen, nitrogen, hydrogen, argon, carbon dioxide, helium) are indispensable inputs across Europe's economy – from steel and chemicals to healthcare and food. Two production and supply models coexist: **insourced (captive) production** at the user's site and **outsourced (merchant) production** supplied by specialised providers.

Both the insourced and outsourced route have their merits: while insourced production can offer tight process integration and operational independence, merchant supply via the outsourced route typically enhances utilisation, reliability and emissions performance through networked assets, certified quality regimes and specialist safety management. Beyond day-to-day operations, industrial gases underpin decarbonisation (e.g., low-carbon hydrogen, oxygen-based processes) and strengthen resilience in crises, as illustrated by the surge in medical oxygen demand during COVID-19.

Because production is highly energy- and capital-intensive, evolving carbon cost and state aid regimes will materially shape competitiveness and sourcing choices across these models. This study quantifies the sector's economic footprint and assesses how recent and forthcoming policy changes – EU ETS free allocation reform, the Carbon Border Adjustment Mechanism (CBAM), national indirect cost compensation (ICC), and the new Clean Industrial Deal State Aid Framework (CISAF) – affect the level playing field between insourced and outsourced supply of industrial gases within the EU-27.

Economic contribution of the industrial gas sector

The EU-27 industrial gases (IG) sector (NACE 20.11) which covers the outsourced supply side of industrial gases, generated €21.2bn in revenue and €7.9bn in value added and directly employed c.40,100 people in 2024. Although modest in size relative to total manufacturing (c.0.3% of value added; c.0.1% of jobs), growth has outpaced industry averages since 2012. Production is geographically concentrated (notably France, Italy, Germany, Spain, the Netherlands, Poland), reflecting productivity and energy-cost differentials.

Beyond direct effects, upstream and induced linkages expand the footprint to €51.2bn in revenue, €21.0bn in value added and c.190,200 jobs in 2024. Industrial gases producers purchase a wide range of inputs (beyond electricity), and these flows propagate along EU value chains.

Foreign trade in most gases is limited (logistics and physics favour local supply), with the notable exception of rare gases. Demand is concentrated in manufacturing, chemicals and metallurgy, which together account for c.70% of European industrial gas consumption.

Why the level playing field matters now

EU carbon-leakage protection combines direct cost measures (free allocation under the EU ETS) and indirect cost measures (ICC for ETS pass-through in power prices). CBAM will progressively replace free allocation for a subset of products (including hydrogen), while ICC remains a Member State instrument under state aid rules. The interaction of these tools can unintentionally differentiate between insourced and outsourced production of the same gas made with the same technology which induces distortion and unfair competition between both production routes.

Asymmetries arise through unequal treatment of insourced and outsourced production

- **Direct cost protection for hydrogen under EU ETS & CBAM**: Outsourced hydrogen produced falls under the Hydrogen Benchmark and, crucially, **faces the CBAM reduction factor** that phases down free allocation from 2026 to 2034. Insourced refinery hydrogen can be treated differently (refinery benchmark), so the CBAM factor may not apply in the same way. Our scenarios indicate that potential differences in benchmark trajectories and the CBAM factor can create material divergences in the value of free allowances over 2026–2034. For refinery-related volumes provided by the IG sector alone, the resulting distortion can reach c.€1–2bn (NPV).
- **Indirect cost compensation (ICC)**: 14 ICC schemes operate across the EU including all large IG producing countries; however, only two industrial gases subsectors (hydrogen; inorganic oxygen compounds) are explicitly eligible. Many energy-intensive users that insource oxygen, nitrogen or argon (e.g., steel, copper, pulp, chemicals) do qualify – often using the same ASU/PSA technology as merchant suppliers. This creates a structural wedge: for example, a German copper plant's insourced oxygen via a cryogenic ASU received c.€11.8/t O_2 in 2024 (c.€37/MWh, c.46% of the average power price in 2024), while an outsourced supplier using the same technology was ineligible.
- **Temporary electricity cost relief under CISAF**: CISAF (in force since June 2025 to 31 Dec 2030) adds a further lever: temporary electricity cost relief for electro-intensive users. The measure follows a "50/50/50" rule – up to 50% of wholesale power price, for up to 50% of consumption, with an effective price floor of €50/MWh. Relief can be cumulated with ICC within overall aid caps. However, if temporary electricity cost relief is not made equally available to both insourced and outsourced industrial gas production, it risks creating additional distortions on top of those already arising under ICC.

Policy recommendations

This study assesses level-playing field issues in the context of carbon-leakage protection. This has two dimensions: externally, it concerns the position of EU industries vis-à-vis non-EU competitors; internally, it concerns competitive neutrality within the EU – here, in particular, between insourced and outsourced IG production. The existing carbon-leakage protection regime aims to maintain the competitiveness of EU industries subject to carbon pricing relative to producers in regions with lower or no carbon cost exposure. Adjustments to this regime should therefore be made with caution to avoid unintended competitive disadvantages both externally and internally while supporting the EU's climate objectives. With regard to a fair level-playing field for industrial gases we suggest:

- **Free allocation** remains an established instrument to mitigate leakage. By contrast, **CBAM** effectiveness is yet to be demonstrated and an export adjustment mechanism to shield EU exporters is still pending. It is therefore plausible that the EU has chosen, for the time being, to keep certain sectors outside CBAM until its effectiveness is proven. However, this current regulatory design creates an internal level-playing-field issue for hydrogen used in refineries: as long as refineries continue to receive full free allocation and remain outside CBAM, hydrogen supplied by IG companies to refineries should receive an equivalent level of free allocation to insourced refinery hydrogen.
- **Indirect Cost Compensation eligibility for industrial gas production should be aligned irrespective if produced on-site or not**. To maintain competitive neutrality, ICC eligibility should reflect comparable ASU/PSA processes for oxygen, nitrogen and argon**,** applying consistent treatment whether production is insourced or outsourced, thereby reducing regulatory-induced differences in sourcing.
- Furthermore, if Member States implement **temporary electricity cost relief under CISAF**, it should be applied symmetrically to insourced industrial gas production and outsourced supply to prevent additional distortions.

What this means for resilience

Industrial gases are local in logistics yet systemic in impact. A fair, technology-neutral application of carbon-leakage protection and temporary electricity relief can secure the sector's enabling role for European decarbonisation – while avoiding unintended shifts toward *form* (insource vs outsource) rather than efficiency. Done well, reforms will safeguard competitiveness across the supply routes that customers rely on today, and those they will need tomorrow.

1 Introduction and Background of the Study

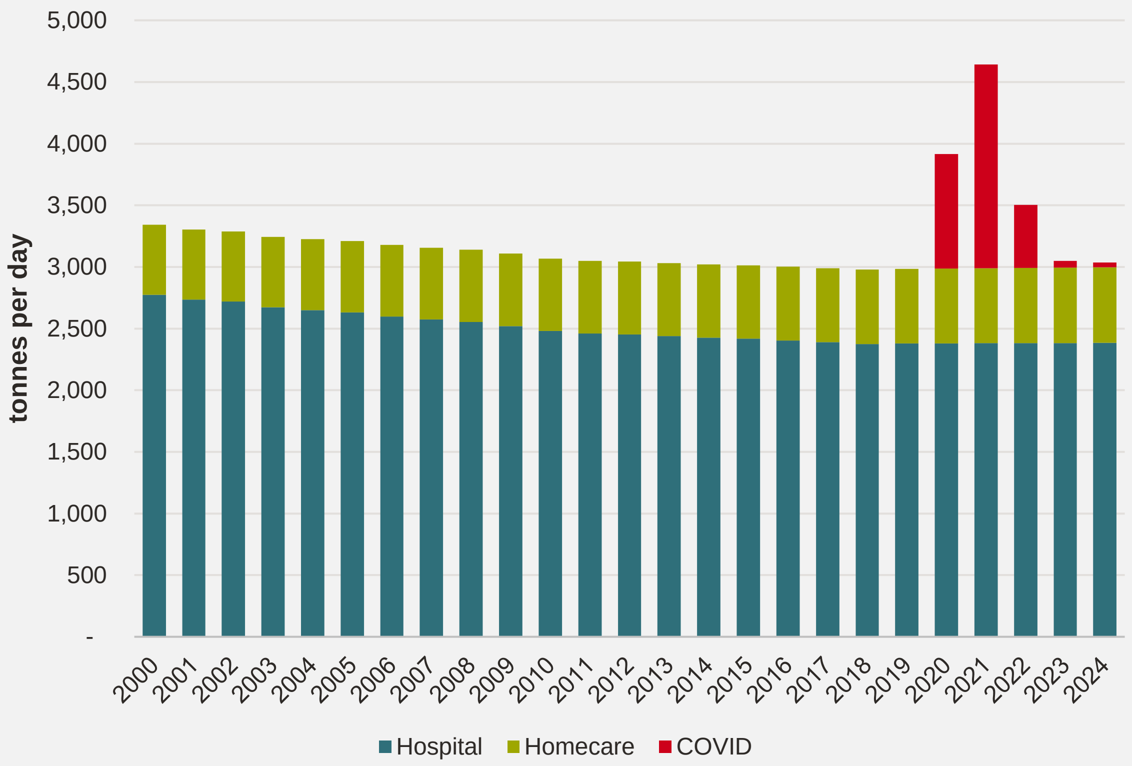
Industrial gases are gaseous chemical elements and compounds – such as oxygen, nitrogen, hydrogen, argon, carbon dioxide or helium – produced, purified, compressed or liquefied and supplied to industrial, medical and commercial users. They serve as process, reaction, protective or energy gases across a wide range of applications: for instance oxygen is used in steelmaking and wastewater treatment; hydrogen in hydrotreating and chemical synthesis; nitrogen for inerting in chemicals, food and electronics; argon for shielding in metallurgy and welding; carbon dioxide for carbonation and modified atmosphere packaging; and medical oxygen is a life-critical input in healthcare.

Owing to this breadth of essential uses, industrial gases are not merely auxiliary inputs – they are strategic enablers across the European economy and society. They underpin the functioning of vital infrastructures and value chains, from hospitals to semiconductor fabs, and play a critical role in ensuring operational continuity and crisis resilience. For example, during the COVID-19 pandemic, the robust and flexible supply of medical oxygen within the EU proved essential in avoiding life-threatening shortages as shown in the following case study.

EU's Oxygen Supply Resilience during COVID-19

Medical oxygen is an indispensable and irreplaceable therapy for hypoxaemia. During the COVID-19 pandemic, demand rose sharply worldwide and within the European Union, as shown in **Error! Reference source not found.**, which made reliable high flow supply critical for hospitals. Many parts of the world struggled to meet this additional demand; for example, in 2021 an estimated 78% of patients in South Asia who needed medical oxygen did not receive it, and in Eastern Europe and Central Asia the figure was about 52%.[1] Within the EU, by contrast, the surge was met without systemic outages because of its domestic industrial gases industry and its network of production and logistics. This experience underlines the sector's strategic relevance.

Figure 1 Medical Oxygen Demand, 2000-2024



Source: gasworld Business Intelligence

Beyond their stabilising function, industrial gases play a vital role in advancing Europe's broader economic and policy goals. They are central to industrial decarbonisation – from low-carbon hydrogen applications to oxygen-based combustion technologies that enhance energy efficiency and significantly cut CO_2 and NO_x emissions. These technologies are particularly impactful in hard-to-abate sectors such as steel, cement, glass, and waste treatment, and they also facilitate the deployment of carbon capture solutions. In parallel, industrial gases help

[1] Greenslade (2025).

reinforce Europe's strategic autonomy by reducing dependence on vulnerable or geopolitically sensitive imports, such as rare gases essential for electronics manufacturing.

Two production and supply models are common. In insourced (captive) production, gases are generated at the user's site for immediate own use – for example, refineries operating steam methane reformers for hydrogen, or steel plants running air separation units for oxygen. In the case of outsourced (merchant) supply, specialised providers (the Industrial Gases Sector) produce gases for external sale and deliver them via supplier-operated on-site plants, pipelines, bulk liquid logistics or cylinders.

Both routes have their merits: while insourced production can offer tight process integration and a higher degree of operational independence, merchant supply typically enhances utilisation, reliability and emissions performance thanks to multi-plant networks and specialist operations. In practice, providers operate high-efficiency assets with advanced process control and by-product recovery (e.g. argon or CO_2), improving resource efficiency and lowering emissions intensity. Networked infrastructure, on-site units backed by pipelines, bulk liquid and cylinder fleets, adds redundancy and maintains continuity during outages or demand spikes. Merchant models also offer scalability and flexibility through modular on-site units and swing volumes, ensure certified purities and traceability (including pharma and semiconductor grades), and embed rigorous safety and compliance regimes. Notably, the industry's safety performance has strengthened over decades: EIGA reports a ten-fold reduction in lost-time incident frequency since the late 1970s, supported by globally harmonised best-practice publications, underscoring the benefits of specialist operators running high-hazard cryogenic and high-pressure systems.[2]

Given the high energy intensity of industrial-gases production, energy costs, including carbon costs, are a key determinant of competitiveness, both for producers and for gas-consuming industries. Ongoing changes to carbon-leakage protection and state aid frameworks, such as the phase-down of free allocation, the implementation of the Carbon Border Adjustment Mechanism (CBAM), adjustments to indirect cost compensation (ICC) for ETS-related electricity price effects, and measures under the new Clean Industrial Deal State Aid Framework (CISAF), are therefore expected to influence the relative economics of insourced and outsourced industrial-gases supply.

The European Industrial Gases Association (EIGA) has commissioned Frontier Economics (Frontier) and Economic Trends Research (ETR) to assess these issues for NACE 20.11 (Manufacture of industrial gases). The study pursues two objectives:

- to quantify the sector's contribution to the European economy (value added and employment), and
- to analyse how recent and forthcoming regulatory changes affect the level playing field between outsourced and insourced production of industrial gases.

2 EIGA (n.d.)

The study is structured as follows:

- In Chapter 2, we first map EU production of relevant industrial gases and trade flows to frame our assessment. We then quantify the sector's direct effects – value added and employment within NACE 20.11 – and its indirect effects along the upstream supply chain, with a brief view on security of supply implications for downstream industries. These analyses are led by ETR.
- In Chapter 3, we analyse developments in direct carbon cost exposure and compensation (benchmark updates, the phase-down of free allocation, and the Carbon Border Adjustment Mechanism for hydrogen) and in indirect cost compensation for electricity-related carbon costs; we also examine potential asymmetries between outsourced and insourced routes and discuss implications of the evolving state aid framework. These analyses are led by Frontier.

2 Why Industrial Gases Matter: Economic Importance of the Sector for the European Economy

In this chapter, we begin by examining the production of relevant industrial gases in Europe and analysing the associated trade flows, to understand the sector's capacity, geographic distribution, and integration into international markets. Building on this foundation, we assess the direct effects of industrial gas production – namely, the immediate contributions to value added and employment generated within the sector itself. We then turn to the indirect effects along the upstream value chain, which arise from the supply of intermediate goods and services from other industries to industrial gas producers. Finally, we explore the implications for security of supply in Europe by analysing the downstream sectors that rely on industrial gases as a critical input for their own production processes.

2.1 Production and trade analysis

We carry out an analysis of developments in production and foreign trade for the following industrial gases:

- Argon
- Rare gases (excluding argon)
- Hydrogen
- Nitrogen
- Oxygen
- Carbon dioxide
- Nitrogen oxides

The analyses are carried out for the EU27. Regional production focuses (countries) are mentioned in the text. The analyses in this chapter are mainly based on PRODCOM statistics from Eurostat (2025a). These statistics consist of two publications: on the one hand sold production, exports and imports (ds-056120), and on the other, total production (ds-056121). Since production values are only available for sold production, the production values for total production are derived based on the prices for sold production and the total production volume. In addition, information on the countries of destination and origin of the trade flows from Gasworld (2025a) is used. As the analysis of individual gases is very detailed, all relevant industrial gases will be considered together at this point. A differentiated analysis for each individual gas can be found in Annex A.1.

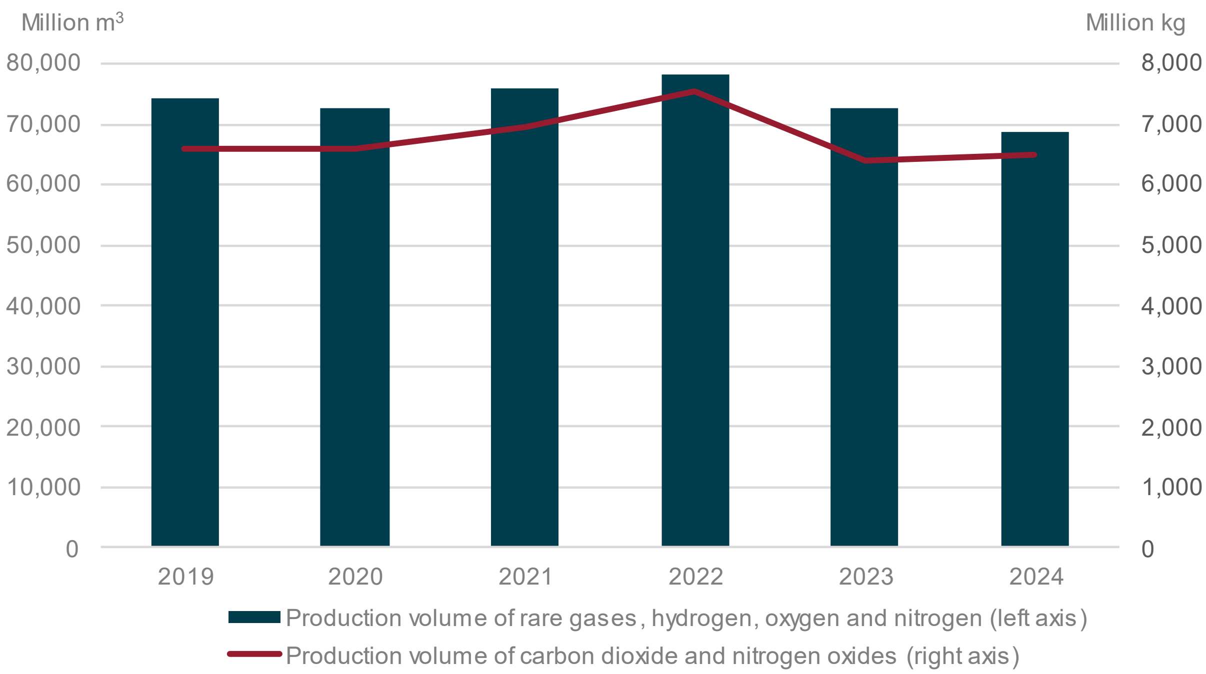
Figure 2 illustrates the development of industrial gas production volumes in the EU27 between 2019 and 2024.[3] Two separate axes are used because the gases shown are measured in

[3] Reliable data for rare gases other than argon is only available from 2019 onwards. Therefore, the analysis is limited to this period. However, Annex A.1 contains a separate analysis of the period from 2012 to 2024 for all other gases.

different physical units: the main industrial gases – argon, hydrogen, oxygen, and nitrogen – are recorded in million cubic meters (left-hand axis), while carbon dioxide and nitrogen oxides are measured in million kilograms (right-hand axis). The production of rare gases, hydrogen, oxygen, and nitrogen remained relatively stable during this period, ranging between around 69 and 78 billion m^3. After a modest increase in 2021 and 2022, volumes declined again in 2023 and 2024, reaching the lower end of the range. By contrast, production of carbon dioxide and nitrogen oxides followed a somewhat different path: after a slight rise in 2020 and 2021, output peaked in 2022 at over 7.5 million kilograms before falling back in 2023. The most recent data for 2024 point to a modest stabilization. Taken together, the figure shows that while the main industrial gases are consistently produced in large quantities to meet steady demand across industry, by-product gases such as carbon dioxide and nitrogen oxides are subject to somewhat stronger cyclical fluctuations.

Production of industrial gases in the EU27 is heavily concentrated in a few countries. Germany is the largest producer for nearly all major gases: it accounted for 23.2% of argon, 24.4% of hydrogen, 25.8% of oxygen, and 27.7% of nitrogen production in 2024. Other important producers include France, which is a key player in nitrogen and rare gases; Italy, especially in nitrogen; and Belgium and the Netherlands, which contribute significantly to oxygen, hydrogen, and carbon dioxide output. Spain and Poland are also relevant producers, particularly for carbon dioxide and rare gases. In the case of carbon dioxide specifically, the Netherlands (20.1%), Spain (16.2%), and Germany (14.1%) dominate, with France and Poland following closely behind.

Figure 2 Volume of industrial gases production in the EU27

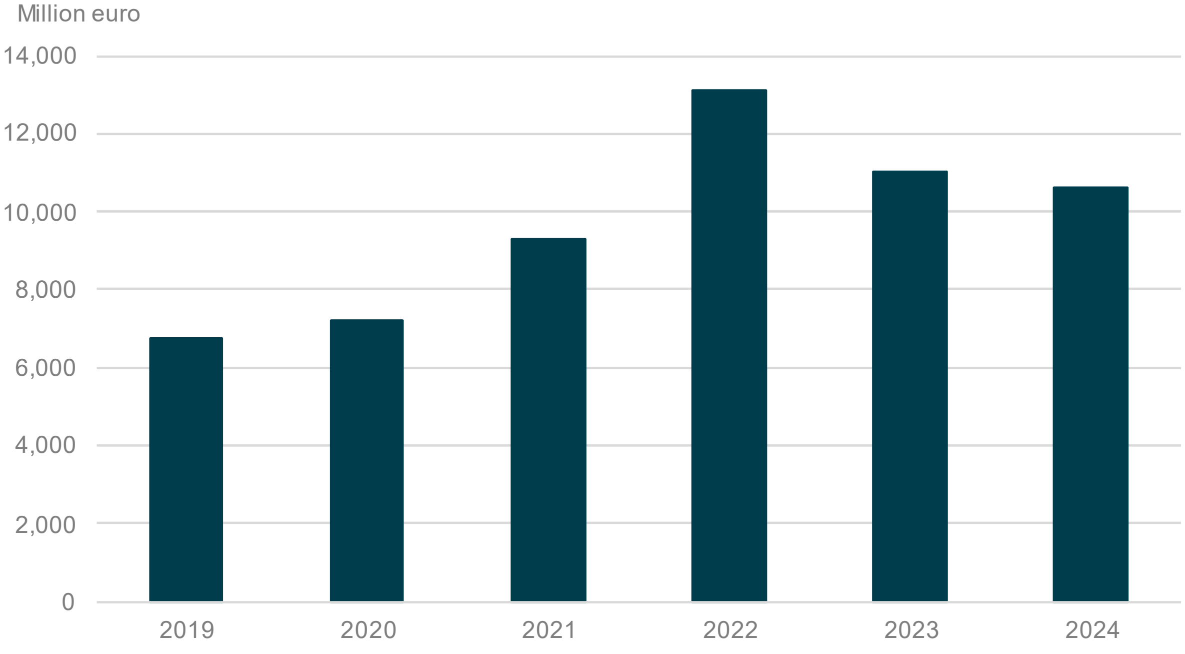


Source: Eurostat (2025a)

Note: m³ for Ar/H_2/O_2/N_2; kg for CO_2/NOx

Figure 3 presents the production values of industrial gases in the EU27 between 2019 and 2024.[4] In contrast to the previous figure, which depicted physical production volumes, this chart shows the corresponding monetary values in million euros. From 2019 to 2020, production values were relatively low and stable, fluctuating between €6.7 and €7.2 billion. Beginning in 2021, however, values rose sharply, reaching a peak of more than €13 billion in 2022 – nearly double the level of 2019. In 2023 and 2024, production values declined somewhat but remained well above the pre-2020 average. The comparison of both figures highlights that economic performance in the sector is not solely determined by production volumes. Prices, cost structures, and product mix strongly influence production values. The sharp increase after 2020, despite relatively stable physical quantities, indicates that price effects and market conditions played a decisive role, reflecting both energy price developments and rising demand for specific industrial gases in key customer industries.

Figure 3 Value of industrial gases production in the EU27



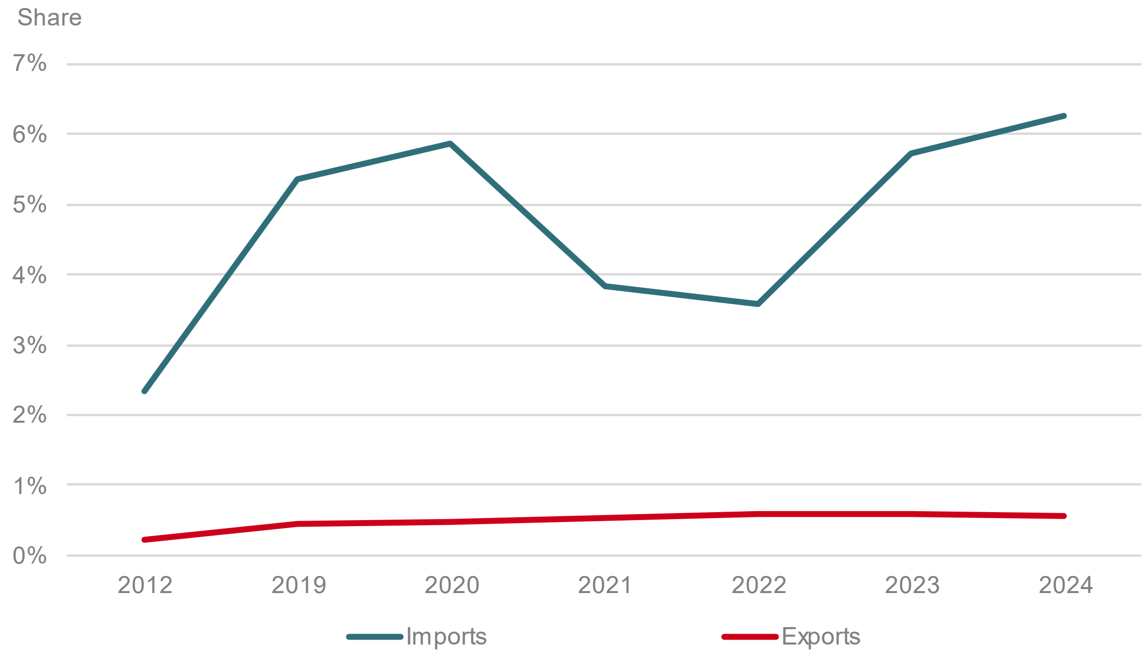
Source: Eurostat (2025a)

Figure 4 shows the development of import and export values of industrial gases as a share of their total production value in the EU27 between 2019 and 2024. Imports accounted for between 3.6% and 6.3% of total production value during this period. After reaching almost 5.9% in 2020, the share declined markedly in 2021 and 2022 to below 4%, before recovering

4 Production values in this chapter and Annex A.1 are calculated based on PRODCOM statistics, which typically use the manufacturing prices of products to determine production values. In contrast, the revenue of industrial gas manufacturers calculated in chapter 2.2 is based on the market prices achieved and, in addition to the industrial gases covered in this chapter, also include the production of sulphur trioxide, inorganic oxygen compounds of non-metals as well as liquid air and compressed air. In addition, revenue from secondary activities may also be included.

again in 2023 and 2024. Exports, by contrast, have remained very low throughout the period, never exceeding 0.6%. These very low values reflect the specific characteristics of the industrial gases sector. Industrial gases are generally consumed at or near the location where they are produced. As a result, manufacturers tend to be located close to their customers, and international trade plays only a minor role compared to most other industrial products. The only industrial gases traded to any significant extent are rare gases, particularly helium, which by far dominates Europe's foreign trade in this sector.

Figure 4 Share of foreign trade in industrial gases in the production value in the EU27



Source: Eurostat (2025a)

However, despite the minor importance of foreign trade, the most important trade partners are other European countries, which account for the vast majority of both imports and exports of industrial gases. The United Kingdom is the dominant partner for rare gases, oxygen, and nitrogen exports, while it also represents an important supplier for several gases. Switzerland plays a central role in nitrogen imports, whereas Norway is the most important external supplier of carbon dioxide.

2.2 Direct effects

In this chapter we analyse the direct effects which capture the immediate economic contributions generated by industrial gas production itself in the EU27. They encompass the revenue and value added created within the sector through its core activities, as well as the employment sustained by these operations. By focusing on the direct effects, it is possible to quantify the sector's standalone economic footprint before considering the wider linkages to other industries. These results provide the baseline for understanding the full impact of industrial gas production on the European economy.

As Figure 5 shows, the European industrial gases sector, classified under NACE class 20.11 – Manufacture of industrial gases, is estimated to have generated approximately €21.2 billion in revenue, contributed around €7.9 billion in value added, and directly employed about 40,100 people across the EU27 in 2024. Revenue reflects the total turnover generated by the sale of industrial gases, value added measures the sector's direct contribution to the European economy by capturing the difference between total output and the value of intermediate inputs, and employment represents the number of people directly working in industrial gas production. Together, these indicators provide a comprehensive picture of the sector's immediate economic footprint.

Figure 5 Direct effects of the production of industrial gases in 2024

Source: Eurostat (2025b), ETR

Although the production of industrial gases makes up only a relatively small share of total European manufacturing – it accounts for around 0.3% of value added and 0.1% of employment – it plays an essential role in supporting many other industries.[5] Despite its modest size, the sector has developed dynamically in recent years. Between 2012 and 2024, real gross value added increased by 41.2%, and employment rose by 33.5%. By contrast, manufacturing as a whole grew far more slowly over the same period, with real gross value-added expanding by only 22.6% and employment by just 3.7%.

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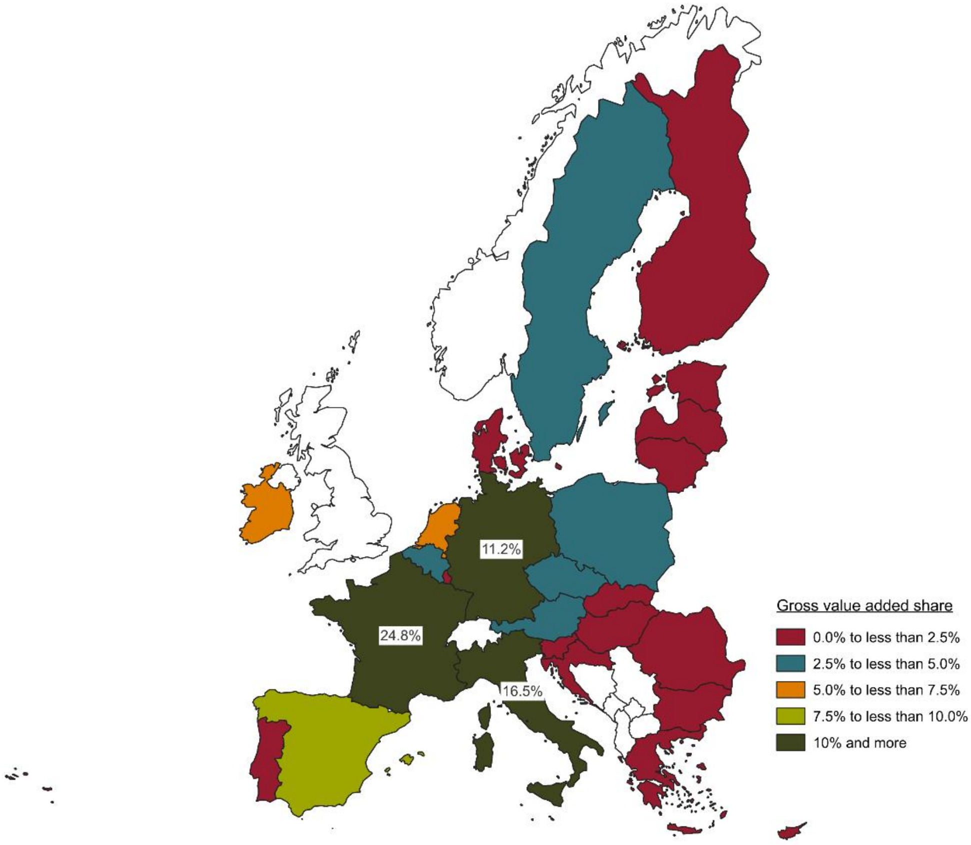
5 These effects are analysed in chapter 2.4.

The statistical foundation for these sector figures is basically the Structural Business Statistics (SBS) published by Eurostat (2025b). At present, SBS data on the 4-digit level are available only up to the year 2023. To obtain estimates for 2024, the most recent official figures were extrapolated using financial data from the annual reports of companies listed under NACE code 20.11. This approach allowed for an update of key indicators at the EU27 level. However, for certain EU member states, 2023 values had to be partially estimated due to missing data caused by anonymisation in the Eurostat database. These methodological adjustments ensure that the presented figures are as complete and up to date as possible, while remaining consistent with the official statistical framework. Since company information at country level is usually only available for a few companies and is often too incomplete to identify meaningful trends, the projections up to 2024 will only be carried out at EU27 level. The distribution among the individual countries will then be based on the country shares in the official Eurostat data for 2023.[6]

Figure 6 shows the distribution of gross value added (GVA) generated by the production of industrial gases across EU Member States, and Figure 7 shows the corresponding figures for employment. The distribution of gross value added and employment in the industrial gases sector (NACE 20.11) across the EU27 shows a clear concentration in a handful of countries. France holds by far the largest share, contributing 24.8% of GVA and 29.5% of employment, followed by Italy with 16.5% and 12.4%, respectively. Germany, while the leading country in terms of production volumes for most industrial gases, ranks only third when measured by economic weight, accounting for 11.2% of GVA and 13.4% of employment. This reflects the fact that, despite its strong production base, structural factors, particularly high energy prices, and regulatory requirements reduce the value added that can be generated in Germany compared to other locations. Other notable contributors include Spain (8.3% GVA, 8.9% employment), the Netherlands (5.1% GVA but only 2.8% employment), and Poland (4.7% GVA, 7.4% employment). While Poland shows a relatively high workforce share compared to its economic contribution, indicating a more labour-intensive structure, the opposite is true for the Netherlands. There, a comparatively small share of employees generates a high share of value added, pointing to high productivity levels in the Dutch industrial gases sector compared to the European average. Smaller shares are distributed among countries such as Belgium, the Czech Republic, Ireland, and Austria, while many Eastern and Baltic member states play only a marginal role or even showing negligible or no activity.

6 The figures for the manufacturing sector as a whole are taken from the national accounts (see Eurostat 2025c). The nominal gross value added of NACE class 20.11 – Manufacture of industrial gases, which is based on SBS, was adjusted for price changes using the manufacturing sector's GVA deflator in order to obtain the real value-added development.

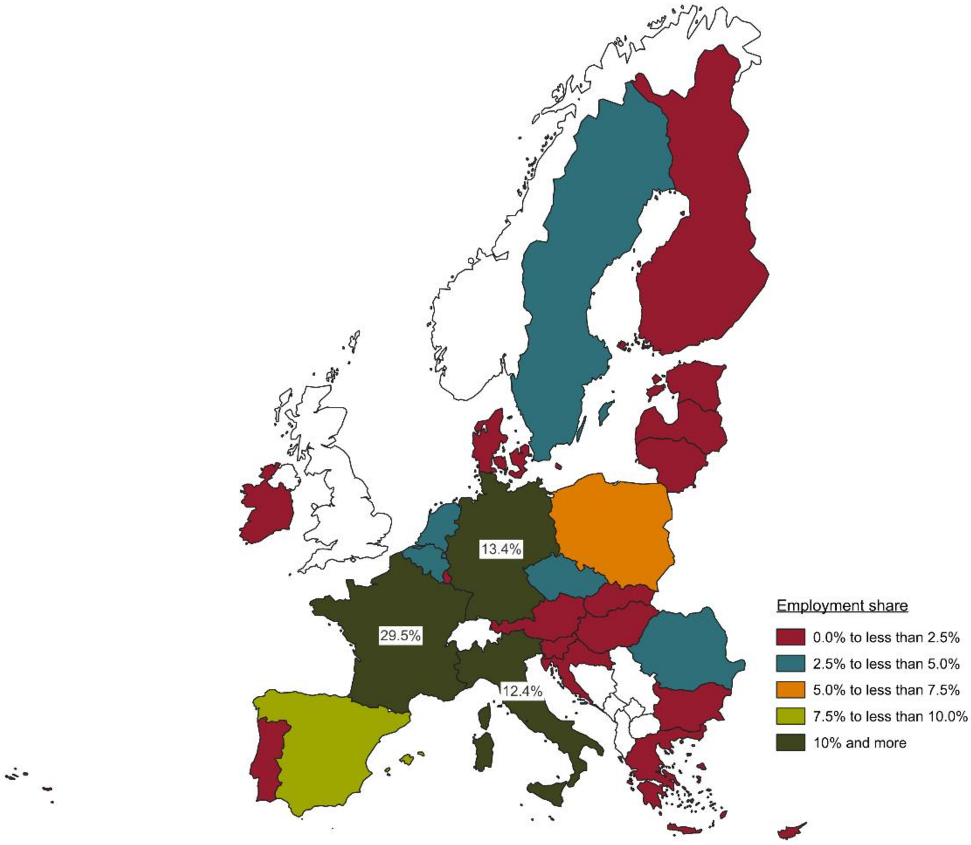
Figure 6 Distribution of GVA in the industrial gases sector in the EU27



Source: Eurostat (2025b), ETR

Note: Percentages reflect each country's share out of total EU27 levels.

Figure 7 Distribution of employment in the industrial gases sector in the EU27



Source: Eurostat (2025b), ETR

Note: Percentages reflect each country's share out of total EU27 levels

2.3 Upstream effects

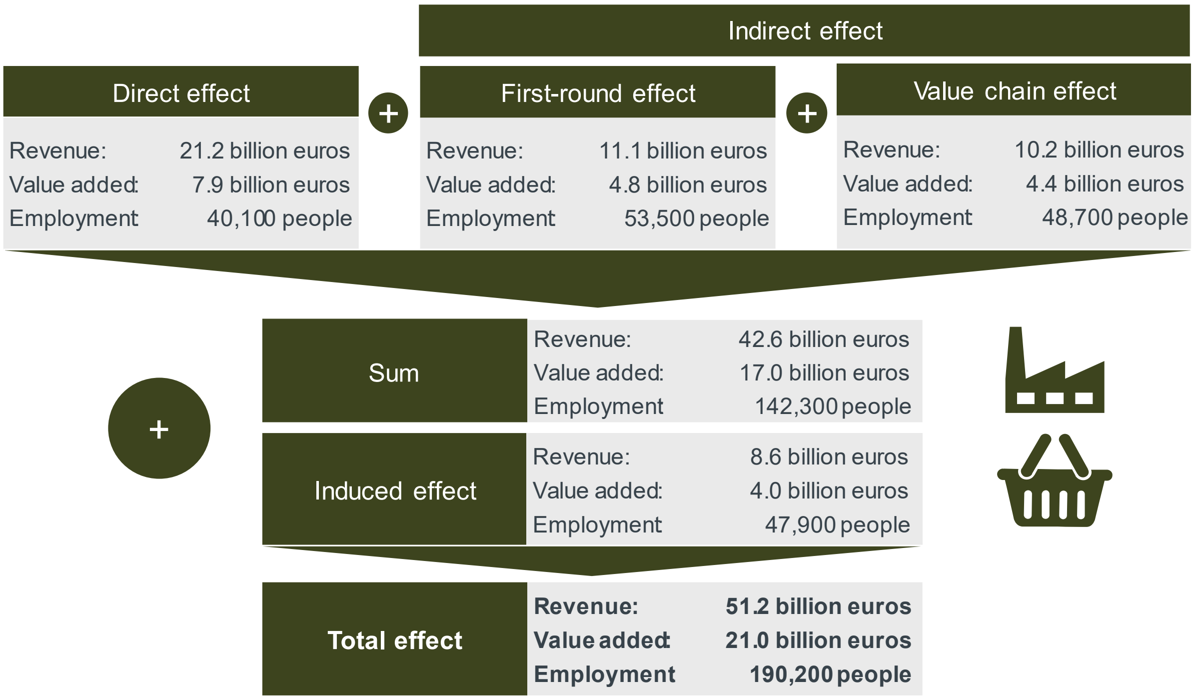
In this chapter, we conduct an analysis of the upstream economic effects of industrial gas production. The upstream effects arise from the demand by industrial gas manufacturers for intermediate goods and services provided by other companies.

Companies in the industrial gases sector require a range of intermediate inputs, which generate additional production in the supplying industries. Although electricity, natural gas and air are the main industrial inputs in the immediate production process, there are a number of products and services that are used by industrial gas manufacturers. These include, for example, banking and insurance services, as well as legal, tax and management consulting. In this respect, the intermediate input requirements of industrial gas production go far beyond only electricity, natural gas and air. In 2021, energy purchases accounted for 19% of the industry's total intermediate inputs. Due to the sharp rise in energy prices following the war in Ukraine, this share increased to 25% in 2022 and fell only slightly to 24% in 2023.[7] We assume that this proportion has remained constant until 2024. The manufacture of industrial gases is therefore a highly energy-intensive industry. Compared with other sectors, its energy intensity, defined as the share of energy costs in value added, is exceptionally high at 44.2% in 2023. In manufacturing as a whole, this share amounts to only 8.0%. Even in other industries that are typically classified as energy-intensive, such as the paper industry (21.1%), the chemical industry overall (21.9%), and glass manufacturing (20.0%), energy intensities are significantly lower than in the industrial gases sector (see Eurostat 2025b).

The use of intermediate inputs in the production of industrial gases creates value added and employment among direct suppliers – the so-called **first-round effect**. As Figure 8 shows, the first-round effect amounts to a revenue of €11.1 billion and a resulting value added of €4.8 billion in the EU27. To generate this value added, 53,500 workers are required.

7 See Eurostat (2025b).

Figure 8 Upstream effects of the industrial gases sector in the EU27 in 2024



Source: ETR

However, these suppliers themselves require intermediate products from other industries, which in turn purchase inputs from further upstream sectors. This chain of transactions along the entire value chain produces additional revenue, value added, and employment beyond the first-round effects. This is known as the **value chain effect**. In total, this stage generates a revenue of €10.2 billion, corresponding to value added of €4.4 billion and supporting 48,700 employees. The first-round effect and the value chain effect together form the indirect effect of the overall economic impact chain.

In addition to these upstream effects, employment and income generated across the entire value chain increase household purchasing power. A part of this additional income is spent on consumption, stimulating further production in the economy. This process is referred to as the **induced effect**. The induced effect is estimated to generate €8.6 billion in revenue, resulting in value added of €4.0 billion and safeguarding 47,900 jobs.

Altogether, the direct, indirect, and induced effects form the total economic footprint of the industrial gases industry in Europe. In 2024, this footprint corresponds to a revenue of €51.2 billion and value added of €21.0 billion, with approximately 190,200 people employed as a result.

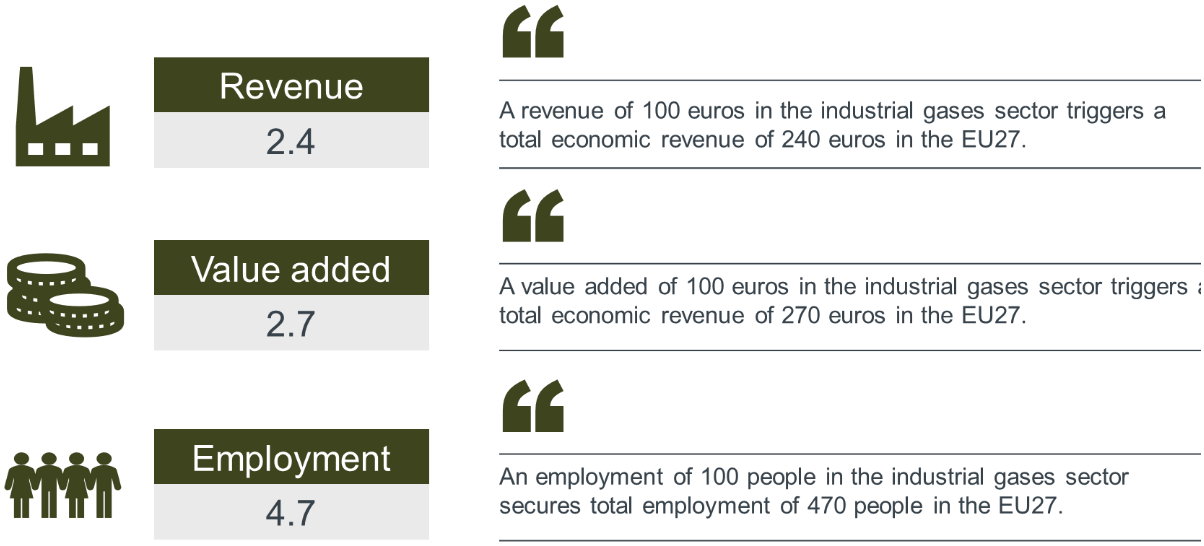
An input-output analysis is carried out to estimate these effects. This is an established method for estimating production, value added and employment in the input chain, as well as income-related effects.[8] The sectoral interdependence structures from the input-output table for the EU27 for 2019 are used to carry out the analysis.[9] However, the input-output table only covers economic interdependencies at the division level (2-digit NACE classification). In the case of the manufacture of industrial gases (NACE 20.11), the higher-level division is the chemical industry. In order to take account of the special input, structures involved in the manufacture of industrial gases, the industrial input interdependencies in the input-output table are adjusted to reflect the fact that electricity is the main input required. However, the input structures of the chemical industry as a whole are used as a basis for industrial products and services purchased.

By comparing the total effects to the direct effects, economic multipliers can be calculated. For the industrial gases sector, the estimated revenue multiplier is 2.4, the value added multiplier is 2.7 and the employment multiplier is 4.7 (see Figure 9). This implies that every €100 of direct output from the industrial gases sector generates around €240 of total revenue throughout the European economy. Likewise, €100 of direct value added in the sector results in roughly €270 of value added across all industries. Furthermore, 100 direct jobs in the industrial gases sector support approximately 470 jobs in the wider economy. For every €100 of direct revenue generated in the manufacture of industrial gases, a further €140 of revenue is created in other sectors of the EU-27 economy. Similarly, for every €100 of value added in the sector, an additional €170 of value added is generated elsewhere in the economy. Moreover, the employment of 100 people in the industrial gases sector supports around 370 additional jobs across the wider economy.

8 See Miller, Blair (2009). A more detailed methodological explanation of the input-output methodology can be found in Annex B .

9 See Eurostat (2025c). Although input-output tables are also available up to 2022, these are not suitable for examining the average supply relationships between industries due to the considerable distortions in supply relationships resulting from the coronavirus pandemic and the war in Ukraine, as well as the associated price fluctuations for (energy) intermediate inputs.

Figure 9 Multiplier effects of the industrial gases sector



Source: ETR

When comparing these multipliers with other industries, it is striking that the employment multiplier for industrial gas production is particularly high. Across the chemical industry as a whole, it stands at 4.2, while in the automotive industry it is 3.5 and in machinery 2.8.[10] This is due to the fact that the industrial gases sector is very capital-intensive and therefore has high production and value added per employee. As a result, indirect effects are triggered in the input chain and effects induced by consumer spending are triggered in sectors that have significantly lower productivity, which in turn generates high employment effects in those sectors.

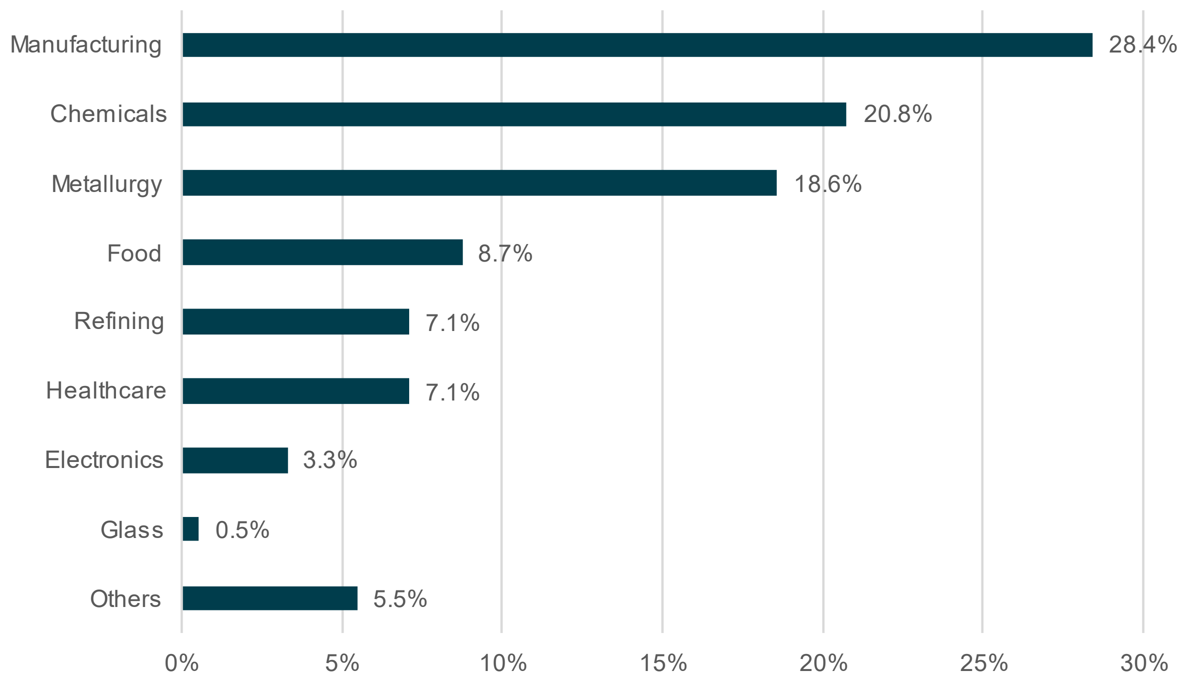
10 In order to compare the results, the multipliers mentioned here for the other industries were calculated using the same methodological approach as for industrial gas production.

2.4 Downstream effects

In this chapter, we analyse the customer structures for industrial gases. The focus is on the most important economic sectors that require industrial gases as an important input product for their own production or services. This includes a large number of sectors that are mainly located in industry, but certain service sectors such as healthcare are also increasingly using industrial gases.

Figure 10 shows the industries with the highest demand for industrial gases in Europe in 2024. Manufacturing accounts for the largest part of the industrial gases market with a share of 28.4%, followed by chemicals (20.8%) and metallurgy (18.6%). Together, these three sectors account for almost 70% of European demand for industrial gases. This distribution has remained relatively constant over the last decades, meaning that no short-term changes have been observed or are expected in the near future. This means that the future prospects for industrial gas production in Europe depend to a large extent on the regional economic strength of these sectors. Although growing sectors such as healthcare and food also play a role, they cannot compensate for potential shortfalls in demand from industry.

Figure 10 Customer structure of the industrial gases market in Europe



Source: Gasworld (2025b).

Producers of industrial gases are generally located geographically close to their customers as the transportation of many gases over long distances is expensive and, in most cases, not physically possible. Due to high energy costs, with energy being the key input factor in the production of industrial gases, European producers of industrial gases are currently facing considerable challenges. It is a major problem that the majority of the production processes (exceptions are hydrogen production and the production of inorganic oxygen compounds of non-metals) and in particular the production of oxygen and nitrogen in Europe does not receive indirect carbon cost compensation.

Although many industrial gas customers' production processes receive cost compensation, the current high electricity costs must be passed on to customers because industrial gas production itself does not receive this compensation. Electricity costs in Europe are currently around twice as high as in China or the USA. As a result, the international competitiveness of customer industries is declining, and they could react by relocating production sites or even closing down. If their customers disappear, this will deprive industrial gas production in Europe of its business basis.

Together, the industrial sectors that are the most important customers of industrial gases (see Figure 10) account for 82.2% of revenue in the entire manufacturing sector and, together with healthcare, 22.1% of revenue in the entire commercial economy in the EU27.[11] Due to this high importance of regional demand for industrial gases in Europe, the most important demand sectors are examined in detail below. However, for reasons of clarity, only the three most important customers of industrial gas production are considered in detail here. These are manufacturing, chemicals and metallurgy, which together account for almost 70% of the demand for industrial gases in Europe. The other customer industries are considered in detail in Annex A.2.

2.4.1 Manufacturing

As Figure 10 shows, manufacturing is the most important consumer of industrial gases in Europe, accounting for 28.4% of total demand in 2024. It is a highly diverse field, encompassing a wide range of activities from the production of complex machinery and vehicles to the fabrication of precision components and everyday consumer goods. The sector provides essential inputs for almost every part of the economy, supplying materials, equipment, and finished products to industries such as construction, energy, transport, healthcare, and information technology. Its performance has a direct impact on Europe’s innovation capacity, trade balances, and global competitiveness. Moreover, manufacturing is a central driver of technological progress, with many of its branches leading developments in automation, digitalisation, and sustainable production. Statistically, the sector consists of several economic divisions according to the 2-digit NACE classification, including the following:

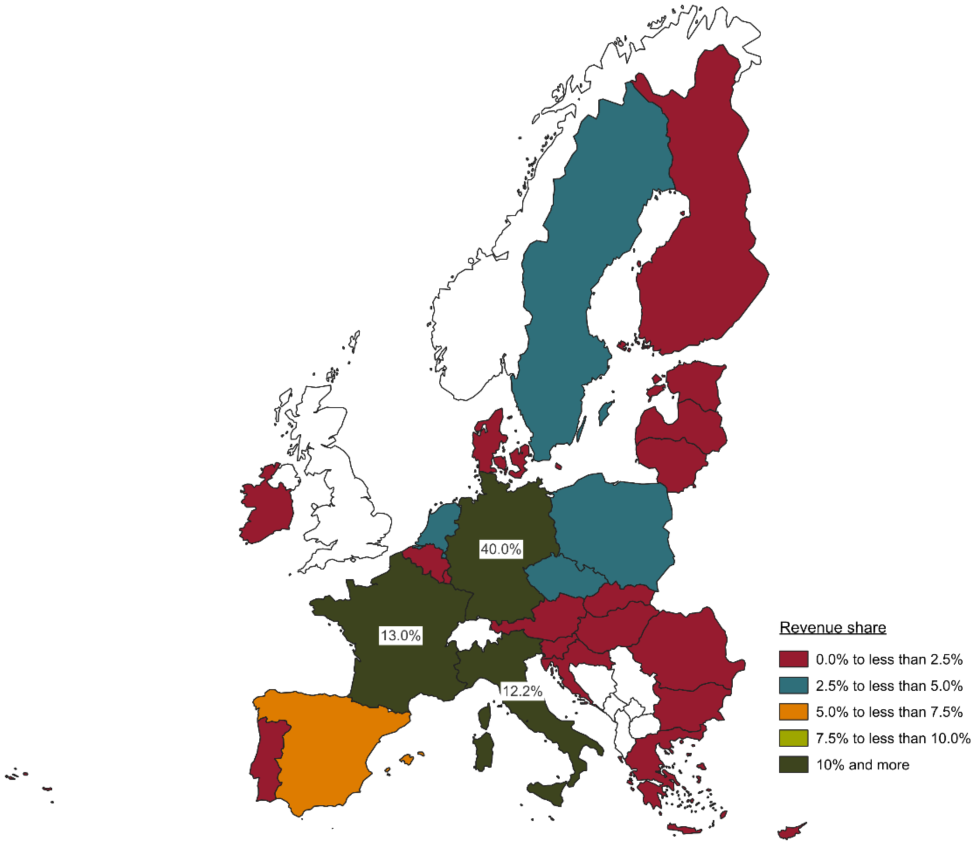
[11] All revenue and employment data presented in this chapter are taken from Eurostat (2025b).

- 25 – Fabricated metal products
- 28 – Machinery
- 29 – Vehicles
- 30 – Other transport equipment

In manufacturing, industrial gases are essential across a wide range of processes and applications, supporting both efficiency and product quality. In the field of fabricated metal products (NACE 25), gases such as oxygen, nitrogen, and argon are widely used for cutting, welding, and surface treatment. They enable precise thermal processes, protect materials from oxidation, and ensure strong, durable joints in metalworking. In machinery (NACE 28), industrial gases are important for heat treatment, hardening, and cooling, which are critical steps in producing high-performance mechanical components.

Protective atmospheres created by gases like nitrogen and hydrogen help maintain the integrity and precision of machine parts during production. The automotive industry (NACE 29) also relies heavily on industrial gases, particularly in welding and joining technologies for vehicle bodies, as well as in processes that improve material strength, corrosion resistance, and safety standards. Finally, in the production of other transport equipment (NACE 30), including ships, aircraft, and rail vehicles, industrial gases play a key role in advanced welding, cutting, and forming techniques. They contribute to the creation of lightweight yet robust structures and support innovative manufacturing methods needed to meet the high safety and performance requirements of the transport sector.

Figure 11 Market structure of manufacturing in the EU27 in 2023



Source: Eurostat (2025b), ETR
Note: Percentages reflect each country's share out of total EU27 levels

Figure 11 provides an overview of the market distribution of manufacturing in the EU. In 2023, the industry generated a total revenue of €3.25 trillion in the EU27 with 10 million people employed. This corresponds to 34.6% of revenue in the entire manufacturing sector (NACE section C). Of this, revenue of €1.3 trillion and thus 40.0% of European revenue were generated in Germany, with roughly 3.3 million employees and thus 32.9% of the industry's European workforce working there. Germany is therefore by far the strongest production location for manufacturing in Europe. It is followed by France and Italy with revenue shares of 13.0% and 12.2% respectively.

The fact that the share of revenue in Germany and France is higher than the share of employees indicates above-average productivity at these locations that is typically associated with highly automated and capital-intensive production. On average, this is typical for northern European locations, while locations in southern and south-eastern Europe generally have larger shares of employment than revenue, which points to lower average labour productivity and a stronger reliance on labour-intensive segments within sector.

2.4.2 Chemicals

The chemical industry ranks second among the most important customer industries, with a market share of 20.8% in 2024 (see Figure 10). It is a cornerstone of modern manufacturing and an essential link in numerous value chains, providing key materials and substances that serve as the foundation for countless other industries. Chemical products are used in everything from agriculture, construction, and transportation to electronics, healthcare, and consumer goods. They enable the production of advanced materials, fuels, coatings, adhesives, and countless formulations that improve product performance, durability, and safety. The sector also plays a crucial role in addressing global challenges, developing solutions for renewable energy, energy storage, sustainable agriculture, and environmental protection. Statistically, the chemical industry consists of three NACE divisions:

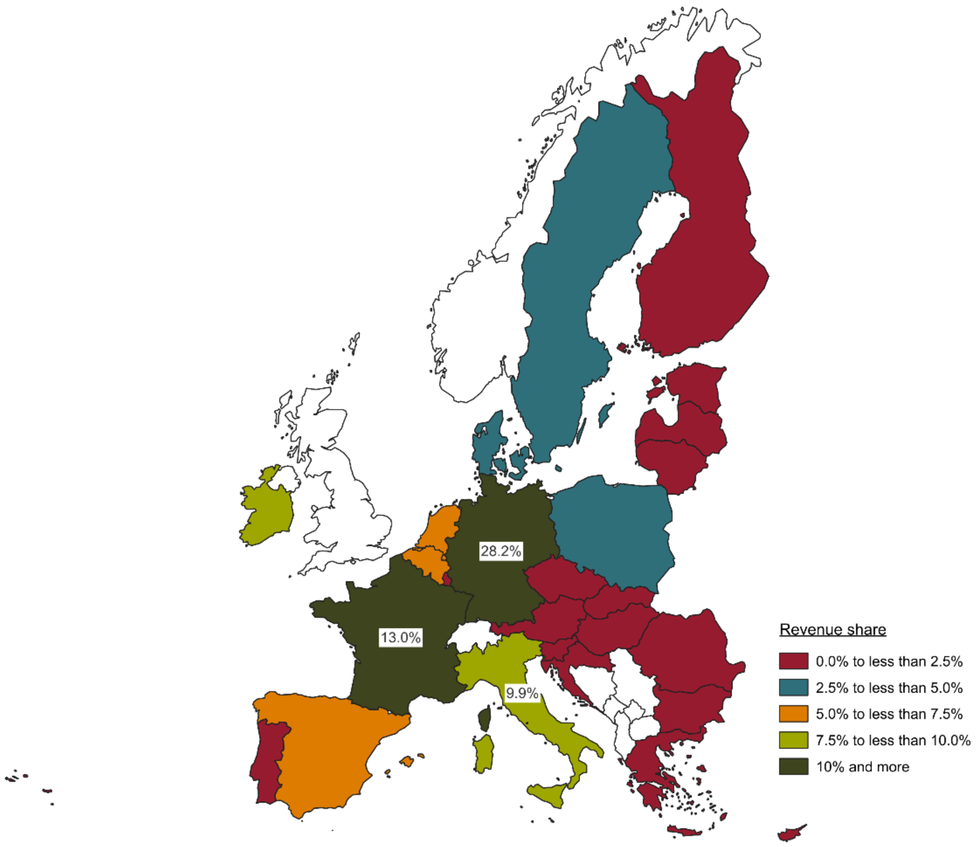
- 20 – Chemicals and chemical products
- 21 – Pharmaceuticals
- 22 – Rubber and plastic products

In the chemical industry, industrial gases are deeply integrated into both core production processes and supporting operations across various branches. In the manufacture of chemicals and chemical products (NACE 20), gases such as hydrogen, oxygen, nitrogen, and carbon dioxide are used as raw materials, reaction agents, or for process control. Hydrogen, for example, plays a key role in hydrogenation reactions and ammonia synthesis, while oxygen is essential for oxidation processes. Nitrogen is commonly applied to create inert atmospheres that prevent unwanted side reactions, enhance safety, and improve product purity. Carbon dioxide is often used for pH control, carbonation, or as a supercritical fluid in extraction processes. In the pharmaceutical sector (NACE 21), industrial gases support both research and manufacturing. Nitrogen and argon are used to maintain clean, inert environments during the synthesis and packaging of sensitive compounds, ensuring product stability and compliance with strict quality standards.

Additionally, carbon dioxide and liquid nitrogen are widely used for temperature control in storage and transport, especially for biologics and vaccines. High-purity gases are also critical in analytical applications such as gas chromatography and mass spectrometry, which are central to pharmaceutical quality control. The manufacture of rubber and plastic products (NACE 22) relies on industrial gases primarily for processing and forming. Nitrogen and carbon dioxide are used in injection moulding and extrusion to create microcellular foams, improving material properties while reducing weight. In addition, gases like hydrogen and oxygen can be involved in polymerization or surface treatment processes, such as plasma activation, which enhances adhesion or modifies surface characteristics. Overall, industrial gases contribute to improving product performance, process efficiency, and environmental compatibility in this sector.

Figure 12 illustrates the structure of the chemical industry within the EU. In 2023, the sector generated total revenues of €1.48 trillion across the EU27 (15.8% of revenue in the entire manufacturing sector), employing more than 3.5 million people. Germany alone accounted for €418 billion of this revenue – representing around 28.2% of EU-wide chemical revenues – and employed over 1 million people, or 28.8% of the sector's workforce. This confirms Germany's dominant position as the EU's leading location for chemical production. France and Italy follow at some distance, contributing around 12.2% and 10.5% of total revenue, respectively.

Figure 12 Market structure of chemicals in the EU27 in 2023



Source: Eurostat (2025b), ETR
Note: Percentages reflect each country's share out of total EU27 levels

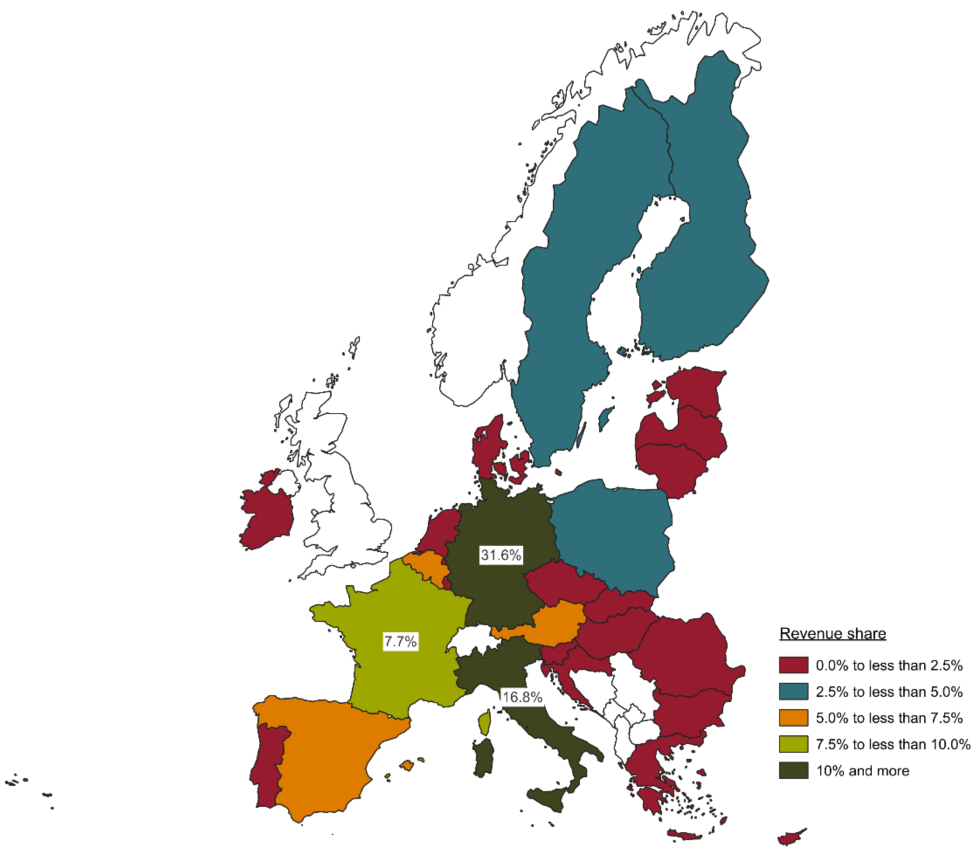
2.4.3 Metallurgy

Another important consumer industry for industrial gases is metallurgy, which accounted for 18.6% of European demand for industrial gases in 2024 (see Figure 10). Metallurgy forms the backbone of industrial production, as it provides the fundamental materials from which machinery, vehicles, infrastructure, tools, and countless everyday products are made. The sector encompasses the transformation of raw ores and recycled metals into steel, aluminium, copper, and other basic metals, which are then further processed into components and structures across virtually all manufacturing industries. Its products are indispensable for construction, energy generation, transportation, and the production of durable consumer goods. Metallurgy is also a key enabler of technological progress, supplying the high-performance alloys and specialty metals required for aerospace, renewable energy systems, electronics, and advanced engineering. Statistically, this industry consists of the manufacture of basic metals (NACE division 24).

In the metallurgy sector (NACE 24), industrial gases are essential for both primary metal production and secondary processing. Oxygen is widely used in blast furnaces and basic oxygen furnaces to intensify combustion and reduce coke consumption during iron and steel production. Its use significantly increases thermal efficiency and lowers emissions. In electric arc furnaces, oxygen is also used to decarburize molten steel and control slag formation. Nitrogen and argon play important roles in refining and alloying processes, particularly in stainless steel production, where they help remove impurities and control temperature without introducing reactive elements. Argon is frequently used for degassing molten metal, ensuring a cleaner, higher-quality final product.

Additionally, hydrogen is applied in the reduction of metal ores and in annealing processes, especially for non-ferrous metals, due to its reducing atmosphere that prevents oxidation. Carbon dioxide and other gases may also be used for cooling, cleaning, or as shielding gases during cutting and welding. Across the entire value chain – from raw material processing to final shaping – industrial gases contribute to energy efficiency, process stability, and the consistent quality of metallic products.

Figure 13 Market structure of metallurgy in the EU27 in 2023



Source: Eurostat (2025b), ETR
Note: Percentages reflect each country's share out of total EU27 levels

Figure 13 provides an overview of the metallurgy sector (NACE 24) within the European Union. In 2023, the industry generated total revenues of €470 billion across the EU27 (5.0% of revenue in the entire manufacturing sector) and employed over 880 thousand people. Germany once again stands out as the leading player in this industrial segment, contributing over €148 billion in revenue, which corresponds to 31.6% of the EU-wide revenue in metallurgy. In terms of employment, almost 260 thousand individuals were working in the German metallurgical industry, accounting for around 29.4% of the European workforce in this sector. These figures underline Germany's central role in Europe's metal production and processing landscape, which is supported by a strong infrastructure, advanced technology, and a well-integrated value chain. Italy and France follow in second and third place, generating 16.8% and 7.7% of the EU's metallurgical revenue, respectively. While their contributions are significantly lower than Germany's, both countries maintain strong national industries with a long tradition in steelmaking, non-ferrous metal production, and foundry technologies.

The data clearly indicate that the European metallurgy sector is relatively concentrated in a small number of core countries. Rather than being broadly distributed across the EU, economic activity in this industry tends to cluster around traditional industrial centres with established infrastructure, energy access, and deep integration into global value chains. This limited geographic spread points to a high degree of specialization and capital intensity but also suggests a vulnerability to regional disruptions within the supply network.

2.5 Summary and Conclusion

In this chapter we examined the European industrial gases sector from production and trade dynamics to its direct, indirect, and downstream economic effects. Overall production volumes remained relatively stable between 2019 and 2024. Production values, however, rose sharply after 2020 due to price effects and demand shifts, peaking in 2022. As industrial gases are mainly produced where they are consumed by customers for economic and physical reasons, foreign trade in industrial gases plays only a marginal role, with imports and exports accounting for a small share of production value – except for rare gases, particularly helium, which dominates cross-border flows.

Production is highly concentrated in a few countries, with Germany leading in volume but France and Italy contributing more in terms of value added and employment. In 2024, the sector directly generated approximately €20.4 billion in revenue and €9.3 billion in value added and employed around 39,500 people. Its broader economic impact is amplified through indirect effects in upstream value chains and induced effects due to consumer spending. Overall, the production of industrial gases triggers a revenue of €46.7 billion, an associated value added of €21.2 billion and provides employment for 176,600 people in the EU27 whose jobs depend directly or indirectly on the manufacture of industrial gases.

In addition, a large share of the industrial sector is heavily dependent on industrial gases. The most important customer industries are manufacturing, chemicals, and metallurgy, together accounting for almost 70% of industrial gas demand in Europe. But other sectors also rely on industrial gases. Therefore, although small relative to total manufacturing, the industrial gases sector is strategically indispensable. Its products are essential across critical value chains, from energy and chemicals to healthcare and metallurgy. At the same time, structural challenges – such as high European energy costs and limited carbon cost compensation – pose risks to competitiveness and supply security. The future stability of the sector will depend heavily on the resilience of its main customer industries and Europe's ability to balance cost pressures with the need for secure, sustainable production.

3 Why Carbon leakage protection matters: Level playing field for insourced and outsourced IG production

The analyses presented in Chapter 2 demonstrate that the IG sector makes a significant contribution to the European economy. To safeguard these contributions, it is essential to maintain a level playing field that allows the IG sector to compete fairly – both with non-EU producers and with industries that insource the production of industrial gases. *Insourcing* refers to a company's decision to produce gases such as oxygen, nitrogen, or hydrogen on-site rather than purchasing them from the IG sector.

Carbon leakage protection measures play an important role in this context, as they help prevent the relocation of production to regions with lower environmental standards. However, in light of the EU's climate objectives and the commitment to achieve net zero by 2050[12], these protection measures are undergoing significant change – for example through the gradual phase-out of free allocation and the introduction of the Carbon Border Adjustment Mechanism (CBAM). In this evolving policy environment, it is important to understand how these changes affect the competitiveness and level playing field of the industrial gases sector, particularly in comparison to insourced industrial gas production, which is not subject to the same regulatory treatment and thus entails a potential distortion between insourced and outsourced production:

To analyse these aspects, this chapter is structured as follows:

- **In Section 3.1**, we provide a brief overview of carbon leakage protection and the envisaged reforms to existing mechanisms.
- **In Section 3.2**, we analyse in detail the potential impact of changes to direct cost compensation for the industrial gases sector, with particular emphasis on hydrogen production.
- **In Section 3.3**, we examine the implications of the unequal treatment of industrial gases production under the indirect cost compensation scheme.
- **In Section 3.4**, we discuss the potential effects of revisions to the state aid guidelines under CISAF, in particular regarding temporary electricity price relief for energy-intensive users.

3.1 The relevance of carbon-leakage protection for industrial gases

3.1.1 Objectives and instruments of EU carbon-leakage protection

With the introduction of Phase I of the EU Emissions Trading System (EU ETS) in January 2005, the EU established a price on CO_2 emissions. Since then, progressively more economic

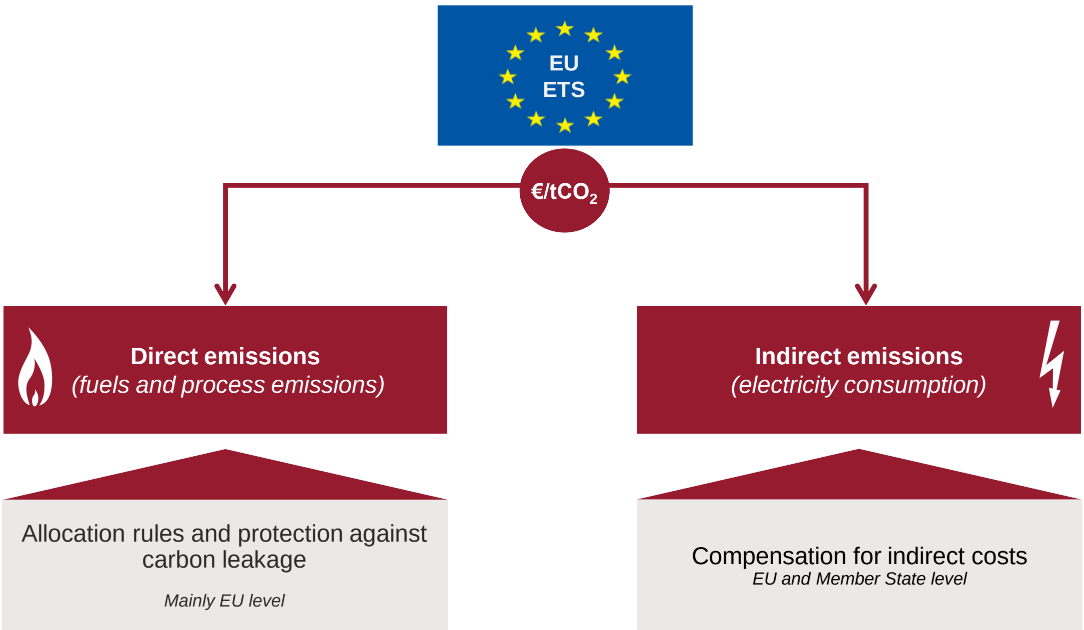
12 See Regulation (EU) 2021/1119 (European Climate Law), Article 2, which establishes the Union-wide objective of balancing greenhouse gas emissions and removals by 2050 (net zero)

activities have been required to hold European Union Allowances (EUAs) – tradable rights to emit one tonne of CO_2 each. The primary economic effect of the system is to embed a CO_2 cost into the production of goods and services covered by the ETS, thereby making carbon-intensive products more expensive and incentivising emissions reductions.

While this carbon pricing mechanism encourages the decarbonisation of economic activities, it also creates challenges. The most important is the risk that EU-based producers bear carbon costs that competitors in other countries outside the EU may not. In a globalised economy with large trade flows, this threatens the competitiveness of EU industries, particularly for trade-exposed sectors, and may lead to carbon leakage, where production shifts abroad to jurisdictions with laxer climate policies.

To mitigate the risk of carbon leakage, the EU has implemented two main types of protection measures: **direct cost compensation** and **indirect cost compensation**.

Figure 14 Overview of Carbon leakage protection mechanism



Source: Frontier Economics

Direct cost compensation addresses the cost of complying with the EU ETS by reducing or offsetting the need for firms to purchase EUAs. The primary tool under this heading has been the **free allocation** of allowances to sectors deemed at significant risk of carbon leakage. These allocations are intended to level the playing field with non-EU competitors while keeping the incentive to improve carbon efficiency.

Indirect cost compensation, by contrast, aims to address the pass-through of carbon costs in electricity prices. Power generators raise electricity prices to reflect the cost of EUAs they must purchase. This affects electricity-intensive industries through higher input costs. To counter this, EU state aid guidelines allow governments to compensate eligible companies for a share of these indirect costs, helping to maintain their international competitiveness while preserving the carbon price signal in the power sector.

Both direct and indirect carbon leakage protection measures have evolved over time and are currently undergoing significant transformation. The **Carbon Border Adjustment Mechanism** (CBAM) – in transition since October 2023 and due to enter its definitive phase-in 2026 – applies a carbon price to selected, carbon-intensive imports (e.g., steel, cement, aluminium, hydrogen) so imported goods bear a comparable carbon cost. For CBAM-covered products, free allocation of EUAs will be phased down and ultimately replaced by CBAM, as the rationale for domestic free allowances recedes once imports are priced. A detailed explanation of the functioning and effects of the CBAM is provided in Annex C

Indirect cost compensation addresses ETS costs passed through in electricity prices. Unlike CBAM, it is implemented by individual Member States under EU state aid guidelines. Scheme design and eligibility rules (covered sectors/products, electricity-intensity thresholds, compensation rates/caps) vary across countries and remain a key level-playing-field issue.

We will examine the expected effects of these policy changes on the industrial gases sector in the following sections.

3.1.2 Implications for insourced vs. outsourced IG production

Although the IG sector itself is not characterised by significant international trade (see also Figure 4), carbon leakage protection remains relevant due to the sector's close integration with energy-intensive industries that operate in globally competitive markets. The potential for carbon leakage therefore arises indirectly through the sector's customers, rather than through the trade exposure of the gases themselves.

Industrial gases such as oxygen, nitrogen, argon, and hydrogen are essential inputs for key industrial sectors including steel, chemicals, glass, and refining. These industries face international competition and are therefore considered at risk of carbon leakage under the EU ETS. Increases in CO_2-related production costs within the EU can directly affect their global competitiveness, particularly where comparable carbon costs are not borne by competitors outside Europe.

The industrial gases sector supplies these customers either through central pipeline networks or by operating on-site production units directly at customer premises. In many cases, however, the same gases can also be produced internally ("insourced") by the customer itself – for instance, through steam methane reforming in refineries or through air separation units in steel production. These insourced facilities are typically classified under the customer's primary activity rather than NACE 20.11 (e.g., insourced oxygen for steel is NACE 24.10). Depending on sector coverage and Member State design, these insourced facilities may be eligible for carbon-leakage protection.

By contrast, outsourced gas production – i.e. the production of the same industrial gases by a specialised supplier operating for instance a pipeline-connected plant – may not automatically receive the same form of protection, even though the underlying process, energy consumption and emissions profile are comparable. This results in a potential asymmetry between insourced and outsourced production: if the customer's in-house gas production is compensated for direct and/or indirect carbon costs while external suppliers are not, outsourcing becomes economically disadvantaged purely for regulatory reasons. In the following sections we will analyse these potential asymmetries in much more detail.

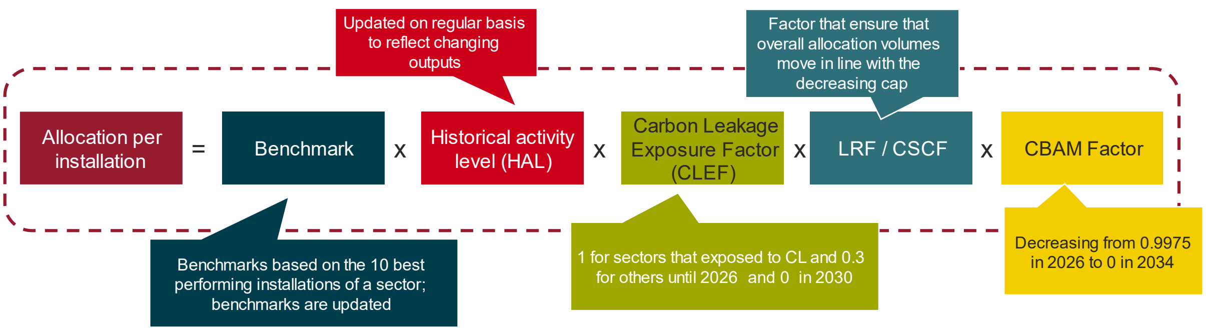
3.2 Direct cost protection: Free Allocation and CBAM effect

3.2.1 Mechanism and recent changes to Free Allocation

Under the EU ETS, compliance costs from direct (process and combustion) emissions are partly offset through free allocation to leakage-exposed installations, granted against product benchmarks and actual output. For products within the CBAM scope, this free allocation will be phased down and replaced by CBAM, which charges an equivalent carbon price on imports to preserve competitive neutrality. For sectors/products outside CBAM, free allocation continues (subject to updated benchmarks), maintaining protection while keeping incentives to decarbonise. Eligibility for free allocation is defined in the EU's carbon-leakage list for 2021–2030, set out in Commission Delegated Decision (EU) 2019/708, which also includes NACE code 20.11 (Manufacture of industrial gases) and specifically the production of hydrogen.[13]

The allocation of free allowances to industrial installations is based on a harmonised methodology, defined primarily in the Free Allocation Regulation (FAR) and implemented via detailed guidance documents. The allocation is ex-ante (based on historic data), and is calculated at the sub-installation level, following the basic formula set in Figure 15.

Figure 15 Free allocation to industrial installations



Source: Frontier Economics

13 See Regulation (EU) 2019/708.

The elements of the free allowance formula are the following:

- **Product Benchmark (BM)**: There are 52 product benchmarks covering standardised products (e.g. cement clinker, hydrogen, steel). Each benchmark reflects the average emissions intensity of the 10% most efficient EU installations in the sector. Where no product benchmark exists, “fall-back” benchmarks apply.
- **Historical Activity Level (HAL)**: The HAL reflects the installation's historical output, usually the median of annual production in the baseline period (2021–2022 for allocations from 2026–2030). For each product, the unit of activity is defined precisely in the sector-specific guidance (e.g. tonnes of 100% pure hydrogen, or CO_2-weighted tonnes for refineries).
- **Carbon Leakage Exposure Factor (CLEF)**: Installations in sectors deemed at risk of carbon leakage receive 100% of their benchmarked allocation (CLEF = 1). Non-exposed sectors receive a decreasing share, declining from 30% in 2026 to 0% by 2030.
- **Linear Reduction Factor (LRF)** and **Cross-Sectoral Correction Factor (CSCF)**: The LRF ensures that the individual free allocation decreases in line with the overall decreasing cap on the new allowances. Currently, the LRF is set to 4.3% and will increase to 4.4% in 2028.
- **CBAM Factor**: For sectors covered by the Carbon Border Adjustment Mechanism, free allocation is phased out gradually between 2026 and 2034. A decreasing CBAM factor is applied (e.g. 97.5% in 2026, 77.5% in 2029, 0% in 2034)

While the formula for calculating the free allowances is common to all products, differences across product stem from the following factors:

- **Benchmark value** (BM): Each product has a different emissions benchmark based on sector-specific data and technological differences.
- **Carbon leakage status**: Not all sectors are exposed to carbon leakage, and this affects the CLEF applied.
- **CBAM coverage**: Only a subset of sectors (e.g. steel, aluminium, cement, hydrogen) are covered by CBAM, influencing the phasing out of free allocation.

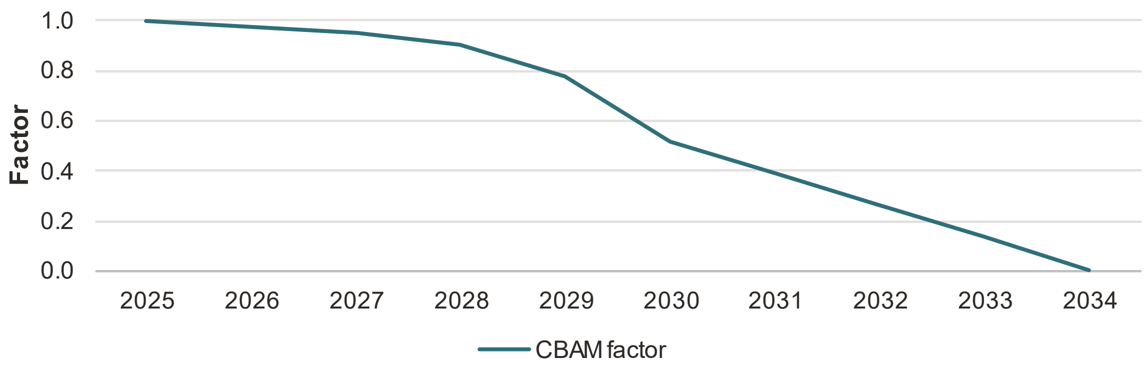
With the introduction of CBAM, the free allocation formula under the EU ETS is affected through a CBAM reduction factor taking value lower than 1 for certain sub-installations. The goods to which CBAM applies are listed in Annex I of the CBAM Regulation (EU) 2023/956[14]. The current list includes goods such as cement, iron and steel, aluminium, fertilisers, hydrogen, and electricity, and can be updated by the European Commission via delegated acts.

Where the sub-installation is covered by a product benchmark, the CBAM factor applies if that product benchmark corresponds to a product listed in CBAM. The CBAM factor progressively reduces the amount of free allocation between 2026 and 2034, starting at 97.5% in 2026 and

[14] See Regulation (EU) 2023/956

reaching 0% by 2034. Therefore, all else equal, sub-installations affected by this factor will receive a declining share of their benchmark based free allocation over time, in line with the CBAM phase-out schedule. The following figure illustrates the evolution of this factor, for those sub-installations to which the CBAM factor applies.

Figure 16 Evolution of the CBAM Factor



Source: Frontier Economics based on European Commission – Directorate-General Climate Action (2024).

CBAM is intended to replace free allocation over time. Because its effectiveness in ensuring a level playing field against imports is not yet established and a complementary export adjustment is still pending, coverage remains limited, and the regime is being phased in. In industrial gases, this creates an internal level-playing-field issue: outsourced hydrogen supplied by IG companies is subject to CBAM and a phase-down of free allocation, while insourced hydrogen produced within refineries is not treated in the same way. We examine this asymmetry in the following case study.

3.2.2 Case study: Distortion from uneven free allocation to hydrogen production

Hydrogen production is an activity where the impact of changing carbon leakage protection measures is particularly evident. Hydrogen is a good that is covered by the CBAM, and therefore the CBAM factor plays a role in the calculation of free allowances for installations that produce hydrogen.

This section analyses the regulatory implications for its production under the EU ETS. Before turning to the analytical exercises, it is important to clarify a key distinction: the difference between insourced and outsourced hydrogen production.

- **Insourced hydrogen** refers to hydrogen produced directly by an industrial facility for its own processes, rather than purchased from an external supplier. A particularly relevant sector is refining, where hydrogen is typically produced on-site via steam methane reforming and falls under the Refinery Products Benchmark (BM1). Other sectors with comparable insourcing practices include ammonia, methanol, and steel production, where hydrogen serves as an intermediate input in core process steps. No CBAM factor is applied (i.e., the CBAM factor is 1).

- **Outsourced hydrogen**, by contrast, refers to hydrogen produced in dedicated industrial-gas production units (NACE 20.11) and delivered as a saleable product. Today this is typically via steam methane reforming; over time, an increasing share will be renewable and low-carbon hydrogen (e.g., electrolysis using renewable electricity, or reforming with CCS). This production falls under the Hydrogen Benchmark (BM50) and the CBAM factor is applied.

This distinction is critical, as it shows that identical end products may receive different treatment under the free allocation rules. Precisely, this case study quantitatively explores the difference in the regulatory treatment of in- and outsourced H_2 production. These differences stem from:

- Possible differences in how the benchmark factor evolves for insourced hydrogen production in refineries compared with outsourced hydrogen produced by the industrial gases sector; and
- The application of the CBAM factor to outsourced hydrogen production, whereas insourced production is not subject to it.

Both of these aspects impact the number of free allowances received per unit of hydrogen produced, and hence the value of support schemes.

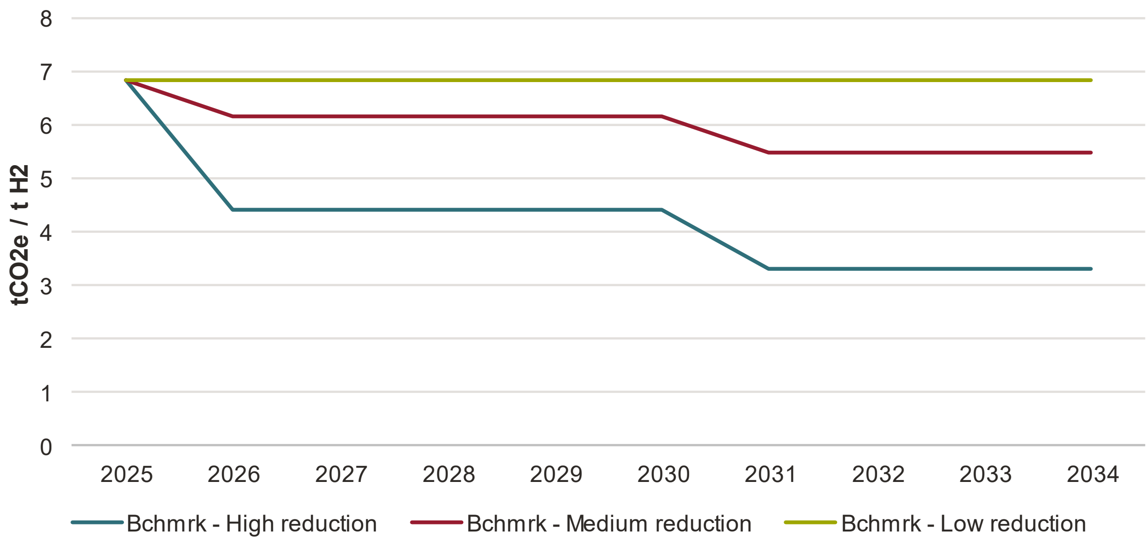
Main Assumptions

For the quantification of CBAM effects and differences in benchmark application, assumptions on key parameters are required. These are described in the following.

Benchmarks

For outsourced hydrogen, the maximum annual benchmark reduction rate of 2.5% is applied, reflecting the expected impact of future green electrolyser deployment, which will lower the benchmark to its minimum level. To account for uncertainty regarding insourced hydrogen, two benchmark reduction scenarios are applied. The low reduction scenario assumes that the benchmark remains constant at 6.84 $tCO_2/t\ H_2$, corresponding to a gradually declining annual reduction rate of 1.51% to 1.14% over 2026–2030 and 0.91% over 2030–2034. The medium reduction scenario maintains the current annual reduction rate of 1.51%, assuming the update rate remains constant. The following chart illustrates the evolution of the applied benchmarks.

Figure 17 Assumed benchmark reductions



Source: Frontier Economics

Note: A high reduction rate is assumed for outsourced hydrogen, while medium and low reduction scenarios are applied for insourced hydrogen produced within refineries.

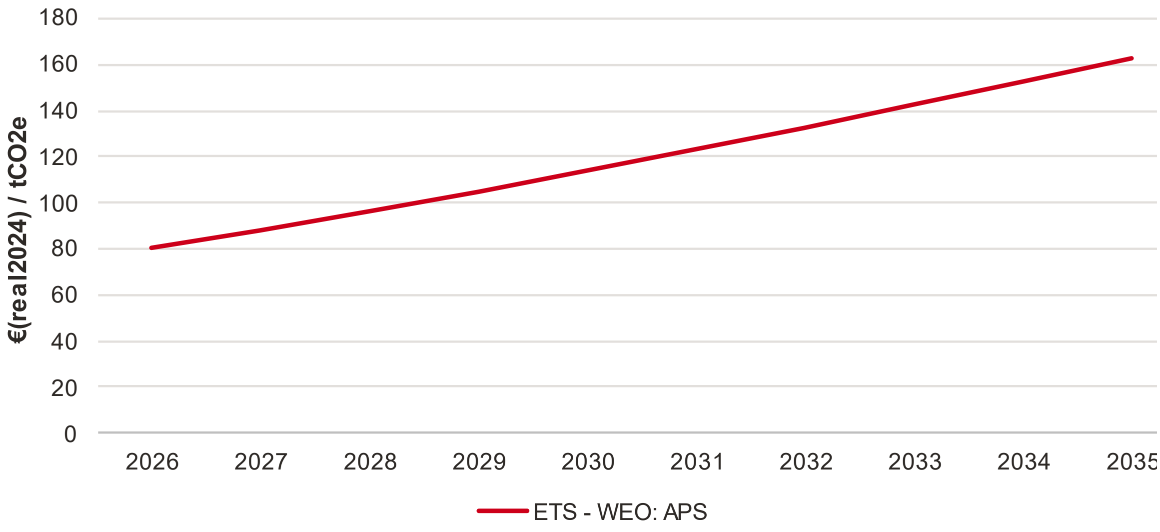
CBAM factor

In line with current regulation, a constant CBAM factor of 1 is applied to insourced hydrogen in refineries, meaning it remains unaffected by CBAM, and the results are not altered. For outsourced hydrogen, the decreasing CBAM factor shown in Figure 16 is applied, leading to a gradual reduction of free allocation over time.

EU ETS prices

We apply ETS 1 price assumptions from the World Energy Outlook Announced Pledges Scenario of 2024. This scenario shows the pathway if all announced government climate and energy pledges are fully implemented. The scenario provides an estimated EUA price for 2050. In order to get a price pathway up to 2050, we interpolate linearly starting from the EEX forward price as of 15/09/2025. The corresponding pathway is converted into nominal terms assuming 2% yearly inflation. Figure 18 illustrates the assumed CO2 price pathway.

Figure 18 Assumed CO2 prices

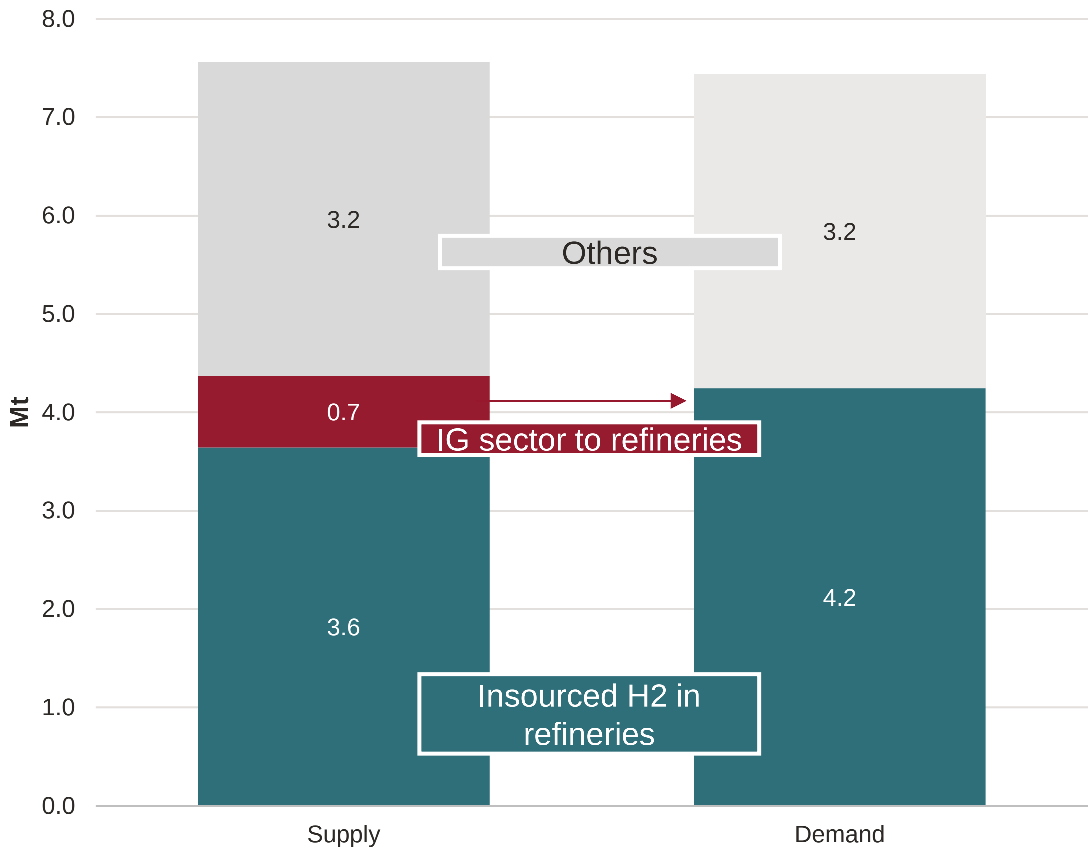


Source: Frontier Economics based on IEA(2025) and EEX
Note: Interpolation between EEX forward price as of 15/09/2025 IEA's 2050 Announced Pledges projection for Europe.

Hydrogen volumes

The segment exposed to potential distortion is limited to the hydrogen volumes produced by the industrial gases sector and sold to refineries. In 2023, the total hydrogen market in EU-27 amounted to 7.4 Mt, of which 4.2 Mt was consumed by refineries as shown in Figure 19. We estimate that approximately 0.7 Mt of hydrogen was supplied by the industrial gases sector to refineries, representing c.17% of total refinery hydrogen demand. The remaining 83% was met through insourced hydrogen production within refineries.

Figure 19 H2 demand and supply in EU-27 2023



Source: Frontier Economics based on EU legislation, IEA (2025), European Hydrogen Observatory (2025), EIGA (2022), Eurostat (2025a).

These assumptions are summarised in the Table 1.

Table 1 Main assumptions

Variable	Insourced H2 in Refineries	Outsourced H2	Source
Benchmarks	Medium / Low benchmark reduction starting from 2021-2025 benchmark.	Maximum benchmark reduction starting from 2021-2024 benchmark (2.5%)	European Commission – Directorate-General Climate Action (2021) and Directive (EU) 2023/959
CBAM factor	Does not apply*	Applies	Directive (EU) 2023/959
EU ETS Prices	World Energy Outlook (2024) estimation for 2050 – Annual Pledges Scenario		IEA (2025)

Variable	Insourced H2 in Refineries	Outsourced H2	Source
H2 production volumes	Production volumes of insourced and outsourced H_2 are assumed to remain constant to 2023 levels		European Hydrogen Observatory (2025); EIGA (2022) and Eurostat (2025a)

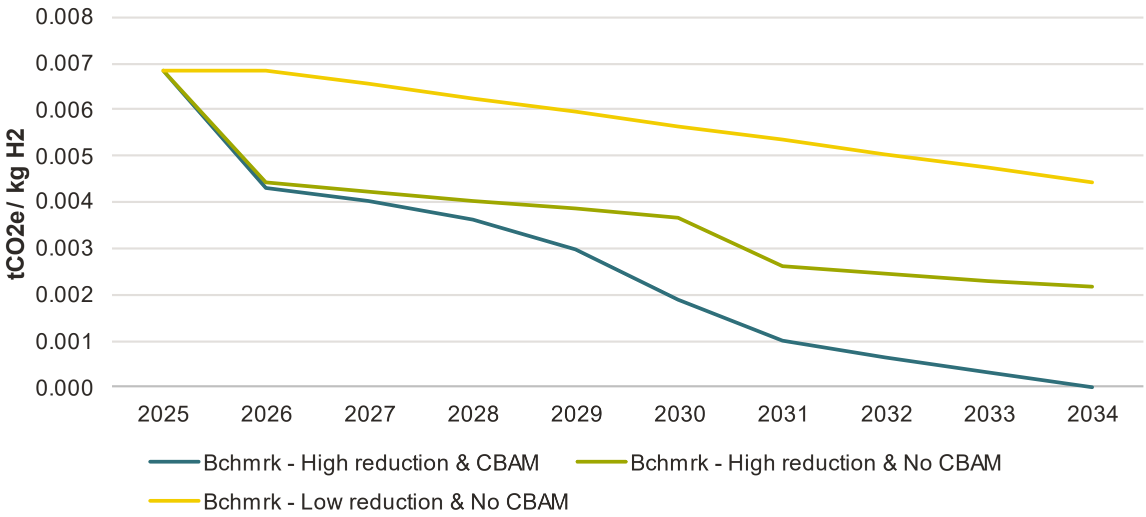
Source: Frontier Economics
*Note: * In reality, this means that the CBAM factor applied is 1, which does not alter the result.*

Results

As explained above, the number of free allowances allocated to hydrogen producers depends on both the applicable benchmark value and whether the CBAM factor is applied. Figure 20 shows the evolution of the number of free allowances allocated per unit of hydrogen produced ($tCO_2e/kg\ H_2$) under different benchmark and CBAM scenarios:

- The **teal line** represents the **case of outsourced hydrogen produced by the industrial gases sector and sold to refineries**, assuming a high benchmark reduction combined with CBAM inclusion. Here, the number of free allowances declines sharply over time, approaching zero by 2034 as the CBAM phase-in fully replaces free allocation.
- The **green line** illustrates the same high benchmark reduction but without CBAM inclusion, showing a more gradual decline in free allowances.
- The **yellow line** corresponds to **insourced hydrogen produced and consumed within refineries** under a low benchmark reduction and no CBAM inclusion, where the number of free allowances remains comparatively stable throughout the period. The graph for the medium benchmark reduction can be found in the annex.

Figure 20 Number of free allowances allocated (per unit of output)



Source: Frontier Economics

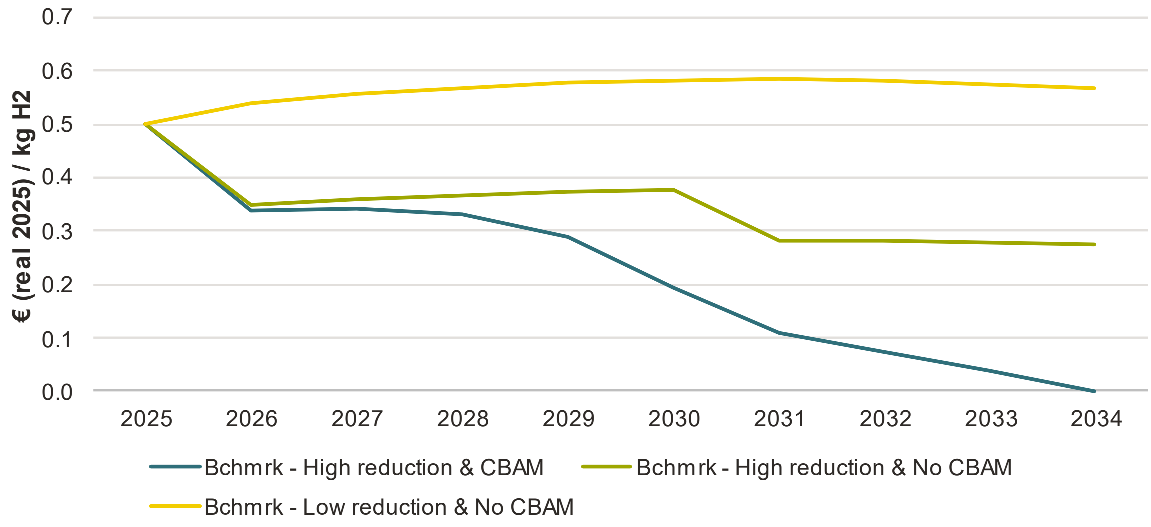
Note: A high reduction rate is assumed for outsourced hydrogen, while medium and low reduction scenarios are applied for insourced hydrogen produced within refineries

Figure 21 complements Figure 20 by translating the number of free allowances per unit of hydrogen production into their monetary value (expressed in €2025/kg H_2). While Figure 19 illustrates the quantitative decline in free allowances over time, Figure 20 shows how this translates into a change in economic value once the assumed EU ETS price trajectory is applied.

As in Figure 19, the teal line represents outsourced hydrogen produced by the industrial gases sector and sold to refineries under a high benchmark reduction and CBAM inclusion. Here, the value of free allowances falls sharply and reaches zero by 2034, reflecting the full CBAM phase-out. The green line, which applies the same high benchmark reduction but without CBAM inclusion, shows a more gradual decline in value, mirroring the slower reduction in the number of allowances. The yellow line, representing insourced hydrogen in refineries under a low benchmark reduction and no CBAM inclusion, remains largely stable.

Across all three cases, rising CO_2 prices partly offset the decline in the number of allowances, keeping the overall value of free allocation higher than the reduction in quantity alone would suggest. Nevertheless, the inclusion of CBAM and faster benchmark reductions significantly reduce both the quantity and value of free allocation for outsourced hydrogen, while insourced refinery hydrogen maintains a relatively constant level of support. Again, the graph for the medium benchmark reduction applied to insourcing H2 production can be found in the annex.

Figure 21 Value of free allowances (per unit)

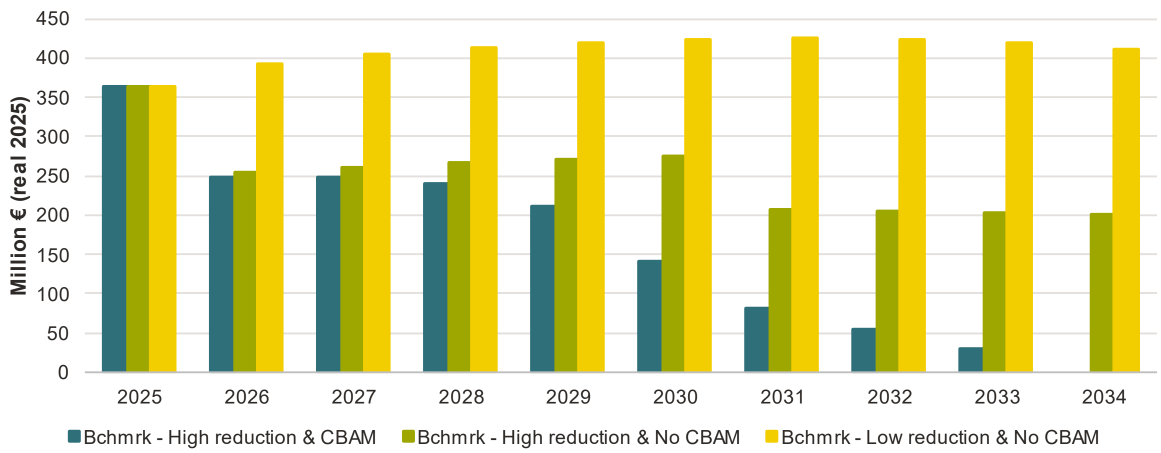


Source: *Frontier Economics*

Note: *A high reduction rate is assumed for outsourced hydrogen, while medium and low reduction scenarios are applied for insourced hydrogen produced within refineries*

Beyond the per unit comparison, it is also important to analyse the effect in absolute terms. In this analysis, this represents the total value of free allowances granted for hydrogen produced and sold by the industrial gases sector to refineries across the EU. The calculation assumes an annual volume of 0.7 Mt of hydrogen supplied by the industrial gases sector to refineries.

Figure 22 Total value of free allowances for H2 sold to refineries by the IG sector



Source: *Frontier Economics*

Note: *A high reduction rate is assumed for outsourced hydrogen, while medium and low reduction scenarios are applied for insourced hydrogen produced within refineries.*

Figure 22 illustrates the annual difference in the total value of free allowances for the 0.7 Mt of hydrogen supplied by the industrial gases sector to refineries, depending on benchmark assumptions and CBAM application. The chart therefore reflects the yearly distortion in compensation that arises between outsourced hydrogen (teal) and insourced hydrogen (yellow), with the green bars isolating the specific effect of CBAM alone.

The **teal bars** represent outsourced hydrogen under a high benchmark reduction combined with CBAM inclusion. In this case, the total value of free allowances starts at around €360 million in 2025 and declines steadily to zero by 2034, as the CBAM phase-in fully replaces free allocation.

The **yellow bars** correspond to insourced hydrogen in refineries under a low benchmark reduction and no CBAM inclusion. Here, the value of free allowances remains broadly stable between €360 million and €420 million over the period, as increasing CO_2 prices compensate for the moderate benchmark reduction.

The **green bars** show the isolated impact of CBAM, applying the same high benchmark reduction but without CBAM inclusion. In this scenario, the value of free allowances declines from roughly €360 million in 2025 to around €200 million in 2034, indicating the effect of benchmark reductions alone.

The difference between the teal and yellow bars represents the *annual distortion* between outsourced and insourced hydrogen, which ranges from around €150 million in 2026 to €400 million by 2034 (for context, the production value of outsourced hydrogen sold to refineries was €1.8 billion in 2024). The gap between the teal and green bars isolates the CBAM-related effect. For readability, results for the medium benchmark reduction scenario are presented in the Annex.

To complement the annual results shown in the previous figures, it is also useful to look at the cumulative effect of the different scenarios over time. To this end, the net present value (NPV) of differences in the value of free allowances is calculated. The NPV aggregates the annual differences between scenarios over the full period 2026–2034, discounting future values to reflect their worth in today’s terms. In other words, it expresses the total financial impact of benchmark and CBAM differences as a single, comparable measure. A discount rate of 6.76% is applied, corresponding to the average weighted cost of capital observed in similar industrial sectors[15].

Figure 23 presents the resulting NPVs for outsourced hydrogen sold to refineries. The left-hand chart shows results for the low benchmark reduction scenario, in which the benchmark for insourced hydrogen is assumed to remain constant at 6.84 $tCO_2/t\ H_2$, while outsourced hydrogen is subject to the maximum annual reduction rate of 2.5%. Under these assumptions, the combined effect of CBAM inclusion and different benchmark reductions results in a

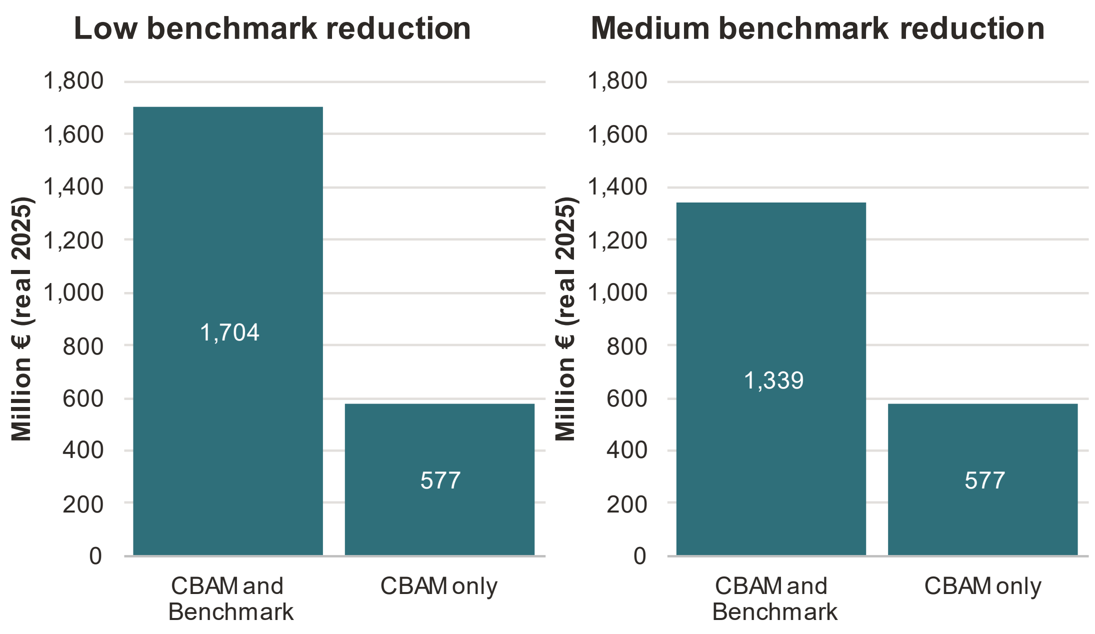
15 This WACC corresponds to the average WACC of chemical (diversified and specialty) industries in Europe, according to Damodaran.

cumulative NPV loss of €1,704 million, while isolating the CBAM effect only – with identical benchmark reductions in both cases – yields an NPV of €577 million.

The right-hand chart shows the same comparison for the medium benchmark reduction scenario, in which the benchmark for insourced hydrogen declines gradually over time at an annual rate of 1.51%, while outsourced hydrogen is subject to the maximum reduction rate of 2.5%. Under these assumptions, the combined effect of CBAM inclusion and different benchmark reductions results in an NPV loss of €1,339 million, while the CBAM-only impact – holding benchmark reductions constant between scenarios – amounts to €577 million.

Overall, this means that, over the 2025–2034 period, CBAM and benchmark differences together could reduce the value of free allowances for outsourced hydrogen by around €1.3–€1.7 billion in total – illustrating a sizeable effect relative to the 2024 production value of outsourced hydrogen sold to refineries of €1.8 billion noted above. The medium benchmark reduction scenario corresponds to the benchmark trajectories provided in the Annex.

Figure 23 NPV of differences in value of free allowances - outsourced hydrogen sold to refineries



Source: Frontier Economics

3.3 Level playing field risks from electricity pass-through – the role of ICC

3.3.1 Mechanism and application in EU Member States

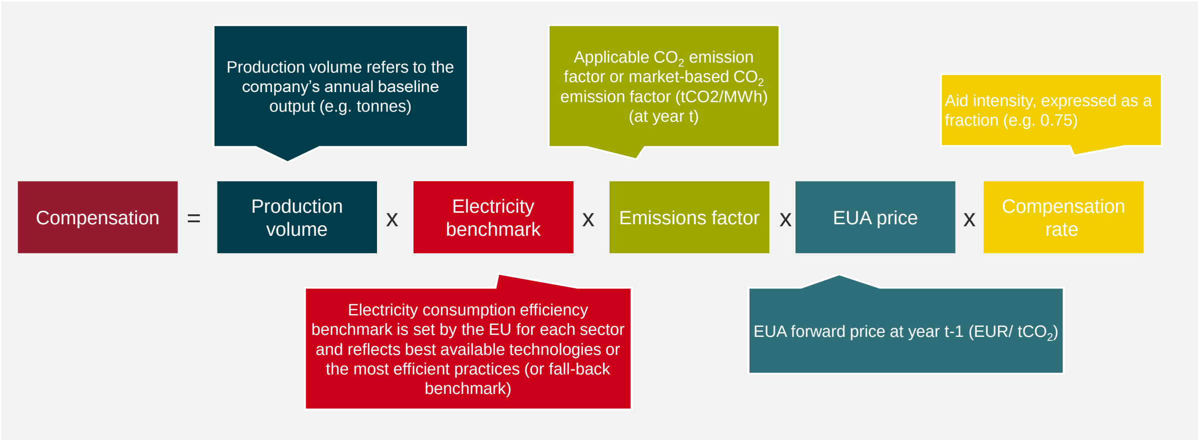
Indirect cost compensation as refers to state aid granted to energy-intensive industries to offset the increase in electricity prices resulting from the EU Emissions Trading System (EU ETS). Since power generators pass-through the cost of purchasing emission allowances to consumers, eligible companies may receive compensation for this indirect CO_2 cost to preserve their international competitiveness while maintaining the carbon price signal in the power sector.

While the implementation of an ICC scheme is a national decision, the methodology to calculate ICC set on the EU level for all countries centrally.[16] The formula as shown in Figure 24 consists of the following components:

- **Production volume** is the installation's actual output in the aid year, typically measured in tonnes and determined ex post. More output generally means a larger eligible base for compensation.
- **Electricity benchmark** is a product-specific efficiency value, expressed in MWh per tonne, that reflects best available practice for electricity use in producing that product. If no product benchmark exists, a fallback applies that uses a defined share of the installation's actual electricity consumption instead of a product benchmark.
- **Emissions factor** is the amount of CO_2 associated with one megawatt-hour of electricity in the relevant Member State or bidding zone. A higher factor implies that each MWh carries more indirect CO_2 cost and therefore raises the eligible amount.
- **EUA price** is the average carbon price used in the calculation, taken as the mean of one-year forward EUA prices over the preceding calendar year. When the carbon price is higher, the eligible indirect cost is higher.
- **Compensation rate** (aid intensity) is the percentage of eligible indirect costs that may be compensated, subject to the guideline cap (typically up to 75%), and some schemes may also apply an overall cap at company level.

[16] (EC) 2020/C 317/04

Figure 24 ICC formula

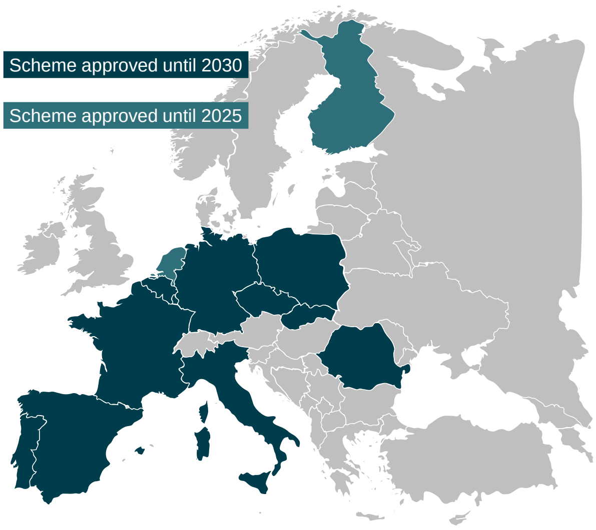


Source: *Frontier Economics based on (EC) 2020/C 317/04*

As shown in Figure 25, there are currently 14 approved indirect cost compensation schemes in place across 13 EU Member States. This includes all major industrial gases producing countries, in particular France, Italy, Germany, Spain and the Netherlands. Most schemes are approved for the period 2021–2030, while a few, such as those in Finland and the Netherlands, are valid until 2025.

Figure 25 Approved Indirect Cost Compensation Schemes currently in place

Country	Period	SA Decision(s)
Belgium (Flanders)	2021–2030	SA.103704 (amend. SA.106504)
Belgium (Wallonia)	2021–2030	SA.103490
Germany	2021–2030	SA.100559
Finland	2021–2025	SA.63581
France	2021–2030	SA.63404
Italy	2021–2030	SA.60787
Luxembourg	2021–2030	SA.63709
Netherlands	2021–2025	SA.102626
Poland	2021–2030	SA.64719
Portugal	2021–2030	SA.100103
Romania	2021–2030	SA.102431
Slovakia	2021–2030	SA.102712
Spain	2021–2030	SA.100004
Czech Republic	2021–2030	SA.100159



Source: *Frontier Economics based on DG Competition, Link here*
Note: *[Insert Notes]*

These national aid schemes, authorised under EU State aid rules by the European Commission's Directorate-General for Competition (DG Competition), compensate eligible energy-intensive industries for higher electricity prices resulting from the EU Emissions

Trading System (EU ETS). Eligibility is defined in the Guidelines on State Aid for Climate, Environmental Protection and Energy 2022–2030 (CEEAG)[17]. Annex I of these guidelines lists the sectors and subsectors considered at significant risk of carbon leakage due to indirect emission costs, based on their trade intensity and indirect carbon cost intensity as a share of gross value added. It covers mainly electricity-intensive and trade-exposed industries such as aluminium, steel, copper, fertilisers, paper, chemicals and hydrogen. Member States may only grant compensation to companies operating in these eligible sectors, subject to approval by the European Commission.

According to Annex I, only two industrial gases subsectors are explicitly eligible for indirect cost compensation: the manufacture of hydrogen and of inorganic oxygen compounds of non-metals. By contrast, many energy-intensive industries that insource industrial gas production – such as steel, copper, refineries, pulp, paper and large chemical plants – are included among the eligible sectors. These industries typically operate cryogenic air separation units (ASUs) or pressure swing adsorption (PSA/VPSA) systems to produce oxygen, nitrogen or argon on-site, and therefore receive compensation for the indirect CO_2 costs embedded in their electricity use. External gas suppliers operating equivalent technologies to serve these same customers are, however, not covered by the eligibility list. This asymmetry can create unequal treatment between insourced and outsourced gas production, even though the underlying production processes and exposure to indirect carbon costs are essentially identical.

The quantification of the total distortion resulting from unequal treatment of insourced and outsourced industrial gas production is complex for several reasons.

- First, the level of compensation differs across Member States**,** reflecting variations in national electricity mixes and corresponding CO_2 emission factors. Countries with more carbon-intensive power generation typically provide higher levels of indirect cost compensation than those with cleaner electricity systems, which complicates a consistent comparison across jurisdictions.
- Second, the extent to which industrial gas use is reflected in product benchmarks under the EU ETS depends on the production technology applied in the most efficient installations of a given sector. Product benchmarks are designed to represent the average performance of the 10% most carbon-efficient plants within each sector. If these benchmark installations include insourced gas production, the associated emissions are (at least partially) included in the benchmark value.

For sectors or products without a defined product benchmark, the EU ETS applies so-called fallback benchmarks, which are based on generic parameters such as fuel, heat or process emissions. In these cases, the electricity consumption of insourced industrial gas production is typically included in the benchmark value, meaning that the associated indirect CO_2 costs are implicitly covered by the compensation scheme. This issue will be examined in more detail

17 (EC) 2020/C 317/04

in the following case study, which analyses how the treatment of insourced and outsourced gas production differs in practice.

3.3.2 Case Study: ICC for Insourced O_2 Production in a Copper Plant in Germany

To illustrate how indirect cost compensation (ICC) can affect the relative competitiveness of insourced and outsourced industrial gas production, the following case study examines an example of oxygen production in a copper plant in Germany.

Production process and electricity demand

Insourced oxygen production in the copper industry is typically produced in a cryogenic air separation unit (ASU). In this process, ambient air is compressed, purified, cooled to cryogenic temperatures and separated by distillation into its main components – oxygen, nitrogen and, to a lesser extent, argon. Electricity consumption is dominated by the main air compressor, while cooling and distillation also require significant energy input. For this analysis, a specific electricity consumption of 0.32 MWh per tonne of oxygen (O_2) is assumed, which reflects the typical energy requirement of large-scale ASUs supplying copper or other metallurgical industries[18].

Parameters and compensation mechanism

Under the German indirect cost compensation scheme approved for the period 2021–2030, energy-intensive industries may receive financial support to offset the indirect CO_2 costs embedded in electricity prices. For the year **2024**, the relevant parameters[19] are as follows:

- Aid intensity: 75%
- CO_2 factor: 0.72 t CO_2/MWh (reflecting Germany's electricity mix)
- CO_2 price: €89/t CO_2[20]
- Benchmark (fallback): 0.77 (corresponding to 77% of reference emissions)
- Specific electricity consumption for oxygen: 0.32 MWh/t O_2

Applying these parameters results in an aid level of approximately €37 per MWh of electricity consumed. Compared to an average German wholesale electricity price of €79.6/MWh in 2024, this implies a compensation rate of about 46%. When translated to the unit of production, this corresponds to around €11.8 per tonne of oxygen.

18 Aneke, M.; Wang, M. (2015).

19 Deutsche Emissionshandelsstelle (2024).

20 Energate (2025).

Figure 26 ICC for insourced O_2 production in a copper plant in Germany via ASU

Parameters for 2024 for Germany

- **Aid intensity:** 75%
- **CO_2 factor:** 0.72 t CO_2/MWh
- **CO_2 price:** 89 €/t CO_2
- **Benchmark (fallback):** 0.77 (= 77%)
- **Specific electricity consumption :** 0.32 MWh/t O_2

Indirect cost compensation

- **Aid per MWh:** c.37 €/MWh
- **Aid per tonne O_2:** c.11.8 €/tO_2

Result: Significant cost reduction for insourced oxygen production

- **Aid per MWh**: €37/MWh vs. average German day-ahead price of €79.57/MWh in 2024 → compensation rate c.46%
- **Aid per tonne O_2**: c.€11.8 compared to electricity costs of c.€25.5 per tonne

In our example, insourced O_2 production under the fallback benchmark receives c. €11.8 per tO_2 in compensation, which distorts competition with outsourced production that is not eligible for ICC.

Source: Frontier Economics

Result and interpretation

The analysis shows that insourced oxygen production under the fallback benchmark receives a significant level of cost relief – around €11.8 per tonne of O_2, effectively reducing the electricity cost by nearly half. For context, according to an index of oxygen prices, the price of oxygen in Europe has lied between €125 and €190 per tonne from 2022[21].

However, outsourced industrial gas suppliers producing oxygen using the same technology (cryogenic ASUs) are not eligible for indirect cost compensation, as their activities are not included among the eligible NACE codes listed in Annex I of the CEEAG. This creates an unequal treatment between insourced and outsourced production: both processes face comparable indirect CO_2 cost exposure, yet only the insourced variant benefits from compensation.

This example illustrates how differences in eligibility under current EU and national rules can distort competition within the industrial gases value chain. The fallback benchmark used for sectors without specific product benchmarks automatically includes the electricity consumption of insourced gas production. In contrast, outsourced gas supply – even when it serves the same industrial process – remains outside the scope of compensation.

As a result, insourced oxygen production receives roughly €11.8 per tonne in support, while outsourced production receives none, leading to a cost differential that may influence investment and sourcing decisions in favour of on-site production.

21 Business Analytiq (2025), with EUR/USD lying between 0.8 and 1.05 during that period.

Summary of main findings on indirect cost compensation

Our analysis shows that 13 indirect cost compensation (ICC) schemes are currently in place across EU Member States, including all major industrial gas producing countries. However, only two subsectors of the industrial gases sector – hydrogen and inorganic oxygen compounds of non-metals – are explicitly eligible for compensation, whereas many energy-intensive industries that insource gas production (such as steel, copper, chemicals and pulp) are covered. This creates potential distortions between insourced and outsourced gas production.

The gases most affected are oxygen, nitrogen and argon, typically produced through cryogenic air separation units (ASU) or pressure swing adsorption (PSA/VPSA) technology. Electricity consumption and product output ratios vary by industry and country, leading to differences in ICC levels that complicate the quantification of the overall distortion.

In a case study for Germany, insourced oxygen production at a copper plant in 2024 received compensation of about €11.8 per tonne of O_2 (equivalent to €37/MWh, or 46% of the average power price). This example illustrates how insourced production benefits from ICC, while outsourced producers using the same technology remain ineligible, highlighting the need to ensure a level playing field between insourced and outsourced industrial gases – particularly oxygen, nitrogen and argon – through equal treatment under ICC.

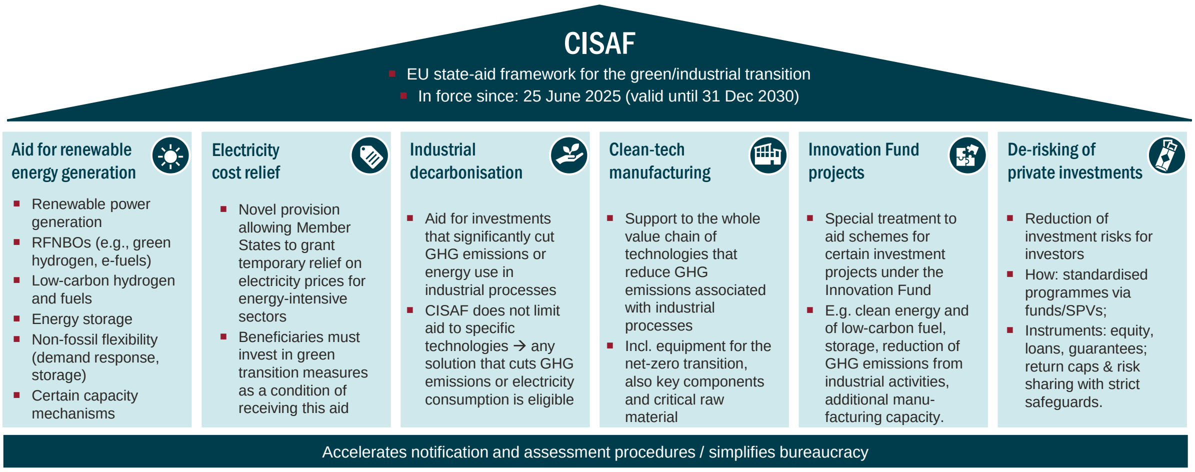
3.4 State Aid Changes under CISAF may further distort competition between insources and outsourced IG production

In addition to the established direct and indirect cost compensation mechanisms, the EU's Clean Industrial Deal State Aid Framework (CISAF) now provides an additional basis for supporting the green and industrial transition.[22] It replaces the **Temporary Crisis and Transition Framework**, the Commission's 2023 temporary state aid regime that eased EU rules to mitigate the economic impact of Russia's war and the energy price shock, and to accelerate the net zero transition through targeted support for liquidity, energy-cost relief, and clean-tech investment.

In force since June 2025 and valid until 31 December 2030, CISAF aims to accelerate renewable energy deployment, drive industrial decarbonisation, and strengthen clean-tech manufacturing capacity across Europe. It provides Member States with a comprehensive toolbox that includes support for renewable power and low-carbon fuels, temporary electricity-cost relief for electro-intensive users, aid for industrial decarbonisation investments, and measures to scale up clean-tech manufacturing. CISAF also offers special treatment for Innovation Fund projects and instruments to de-risk private investment.

[22] European Commission (2025).

Figure 27 CISAF Toolbox



Source: *Frontier Economics based on (EC) C/2025/3602 and Freshfield (2025).*

With the provision for a temporary electricity cost relief an additional tool to reduce electricity costs of energy-intensive industries has emerged

CISAF's overall impact is still to be determined. Its effectiveness will depend on national roll-out, budget availability, scheme design and how it interacts with existing instruments such as indirect cost compensation. The most tangible provision is the temporary electricity cost relief measure. It allows Member States to grant time-limited discounts on electricity prices for eligible energy-intensive users. Eligible are sectors listed in Annex 1 CEEAG and does thus also include the industrial gases sector (NACE 20.11).

The provision follows a "50/50/50 rule". It allows Member States to grant support covering up to 50 % of the wholesale power price and no more than 50 % of a company's annual electricity consumption. The effective electricity price paid by beneficiaries is capped at a minimum of €50/MWh, limiting the maximum discount that can be granted. The measure can be applied for a maximum period of three years per company and must end no later than 2030.

Beneficiaries are required to invest at least 50% of the aid in decarbonisation measures aimed at reducing electricity system costs, with a potential bonus of 10% if 75% of the amount is reinvested and 80% is directed towards demand flexibility improvements.

The support provided under the temporary electricity cost relief may be cumulated with indirect cost compensation (ICC), but only within the overall aid intensity and cumulative funding limits established by EU State-aid rules. These limits effectively cap total support at the equivalent of €50/MWh. For companies already benefiting from ICC, the scope for additional relief under CISAF may therefore be limited once these ceilings are reached.

Unequal treatment of insourced and outsourced industrial gas production may exacerbate existing distortions

As with indirect cost compensation, it will be essential to ensure equal treatment between insourced and outsourced industrial gas production. If only certain sectors benefit from temporary electricity cost relief, the measure could inadvertently amplify existing distortions. Three potential cases can be distinguished:

- Both insourced and outsourced industrial gas production receive temporary compensation → no additional distortion arises.
- Both receive compensation, but the insourced payment is capped because the cumulative aid limit is reached → the relative distortion caused by ICC is temporarily – as long as the temporary electricity cost relief is in place - reduced.
- Only insourced production receives compensation, while outsourced production remains ineligible → the existing distortion from ICC is further exacerbated.

Maintaining consistency in the treatment of all industrial gas production models is therefore key to avoiding new market distortions and ensuring that insourced and outsourced production can compete fairly within the EU.

3.5 Summary and Conclusion

Our analysis demonstrates that recent and forthcoming changes to the EU's carbon-leakage protection framework – including the phase-down of free allocation under the EU ETS, the introduction of the CBAM, adjustments to indirect cost compensation (ICC), and new state aid instruments under CISAF – will have significant implications for the competitiveness of industrial gas producers in Europe.

With regard to **direct cost protection**, we find that unequal treatment between insourced and outsourced hydrogen used in refineries can lead to substantial market distortions. The distortion arises because outsourced hydrogen is likely to be subject to both faster benchmark reductions and the application of the CBAM reduction factor, while insourced refinery hydrogen is not. Taken together, these regulatory differences could translate into a net present value impact of around €1–2 billion between 2026 and 2034 for this segment of the market. In 2034, where differences are largest, the regulatory differences can be around €0.6/kg of H2.

With regard to **indirect cost compensation**, ICC schemes exist in 13 EU Member States, including all major industrial gas producing countries such as France, Germany, Italy, Spain, and the Netherlands. However, eligibility currently extends only to two industrial gas subsectors (hydrogen and inorganic oxygen compounds), while many energy-intensive industries that produce oxygen, nitrogen, or argon in-house receive compensation for identical electricity-related CO_2 costs. Quantifying the overall distortion from this unequal treatment is complex, as compensation levels vary by country, electricity mix, and plant configuration.

Nevertheless, in a case study for oxygen production in Germany's copper industry, we find that insourced oxygen generated via cryogenic air separation receives around €12 per tonne O_2 in indirect cost relief, effectively covering about 46% of the average power price in 2024. By contrast, outsourced suppliers using the same technology remain ineligible, highlighting a significant level-playing-field concern within the EU's current ICC framework.

Furthermore, the new Clean Industrial Deal State Aid Framework (CISAF) expands national options for supporting industrial decarbonisation, including temporary electricity price relief for energy-intensive users. Its actual impact will depend on national implementation and interaction with existing ICC schemes. If only certain sectors or production models qualify, the measure could reinforce existing asymmetries between insourced and outsourced industrial gas production.

To safeguard fair competition across all production routes for industrial gases, equal treatment should be ensured in the application of EU and national carbon-leakage protection instruments. This includes:

- **Free allocation** remains an established instrument to mitigate leakage. By contrast, **CBAM** effectiveness is yet to be demonstrated and an export adjustment mechanism to shield EU exporters is still pending. It is therefore plausible that the EU has chosen, for the time being, to keep certain sectors outside CBAM until its effectiveness is proven. However, this current regulatory design creates an internal level-playing-field issue for hydrogen used in refineries: as long as refineries continue to receive full free allocation and remain outside CBAM, hydrogen supplied by IG companies to refineries should receive an equivalent level of free allocation to insourced refinery hydrogen.
- **Indirect Cost Compensation eligibility for industrial gas production should be aligned irrespective if produced on-site or not**. To maintain competitive neutrality, ICC eligibility should reflect comparable ASU/PSA processes for oxygen, nitrogen and argon**,** applying consistent treatment whether production is insourced or outsourced, thereby reducing regulatory-induced differences in sourcing.
- Furthermore, if Member States implement **temporary electricity cost relief under CISAF**, it should be applied symmetrically to insourced industrial gas production and outsourced supply to prevent additional distortions.

Maintaining a level playing field between insourced and outsourced industrial gas production is critical for preserving the sector's competitiveness and its role as an enabler of Europe's broader industrial decarbonisation.

Annex A – Why Industrial Gases Matter

A.1 Production and trade analysis

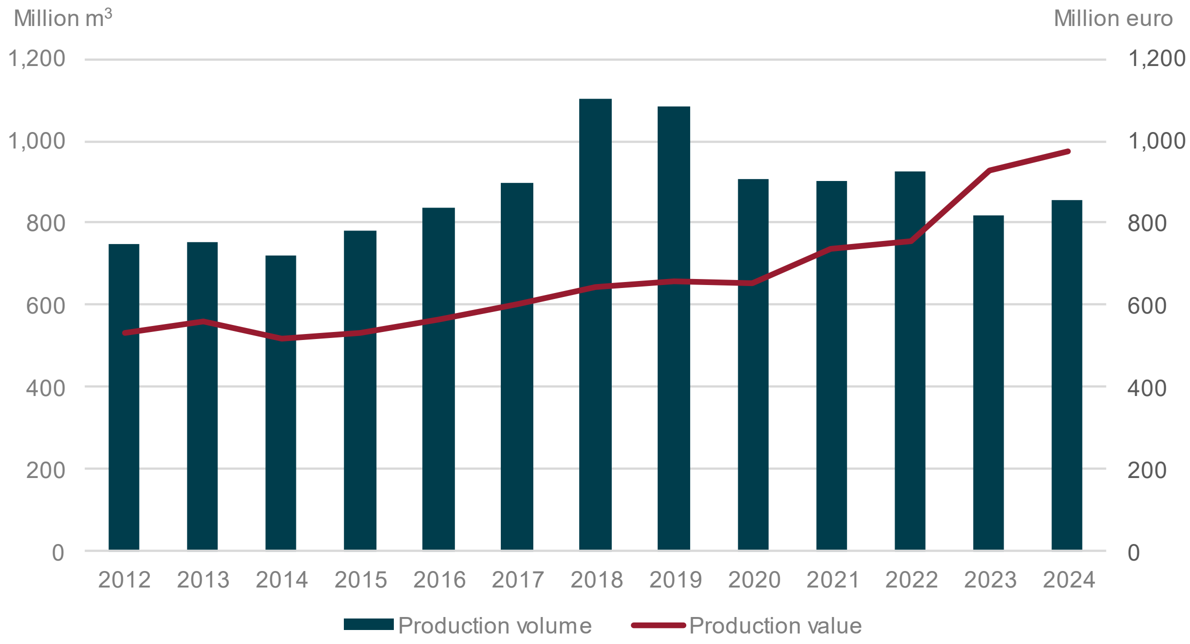
Argon

Argon is a rare gas that is colourless, odourless, and chemically inert under most conditions. Although it makes up less than 1% of the Earth's atmosphere, argon plays a vital role in numerous industrial processes due to its unique physical and chemical properties. It is most commonly used as a shielding gas in welding and metal processing, where its inertness protects materials from oxidation at high temperatures. Argon is also widely used in the electronics and semiconductor industries, in the production of double-glazed windows, and in filling certain types of light bulbs. The gas is primarily obtained through the fractional distillation of liquid air in large-scale air separation units. As a byproduct of oxygen and nitrogen production, argon is integrated into the broader industrial gas supply chain. Looking ahead, demand for argon is expected to remain stable or grow moderately, particularly in sectors that rely on precision manufacturing and advanced materials. Its role in high-tech applications – such as additive manufacturing (3D printing) and specialized laser technologies – may expand further. In parallel, Europe’s industrial gas market is increasingly shaped by efficiency, energy costs, and cross-border trade flows, making argon both a strategically relevant and logistically sensitive commodity.

As Figure 28 shows, a total of 854 million m^3 of argon was produced industrially in the EU27 in 2024. The resulting production value amounted to €974 million. While production volumes have remained largely constant in the years since the start of the COVID-19 pandemic, production values have risen relatively sharply due to significant price increases. Production prices per m^3 of argon increased by 87.3% between 2019 and 2024. As a result, the production value in 2024 was 47.6% higher than in 2019, although the volume produced fell by 21.2% during this period. This contrasts with the period before the pandemic and the subsequent geopolitical developments, when production tended to develop positively while prices remained relatively stable. Overall, a production growth of 44.6% was recorded between 2012 and 2019.

The most important European country in argon production in 2024 was Germany, that accounts for 23.2% of total production in the EU27. Based on data from 2012, it can be assumed that France is one of the most important argon producers in Europe. However, no information is available on French production in 2024 due to anonymization. Other important production countries are Belgium (production share of 10.4%), Spain (9.6%), the Netherlands (8.9%) and Poland (8.3%).

Figure 28 EU27 market development argon



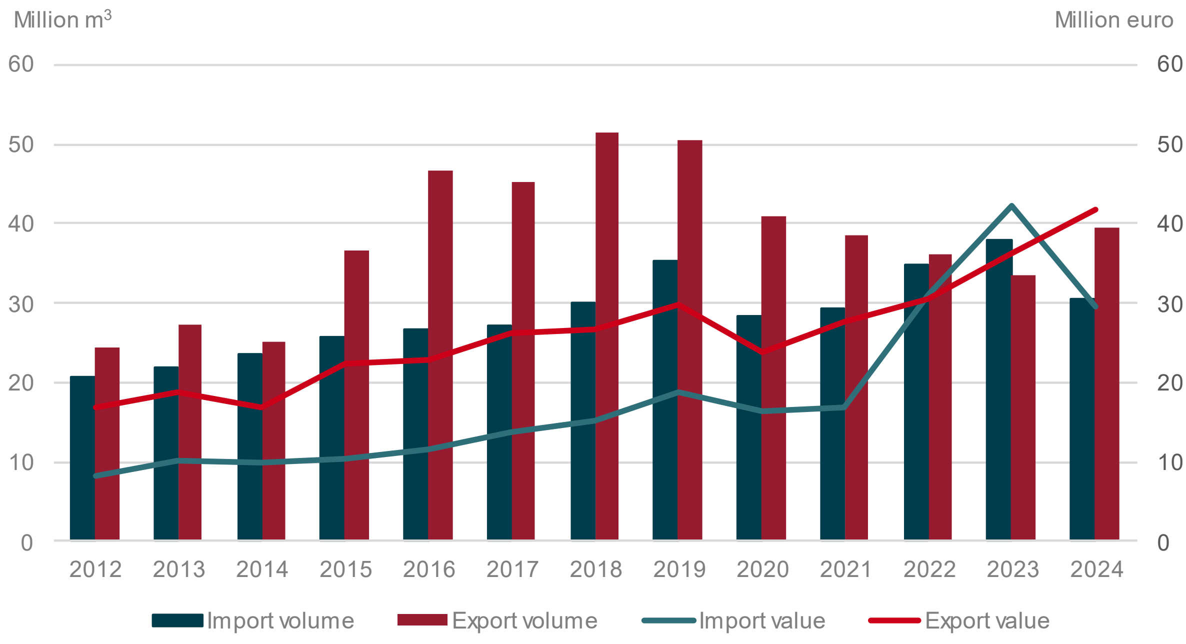
Source: Eurostat (2025).

Figure 29 shows the development of foreign trade in argon for the EU27 in the period from 2012 to 2024. Over long stretches of this period, the four key figures developed largely in parallel with moderate increases. Import and export volumes increased significantly until around 2018, after which they stabilized or even declined. The values for traded volumes increased continuously until 2020. However, a striking trend can be observed from 2021 onwards: Import values increased dramatically, reaching a level in 2023 that was more than five times higher than the initial value in 2012. This is largely due to a massive increase in the price of imported argon. Despite the high price increases, import volumes have also risen. In 2023, a total of 33.3% more argon was imported into the EU27 than in 2020. This is due to a decline in European production, which was offset by higher imports. Due to higher production in 2024, import volumes decreased and export volumes increased. Overall, foreign trade in argon is relatively high compared to many other industrial gases. Imports accounted for 3.6% and exports for 4.6% of total European argon production.

The EU27's foreign trade with argon is predominantly with other European countries. 88.1% of imports and 81.9% of exports in 2023 were with other European countries, with the United Kingdom dominating on both sides. Serbia also plays an important role on the import side. A further 10% of trade is with countries in the Middle East.[23]

[23] Gasworld (2025a).

Figure 29 EU 27 foreign trade development argon



Source: Eurostat (2025).

Rare gases (without argon)

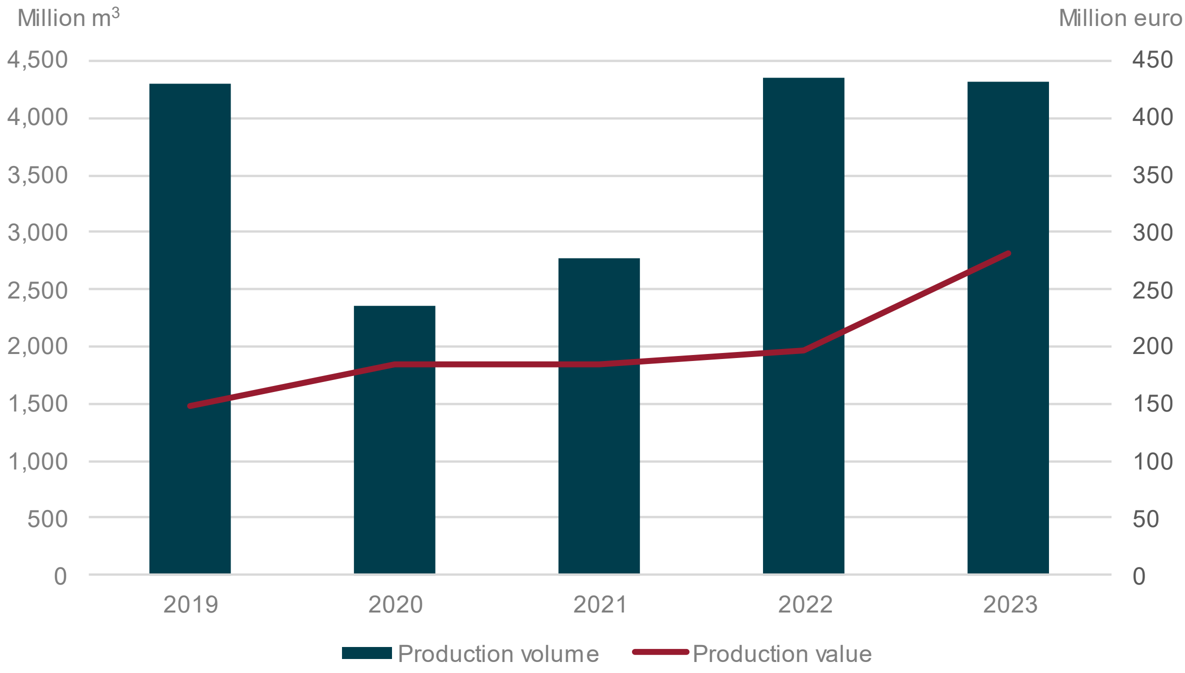
Rare gases – such as neon, krypton, xenon, and helium – occur only in trace amounts in the Earth's atmosphere. Despite their low natural abundance, these elements are essential to a range of high-tech and industrial applications due to their unique physical and chemical properties. They are extracted primarily through the fractional distillation of air or, in the case of helium, from natural gas sources. Each of these gases serves specific niche roles: neon is widely used in lighting and signage, krypton and xenon are employed in specialized lighting systems, laser technologies, and space propulsion, helium, due to its low boiling point and inertness, is crucial in cryogenics, electronics manufacturing, and leak detection. As technology advances, the demand for these rare gases is growing – particularly in sectors like semiconductor production, aerospace, medical imaging, and quantum research. However, their limited availability and reliance on complex separation processes make them sensitive to supply disruptions and price volatility.

Figure 30 shows the development of production volume and value for rare gases (excluding argon) in the EU27 between 2019 and 2023.[24] Between 2019 and 2023, the production volume of rare gases remained relatively stable, with a temporary dip in 2020 and 2021 likely reflecting the effects of the COVID-19 pandemic on industrial activity. Since then, volumes recovered steadily and returned to pre-2020 levels by 2022 and 2023. More notable is the development

[24] It is important to note that a change in statistical methodology was introduced in 2019. As a result, the data from 2019 onward is not directly comparable with figures from earlier years. For this reason, the analysis in this section starts with the year 2019.

of production value, which rose consistently until 2023. While the physical output in 2023 is similar to that of 2019, the production value almost doubled. This is due to sharply rising market prices as a result of supply chain problems and geopolitical risks. In this context, rare gases – while small in volume – represent a strategically important segment of the industrial gas market, closely tied to innovation-driven industries and international trade flows.

Figure 30 EU27 market development rare gases



Source: Eurostat (2025).

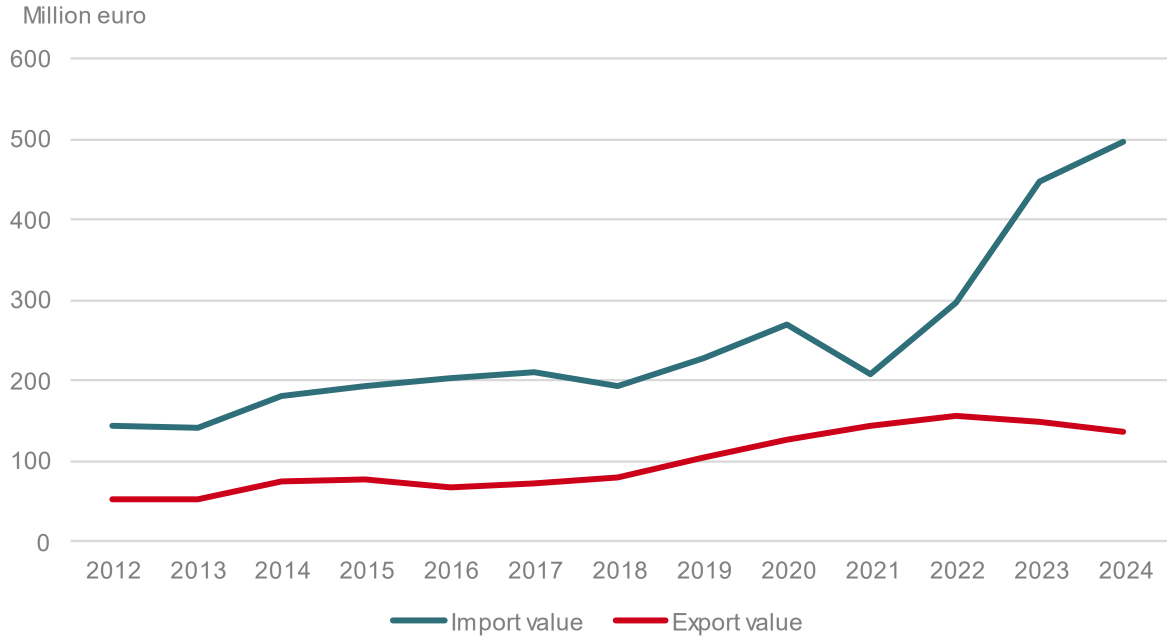
Figure 31 illustrates the development of import and export values for rare gases in Europe between 2019 and 2023. As no reliable information on trade volumes is available, the analysis at this point is limited to trade values. Import values show a clear upward trend. From just over €228 million in 2019, the value of rare gas imports increased steadily to €498 million by 2023. This development points to rising prices. Export values remained comparatively flat during the same period, staying within a range of roughly €100 to €160 million. Measured against the share of total production value, the significance of foreign trade in rare gases is extremely high compared to other industrial gases. Taken together, the export and import values of rare gases are 2.5 times higher than the total production value in the EU27. This is mainly due to trade in helium, which is the industrial gas that is traded internationally on the largest scale.

The most important partners in international trade with rare gases on the export side are other European countries. 70.0% of exports in 2023 were destined for European countries, with a large proportion going to the United Kingdom.[25] A further 17.0% was delivered to the Middle

[25] Gasworld (2025a).

East. The majority of imports were also sourced from there (share of 33.6%). Africa was in second place with an import share of 32.8%, ahead of North America (25.2%).

Figure 31 EU 27 foreign trade development rare gases



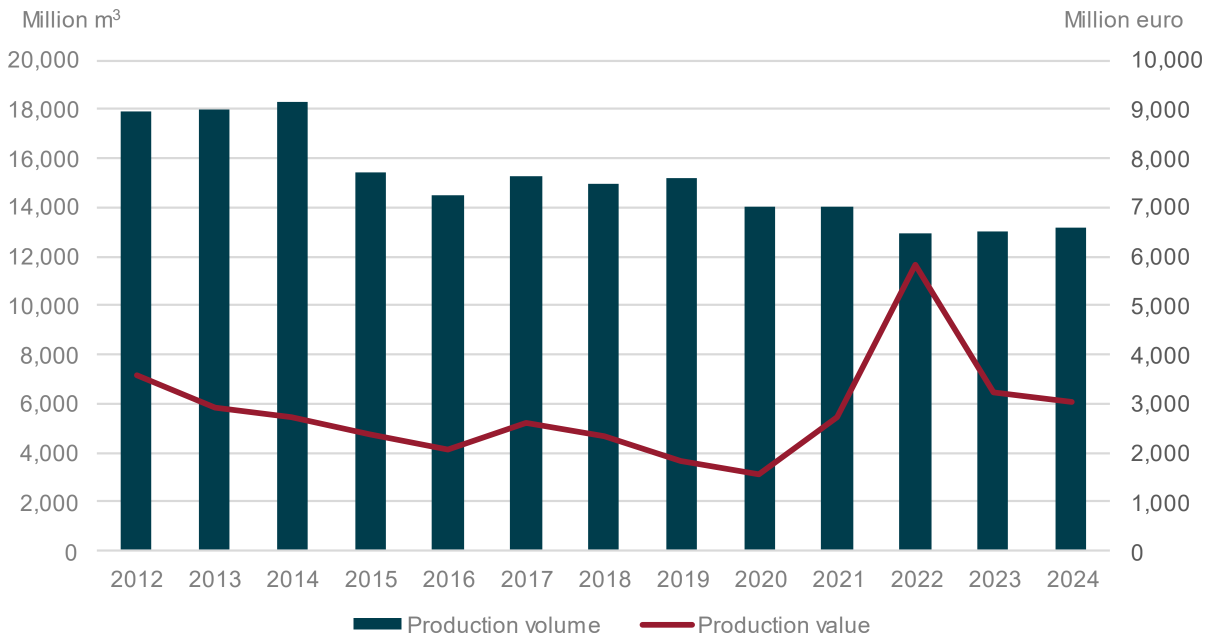
Source: Eurostat (2025), Gasworld (2025)

Hydrogen

Once considered a niche industrial gas, hydrogen has emerged as a central element in discussions about the future of energy and decarbonization in recent years. While its current uses are still dominated by conventional sectors such as ammonia production and oil refining, hydrogen is increasingly valued for its versatility – as both a feedstock and an energy carrier. It plays a key role in processes like hydrocracking, methanol synthesis, and as a protective gas in certain metallurgical applications. What sets hydrogen apart is its potential for clean energy transformation. When produced via electrolysis using renewable electricity – so-called green hydrogen – it offers a zero-carbon alternative to fossil fuels. This positions hydrogen as a promising solution for hard-to-decarbonize sectors, including heavy industry, long-distance transport, and energy storage. At present, however, the majority of hydrogen in Europe is still produced in grey, with a slow transition to blue hydrogen. A mass regional production of green hydrogen is only just beginning. To speed this up, hydrogen is also gaining strategic importance in the European context. With growing investment in production technologies, infrastructure, and cross-border trade, the gas is moving from a purely industrial commodity toward a cornerstone of future energy systems. As supply chains expand and new use cases emerge, hydrogen is expected to play a pivotal role in achieving climate and energy targets.

Despite the growing importance of hydrogen due to these trends, European production has been declining in recent years. In 2024, a total of 13,200 million m³ of hydrogen was produced in the EU27 (Figure 32). This is 26.4% less than in 2012. However, production values showed a continuous decline in the early years. From around €3.6 billion in 2012, it steadily fell to below €2 billion by 2020. This trend suggests decreasing market prices or a reduction in overall market value. From 2021 onward, a sharp reversal occurred: the production value rose significantly, peaking at around €5.8 billion in 2022, before dropping sharply again in 2023. This development points to a phase of strong price increases or rising demand, likely driven by the growing need for hydrogen during the energy crisis and the accelerating energy transition (e.g. increased demand for green hydrogen). Interestingly, production volumes remained relatively stable or slightly declined during this time, indicating that the increase in production value was mainly price-driven, not due to expanded production output.

Figure 32 EU27 market development hydrogen



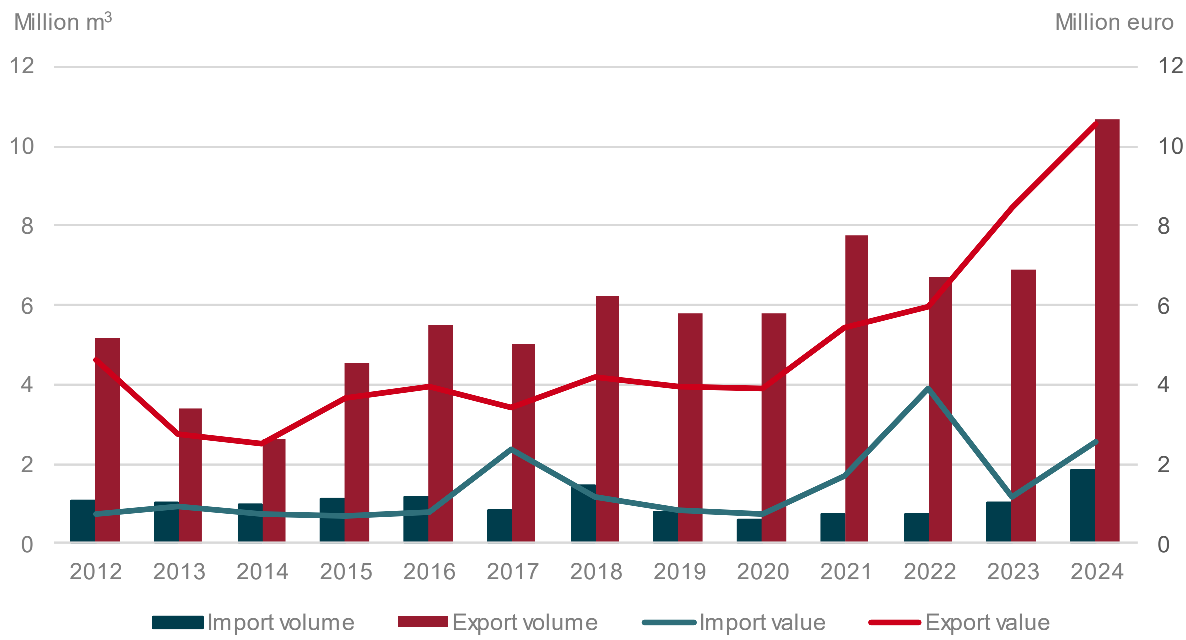
Source: Eurostat (2025).

Germany is the most important producer of hydrogen in Europe. In 2024, 24.4% of European hydrogen production came from Germany. The Netherlands followed with a production share of 15.6%. Belgium is in third place with 14.1%.

Figure 33 illustrates the development of Europe's hydrogen trade between 2012 and 2024, showing both import and export volumes (in million m³) and the corresponding trade values (in million euros). Throughout the entire period, export volumes remained significantly higher than import volumes. Hydrogen export volumes fluctuated between 3 and 8 million m³ with a sharp increase in 2024 up to more than 10 million m³. In parallel, export values showed a steady upward trend. This increase indicates a combination of growing global demand for hydrogen and rising market prices. Import volumes remained comparatively low and relatively stable, showing only slight fluctuations over the years. The import values, however, experienced more volatility. Significant spikes occurred in 2017 and 2022, likely reflecting periods of higher prices or temporary increases in demand. Interestingly, despite a moderate rise in import volumes in 2023, the import value dropped sharply, suggesting a decline in hydrogen import prices. The data suggests that Europe has consistently acted as a net exporter of hydrogen, with export volumes far exceeding imports. Considering the future increase in demand for hydrogen within Europe, it can be assumed that Europe will become a net importer in the future. So far, however, the importance of foreign trade with hydrogen has been very low. Only 0.01% of the European production volume is imported and the export share is also negligible with a share of 0.08% of production. In the future, it can be assumed that trade and, in particular, imports of hydrogen to Europe will increase massively. This is taking place due to the considerable decarbonization requirements and the associated increase in demand for green hydrogen, which cannot be met from European production.

Today, EU27 exports of hydrogen flow almost exclusively to the Middle East and other European countries, in particular Switzerland and the United Kingdom. Imports also come mainly from Europe, particularly from Switzerland.[26]

Figure 33 EU 27 foreign trade development hydrogen



Source: Eurostat (2025).

Nitrogen

Nitrogen is a very important industrial gas that makes up about 78% of the Earth's atmosphere. As one of the most widely used industrial gases, nitrogen plays a vital role across various

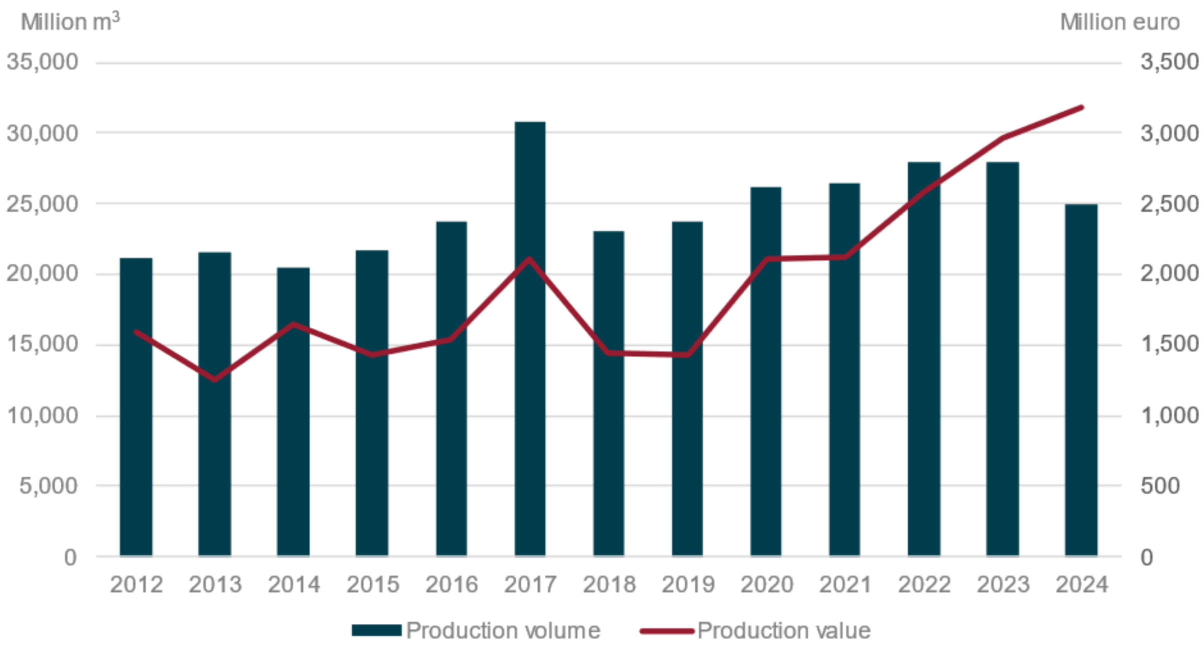
[26] See Gasworld (2025a).

sectors. Its primary application is in the chemical industry, particularly in the production of ammonia through the Haber-Bosch process – a key precursor for fertilizers. Nitrogen is also used extensively in the food and beverage industry for packaging and preservation, where it helps prevent oxidation and spoilage. In addition, nitrogen is crucial in electronics manufacturing, where it provides an inert atmosphere for soldering and semiconductor production. It is also used in the metal industry for heat treatment processes and as a purging gas. Liquid nitrogen, due to its extremely low temperature, is applied in cryogenics, medical storage, and freezing technologies. Looking forward, nitrogen will continue to be a cornerstone of industrial production, especially as global food demand grows and precision manufacturing expands. Although not an energy carrier like hydrogen, nitrogen supports many essential processes that underpin modern economies. Its future potential lies in increasing energy efficiency, reducing waste, and enabling more sustainable production methods, for example, through advanced fertilizer technologies or cleaner industrial cooling and storage systems.

The chart shows the development of nitrogen production in Europe from 2012 to 2024. Between 2012 and 2016, production volumes remained relatively stable, fluctuating between 21,000 and 24,000 million m^3. A noticeable peak occurred in 2017, when production volume exceeded 30,000 million m^3 – the highest level observed in the entire period. However, this increase was short-lived, and volumes declined again in the following years. From 2020 onward, production volume began to rise steadily, reaching nearly 29,000 million m^3 in 2022 before decreasing again in 2023 and 2024. The development of production value followed a similar pattern. Starting at around €1.6 billion in 2012, the production value has continued to rise over the years. From 2019 onward, however, production value increased sharply, reaching approximately €3.2 billion in 2024. This upward trend indicates a rise in market prices or increased value creation in nitrogen-related industries. Pricing dynamics, demand, and added value in downstream applications play a critical role. The increase in production value in 2024, despite a drop in volume, may be attributed to higher nitrogen prices. Overall, the data reflects a stable but gradually growing nitrogen production sector in Europe, with a clear increase in economic significance in recent years. The strong rise in value since 2020 likely results from rising input costs, growing industrial and agricultural demand, and the strategic importance of nitrogen for food production and manufacturing processes.

As with other industrial gases, European production is heavily dominated by Germany. 27.7% of total EU27 nitrogen production comes from Germany in 2024. France is in second place with a share of 14.3%. Also, Belgium, Italy, and the Netherlands play an important role with production shares of around 9%.

Figure 34 EU27 market development nitrogen



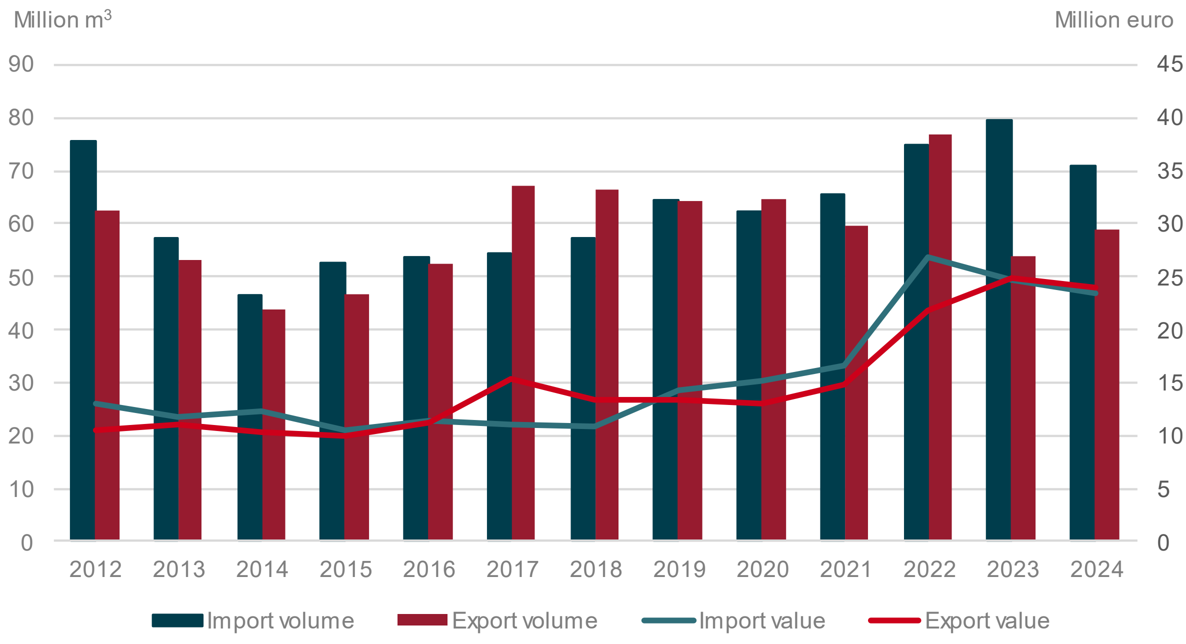
Source: Eurostat (2025).

Figure 35 shows the development of nitrogen trade in Europe between 2012 and 2024. Over this period, import volumes were mostly higher than export volumes, although both grew overall. In 2012, import volume was significantly above export volume, and this pattern remained consistent, with some narrowing of the gap in more recent years. Both import and export values show a gradual upward trend over the period, with a particularly sharp increase after 2021. Import values peaked in 2022 at almost €25 million, before slightly decreasing in 2023 and 2024. Export values followed a similar path, with a notable increase between 2021 and 2023, reaching around €25 million in the final year. Import prices are obviously significantly higher than export prices, because although import volumes were 20.2% higher than export volumes, import and export values were almost identical in 2024. Despite strong domestic production, the relatively high import volumes indicate that Europe relies increasingly on nitrogen imports to meet industrial and agricultural demand. However, given that total production volumes in Europe are much higher than import or export volumes, foreign trade still represents a small share of the overall European nitrogen market, though its significance is increasing.

With a share of 97.2%, nitrogen imports come almost exclusively from other European countries, with Switzerland dominating. On the export side, other European countries are also the main buyers of nitrogen from EU27 production with a share of 88.5%.[27]

[27] Gasworld (2025a).

Figure 35 EU 27 foreign trade development nitrogen



Source: Eurostat (2025)

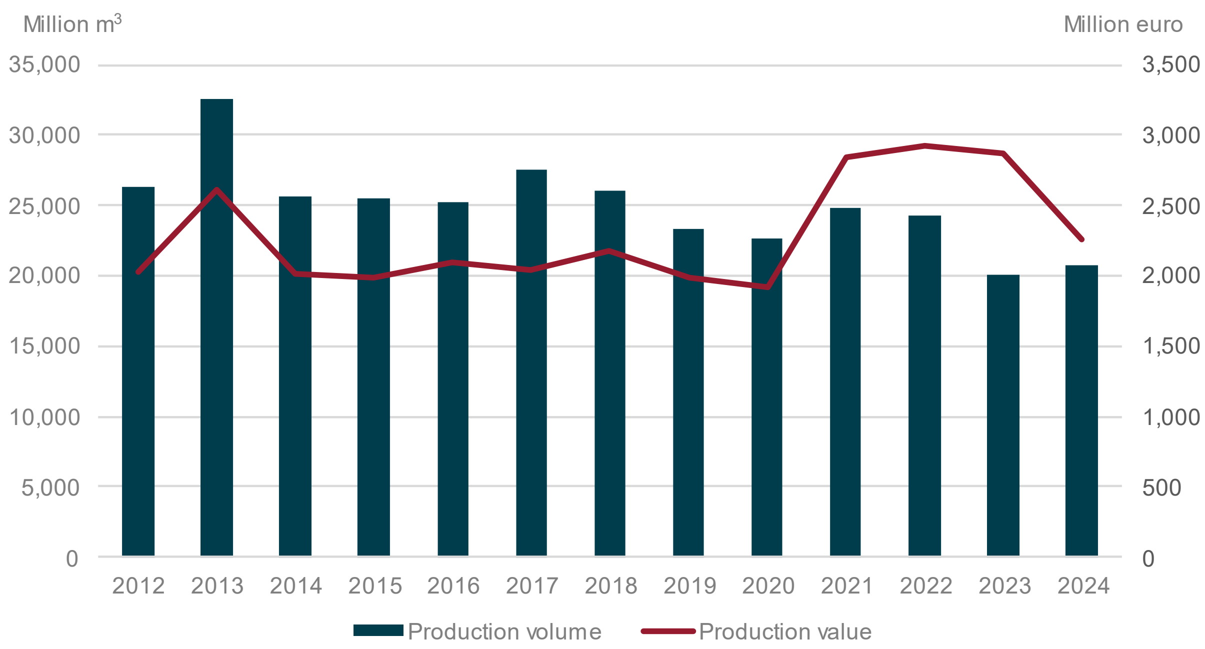
Oxygen

Among the most widely used industrial gases, oxygen serves a crucial role in both everyday life and a broad range of technical applications. Although it is best known as essential for human and animal respiration, oxygen is also a key element in many industrial processes. Its primary use lies in the steel and metal industries, where it enables high-temperature combustion and helps remove impurities during smelting. The chemical and petrochemical sectors also rely on oxygen for oxidation reactions and the production of synthesis gas. In addition to its industrial applications, oxygen is important in healthcare. Medical-grade oxygen is indispensable in hospitals, emergency care, and home treatment for respiratory conditions. Other notable uses include wastewater treatment, glass manufacturing, paper bleaching, and space technologies. Looking to the future, oxygen will continue to be a fundamental input for numerous sectors. It may gain additional relevance in environmental technologies – such as advanced combustion systems and carbon capture – especially as industries move toward cleaner and more efficient production methods.

Oxygen production in Europe between 2012 and 2024 remained relatively steady, though not without notable fluctuations (see Figure 36). The most striking peak occurred in 2013, when production volumes soared to over 32,600 million m^3. In most other years, output ranged between 23,000 and 27,000 million m³. However, a downward trend set in after 2020, culminating in a significant drop in 2023, when volumes fell to around 20,100 million m³, the lowest level within the observed period. However, production volumes recovered slightly in 2024. In contrast, the production value followed a different trend. After remaining relatively flat or declining slightly for several years, a sharp increase began in 2021. By 2022, the total value of European oxygen production had surpassed €2.9 billion, marking a new high point. This growth occurred despite falling production volumes, suggesting that prices increased strongly. In 2024, volumes remained relatively flat while production values decreased significantly, indicating a sharp decrease in prices. Several factors may explain this price-driven development: increased energy costs, supply chain challenges, and rising demand in key sectors such as healthcare, metallurgy, and electronics. Overall, the data suggests that while the physical production of oxygen has declined in recent years, its economic significance has increased. This underlines the importance of market dynamics and external influences in shaping the industrial gas sector in Europe.

As for other industrial gases, Germany is the most important oxygen producer in Europe. 25.8% of oxygen production in the EU27 came from Germany. Again, Belgium and the Netherlands also play an important role with a production share of 10.7% and 9.2% respectively.

Figure 36 EU27 market development oxygen

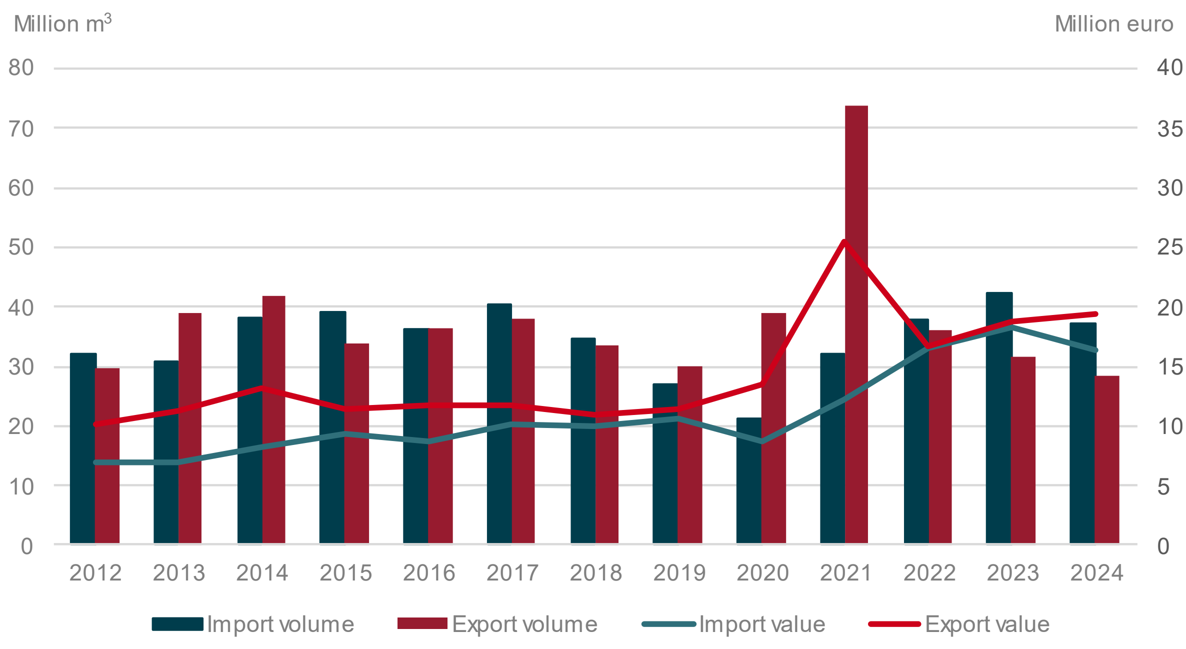


Source: Eurostat (2025).

Figure 37 shows that oxygen trade in Europe has shown moderate fluctuations over the past decade, with several sharp shifts pointing to exceptional events or changes in market dynamics. While both import and export volumes remained relatively stable between 2012 and 2020, 2021 marked a notable outlier. Import volumes ranged mostly between 30 and 40 million m³, with small year-to-year changes. Export volumes followed a similar pattern. One major exception occurred in 2021, when export volumes suddenly surged to over 73 million m³, more than double the previous year. This sharp increase was mirrored by a spike in export value, which peaked at around €25.5 million, suggesting extraordinary demand abroad, likely linked to the COVID-19 pandemic and increased need for medical oxygen. Import values, by contrast, rose more gradually over the period, increasing steadily from around €6.8 million in 2012 to over €18 million in 2023. However, import values decreased to around €16.3 million due to lower imports in 2024. Export values also followed a relatively stable path for most of the timeframe, apart from the sharp spike in 2021 and the subsequent decline in 2022. Since 2023, import volumes had slightly overtaken export volumes again, with import and export values converging at just under €19 million each. Nevertheless, import volumes were almost a third higher than export volumes, meaning that export prices were significantly higher than import prices. In relation to total production, foreign trade in oxygen only plays a minor role. In relation to the European production volume in 2024, imports and exports of oxygen together accounted for just 0.3%.

As with many other gases, Europe is the most important market for oxygen trade. 95.4% of EU27 oxygen exports in 2023 were destined for other European countries. Conversely, 83.5% of the corresponding imports came from other European countries, with Switzerland dominating on the import and the United Kingdom on the export side. In previous years, Russia was the most important buyer of European oxygen. However, the introduction of trade sanctions in 2022 has significantly reduced Russia's importance for foreign trade with industrial gases.[28]

Figure 37 EU 27 foreign trade development oxygen



Source: Eurostat (2025).

28 See Gasworld (2025a).

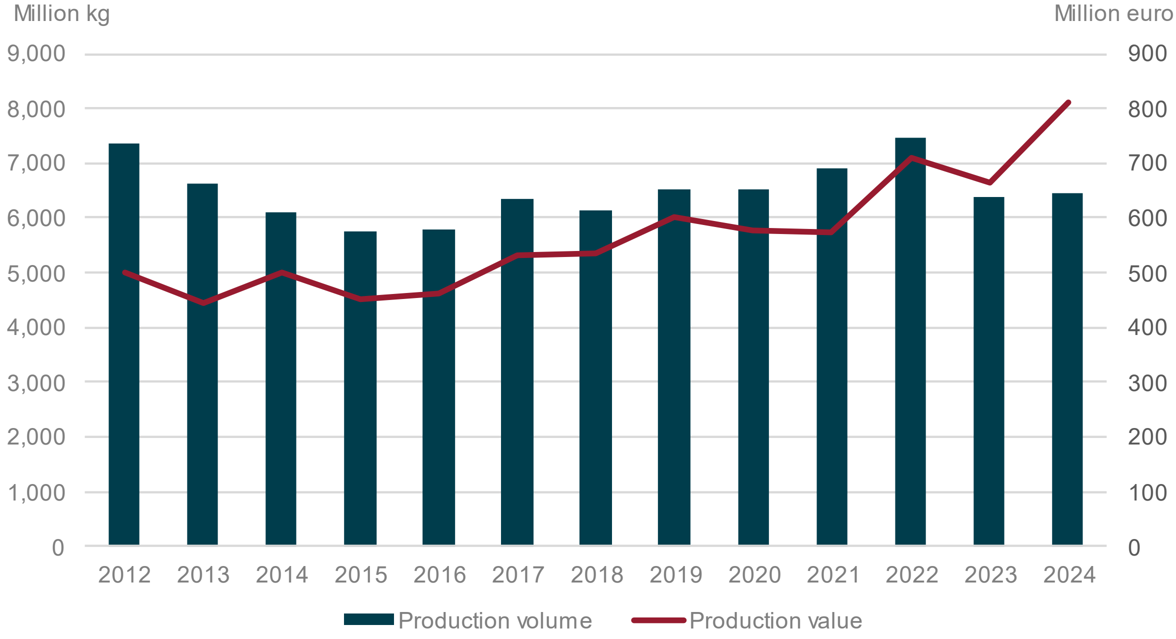
Carbon dioxide

Although often associated with climate change, carbon dioxide is also an important industrial gas with a wide range of commercial applications. It is produced both as a natural byproduct and through industrial processes such as ammonia and hydrogen production, fermentation, and combustion. In the industrial gas sector, CO_2 is primarily used in the food and beverage industry – for example, in carbonation of drinks, food preservation, and packaging. It also plays a role in welding processes, fire suppression systems, greenhouse plant growth, and as a refrigerant in cooling technologies. In recent years, carbon dioxide has also gained attention in emerging technologies such as carbon capture and storage (CCS) and carbon utilization, where captured CO_2 is converted into fuels or chemical products. These innovations aim to reduce net emissions and support the transition to a low-carbon economy. Despite its role as a major greenhouse gas, carbon dioxide remains a valuable industrial input in many sectors. As climate targets tighten, both the source and management of CO_2 are becoming increasingly important – not only in reducing emissions, but also in enabling circular carbon use within industrial systems.

Figure 38 shows carbon dioxide production in Europe has followed a relatively stable path over the past decade, though certain years reflect notable shifts. In 2012, production volumes started at 7,346 million kg, the second highest level recorded during the observed period. Afterwards a gradual decline started, reaching a low point with the production of only 5,760 million kg in 2015. From then on, production volumes slowly recovered, peaking again in 2022 before dipping remarkably in 2023. Production value, on the other hand, tells a slightly different story. While volumes fluctuated within a fairly narrow range, the value of CO_2 production increased steadily – particularly from 2017 onward. By 2024, the total production value reached more than €811 million, marking a clear upward trend despite the volume decline that same year. The sharp rise in value between 2021 and 2024 can also be attributed to energy price inflation, rising costs for CO_2, or heightened demand during periods of supply disruption.

The most important production countries for carbon dioxide in the EU27 in 2024 were the Netherlands (production share of 20.1%), Spain (16.2%), and Germany (14.1%). France (12.8%) and Poland (11.9%) followed in the next places.

Figure 38 EU27 market development carbon dioxide

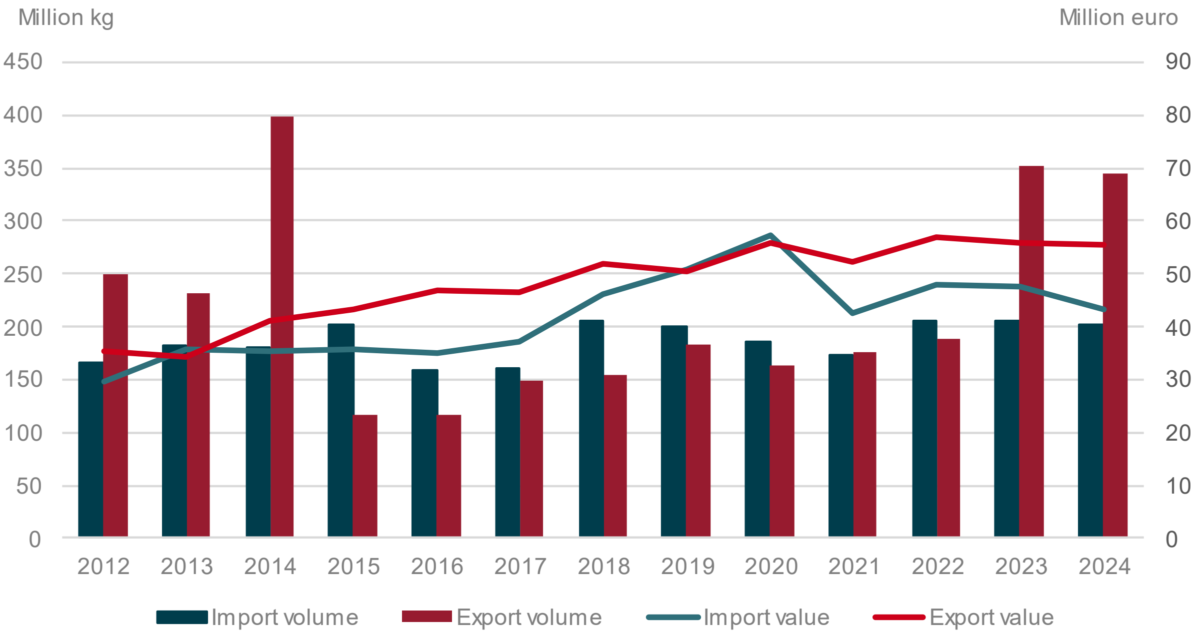


Source: Eurostat (2025).

Trade in carbon dioxide across Europe has evolved steadily over the past decade, with notable differences between volume and value trends (see Figure 39). Between 2012 and 2024, import volumes fluctuated within a relatively narrow band, typically ranging from 160 to just under 210 million kg. While the quantities changed only moderately, the import value showed a more distinct upward movement, gradually increasing from around €30 million in 2012 to above €57 million in 2020. On the export side, the picture is more uneven. Export volumes peaked sharply in 2014, temporarily rising to nearly 400 million kg – an anomaly compared to all other years in the data set. After that spike, volumes fell and remained comparatively lower and more stable. In 2023, however, export volumes rose again markedly, reaching a level similar to the 2014 peak which was also retained in 2024. Export values, in contrast, showed a much smoother path. They increased gradually over the entire period, from roughly €35 million in 2012 to nearly €56 million in 2024, despite the fluctuations in quantity. This decoupling of value and volume suggests that the role of CO2 as a tradable product is shifting: while volumes do not change drastically year by year (with some exceptions), the monetary value of the traded gas is on the rise. In summary, although carbon dioxide remains a relatively modest segment of the industrial gas trade, its rising value points to a trend of increasing economic importance and possibly more targeted use in higher-value applications.

The countries of origin of EU27 imports of carbon dioxide are almost exclusively in Europe. 98.2% of imports in 2023 came from here, with the largest share by far coming from Norway, followed by North Macedonia and Serbia. On the export side, the majority (87.7%) of carbon dioxide exports also go to European countries, with the United Kingdom being the most important buyer.[29]

Figure 39 EU 27 foreign trade development carbon dioxide



Source: Eurostat (2025).

Nitrogen oxides

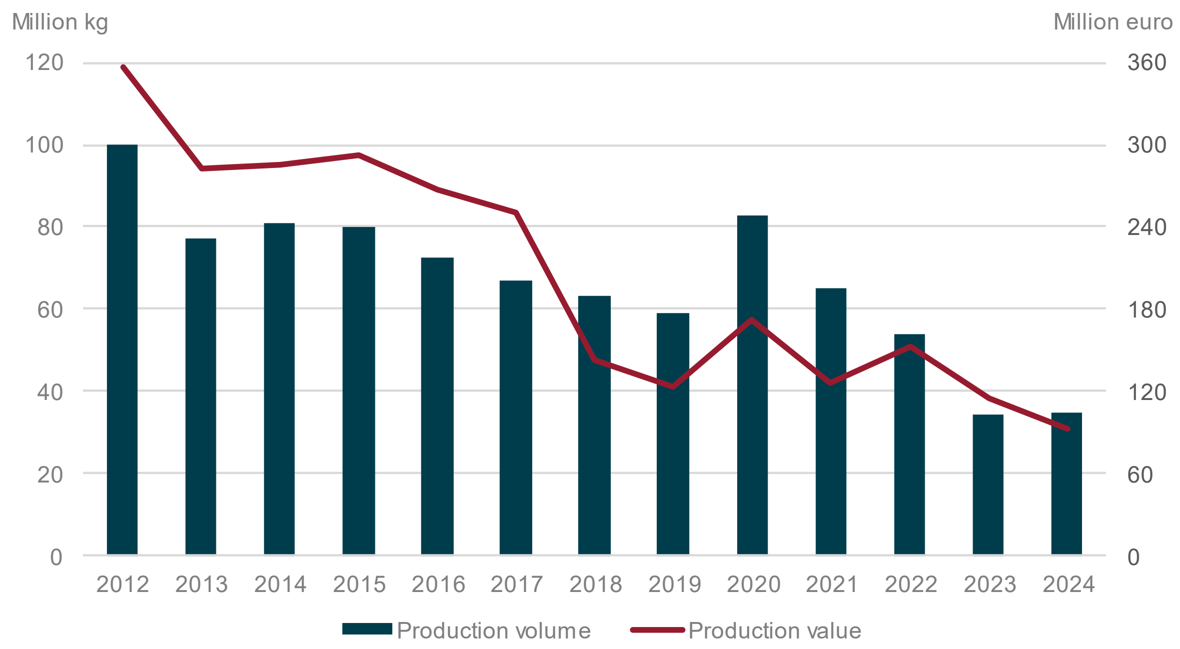
Nitrogen oxides, primarily nitrogen monoxide (NO) and nitrogen dioxide (NO2), are mostly produced as byproducts during high-temperature combustion processes in various industries such as power generation, cement manufacturing, waste incineration, glass production, and refineries. Although nitrogen oxides themselves are rarely used directly as industrial products, there are some specialized applications where related nitrogen compounds and nitrogen oxides play an important role. In the semiconductor and electronics industry, gases like nitrous oxide (N2O), ammonia (NH3), and nitrogen trifluoride (NF3) are used in processes such as chemical vapor deposition to create thin layers on silicon wafers. Nitrogen oxides may also form as byproducts that require careful handling. In medicine, nitric oxide (NO) is used therapeutically due to its ability to dilate blood vessels and is essential for treating conditions like pulmonary hypertension and certain cardiovascular diseases. Furthermore, environmental protection technologies in industry focus on reducing nitrogen oxide emissions – using methods such as selective catalytic reduction (SCR) or selective non-catalytic reduction (SNCR) – where ammonia or urea is injected into exhaust gases to convert harmful nitrogen oxides into harmless nitrogen and water. Overall, nitrogen oxides are primarily considered pollutants in industrial contexts, but their controlled application in medicine and certain

29 Gasworld (2025a).

manufacturing processes, as well as their management in emission control, make them significant in various technical fields.

Figure 40 shows that over the past decade, nitrogen oxides production in Europe has experienced a steady and significant decline. In 2012, production volumes were 100 million kilograms. By 2023, that figure had dropped by more than half, falling below 35 million kilograms – the lowest level recorded during the observed period. The production value shows a similar pattern. After starting at just over €356 million in 2012, the value declined sharply in the following years, with only short-lived recoveries in 2020 and 2022. In 2024, the production value fell again, reaching €93 million. These trends reflect both reduced production and likely falling market demand or unit prices. Several factors could explain this long-term downward movement. On the one hand, stricter environmental regulations and emission limits in Europe have reduced the permissible use and unintentional release of nitrogen oxides. On the other hand, the shift towards cleaner technologies and alternative production methods – particularly in the chemical industry and the energy sector – has reduced reliance on nitrogen oxides as an intermediate or byproduct. Altogether, the data illustrates a clear transition: nitrogen oxides production in Europe is not only shrinking in scale but also declining in economic weight. Whether this trend will continue depends on regulatory developments, technological shifts, and the evolution of demand in chemical production chains.

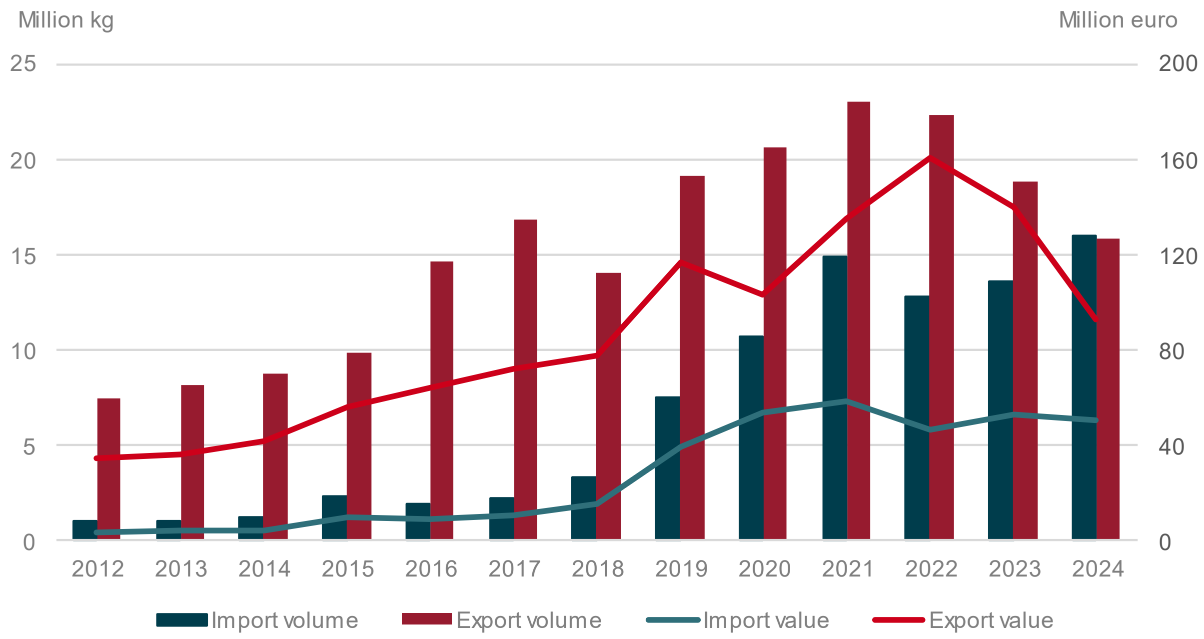
Figure 40 EU27 market development nitrogen oxides



Source: Eurostat (2025).

Figure 41 shows, Europe's trade in nitrogen oxides developed dynamically between 2012 und 2024, with both import and export volumes showing significant growth – especially in comparison to the sharp decline in domestic production during the same period. Export volumes rose steadily, tripling from around 7.5 million kilograms in 2012 to over 23 million kilograms by 2021. Export values followed a similar but even more pronounced trend, increasing from roughly €35 million to a peak of over 160 million euro in 2022. These figures indicate growing international demand for nitrogen oxides-based products or intermediates – most likely connected to the production of nitric acid and other chemical compounds. Imports also grew significantly, with volumes rising from roughly 1 million kilograms in 2012 to 16 million kilograms in 2024. Import values have also risen sharply. This rising trade activity stands in contrast to the overall decline in domestic nitrogen oxides production, which fell sharply between 2012 and 2024, both in volume and in value. The data suggests a structural shift in Europe's nitrogen oxides industry: domestic production is decreasing, while cross-border trade is becoming more important. One possible explanation is the consolidation or relocation of production capacity, probably due to stricter environmental regulations, rising costs, and specialization in high-value-added applications.

Figure 41 EU 27 foreign trade development nitrogen oxides



Source: Eurostat (2025).

A.2 Downstream effects

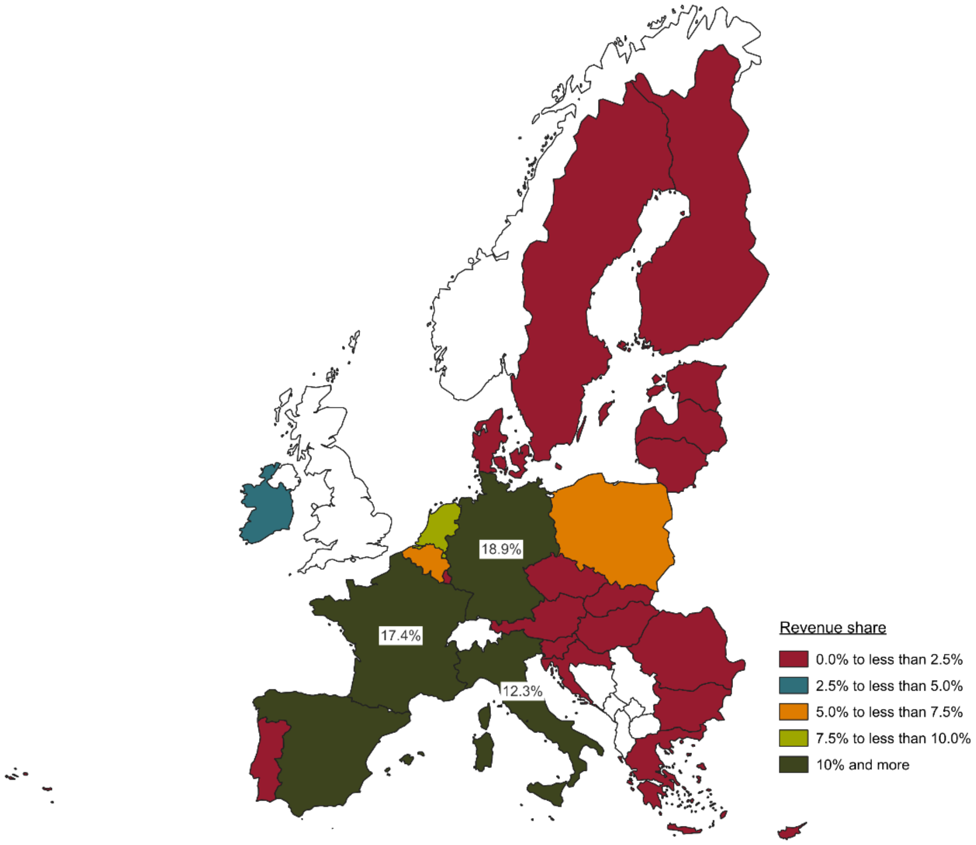
Food

With a market share of 8.7%, the food sector ranks fourth among the most important consumer industries for industrial gases in 2024 (see Figure 10). It is a vital part of everyday life and public well-being, supplying safe, high-quality food and beverages to millions of people across Europe. The sector encompasses the processing of raw agricultural materials into a wide range of products, from staple foods and dairy goods to confectionery, packaged meals, and speciality items. It also includes beverages of all kinds, from bottled water and soft drinks to wine, beer, and spirits, as well as the manufacture of tobacco products. Beyond meeting basic nutritional needs, the food sector supports cultural traditions, regional identities, and consumer lifestyles, while contributing to innovation in areas such as convenience foods, functional nutrition, and sustainable packaging. Statistically, the food sector consists of three NACE divisions:

- 10 – Food products
- 11 – Beverages
- 12 – Tobacco products

In the food sector, industrial gases are widely used to ensure product quality, extend shelf life, and support hygienic, efficient production processes. In the manufacture of food products (NACE 10), gases such as nitrogen and carbon dioxide play a central role in modified atmosphere packaging, which slows down spoilage by inhibiting the growth of bacteria and oxidation. This technique is widely used for meat, dairy, baked goods, and ready-to-eat meals. Liquid nitrogen is also essential for cryogenic freezing and chilling, offering a rapid, uniform cooling process that preserves texture and nutritional value. In baking, carbon dioxide is used as a leavening agent, and gases like nitrous oxide may be used in whipping cream or foams. The beverage industry (NACE 11) relies heavily on carbon dioxide for carbonation in soft drinks, beer, and sparkling water. Nitrogen is increasingly used in still beverages and coffee-based drinks to improve mouthfeel and prevent oxidation. Gases are also involved in inerting processes during bottling and storage to maintain flavour stability and prevent spoilage. Additionally, oxygen is sometimes used in water treatment and cleaning processes to meet strict hygiene standards. In the production of tobacco products (NACE 12), industrial gases serve more specialized functions. Nitrogen is commonly used to create inert atmospheres during storage and processing to protect tobacco leaves from oxidation and microbial growth. Carbon dioxide may be applied in extraction or drying processes, particularly for producing smokeless or reduced-risk tobacco products. Furthermore, gases can be used in packaging to preserve aroma and maintain product consistency over time. Across all three branches, the use of industrial gases contributes significantly to food safety, product quality, and process efficiency, making them an indispensable part of modern food and beverage manufacturing.

Figure 42 Market structure of food in the EU27 in 2023



Source: Eurostat (2025b), ETR
Note: Percentages reflect each country's share out of total EU27 levels

Figure 42 presents the structure of the food sector within the European Union. In 2023, the combined industries of food products, beverages, and tobacco generated total revenues of approximately €1.54 trillion across the EU27 (16.3% of revenue in the entire manufacturing sector) and employed over 4.7 million people. Germany holds the largest share within this sector, contributing around €290 billion in revenue – equivalent to 18.9% of the EU total – and employing more than 983 thousand people, or roughly 20.9% of the sector's European workforce. This highlights Germany's role as the EU's leading location for food production, driven by its large domestic market, advanced processing technologies, and strong export orientation. France and Italy follow with sector revenue shares of 17.4 and 12.3%, respectively. Both countries have highly developed food and beverage industries with strong regional identities and internationally recognized product standards. The fact that the shares of revenue and employment are very similar in most countries indicates that, unlike most other customer industries, there are no such marked differences in productivity in the food sector in European countries.

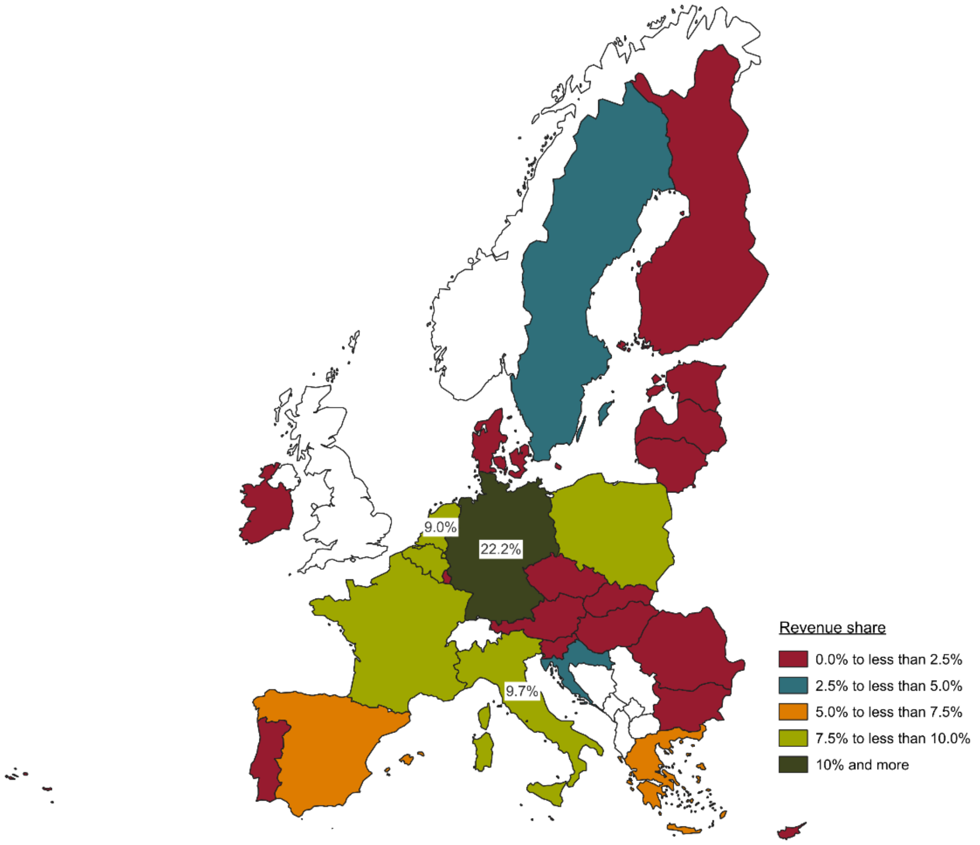
In addition, it becomes clear that, compared to other industrial sectors, the food industry is more geographically distributed across the EU. However, the concentration of revenue and workforce in a few key countries underlines that a substantial share of the sector's economic activity remains clustered in large domestic markets as well as traditional food-producing regions with established infrastructure and global market access.

Refining

Refining is a cornerstone of Europe's energy system, as it transforms crude oil into transportable and versatile fuels that power mobility, industry, and heating. By converting raw feedstocks into products such as gasoline, diesel, jet fuel, and heating oil, the sector ensures a steady and reliable supply of energy to households, businesses, and transport networks. It also produces vital feedstocks for the chemical industry, supporting the manufacture of plastics, lubricants, and a wide range of other industrial materials. Statistically, the sector is represented by NACE division 19 – Manufacture of coke and refined petroleum products. In the context of the European industrial gases market, refining ranks fifth, accounting for 7.1% of total demand in 2024 (see Figure 10). While its overall share is moderate compared to other industries, it is the largest single consumer of certain gases – most notably hydrogen, which plays a critical role in refining processes to meet stringent fuel quality and environmental standards.

In petroleum refineries, industrial gases are vital to numerous core processes that transform crude oil into usable fuels and petrochemical feedstocks. Hydrogen is the most critical gas in modern refining, particularly in hydrotreating and hydrocracking units. These processes use hydrogen to remove contaminants such as sulphur, nitrogen, and metals from intermediate products and to break down heavier hydrocarbons into lighter, higher-value fuels like diesel, gasoline, and jet fuel. The demand for hydrogen in refineries has steadily increased in response to tighter fuel quality standards and environmental regulations, particularly those targeting ultra-low sulphur fuels. In addition, nitrogen is widely used for purging, blanketing, and pressure control throughout the refinery to create inert conditions that prevent fires, explosions, and contamination. It is essential during equipment maintenance, pipeline cleaning, and storage of flammable materials. By displacing oxygen and moisture, nitrogen ensures both safety and product integrity. Oxygen is used more selectively in refining, primarily in oxygen-enriched combustion to improve furnace efficiency and reduce fuel consumption. It can also be applied in certain oxidation reactions or in the treatment of wastewater and off-gases. In addition, carbon dioxide and other inert gases may be used for cooling, cleaning, or as part of emissions control systems. Overall, industrial gases play a central role in making refinery operations safer, cleaner, and more efficient, and are indispensable in supporting compliance with modern environmental and performance standards.

Figure 43 Market structure of refining in the EU27 in 2023



Source: Eurostat (2025b), ETR
Note: Percentages reflect each country's share out of total EU27 levels

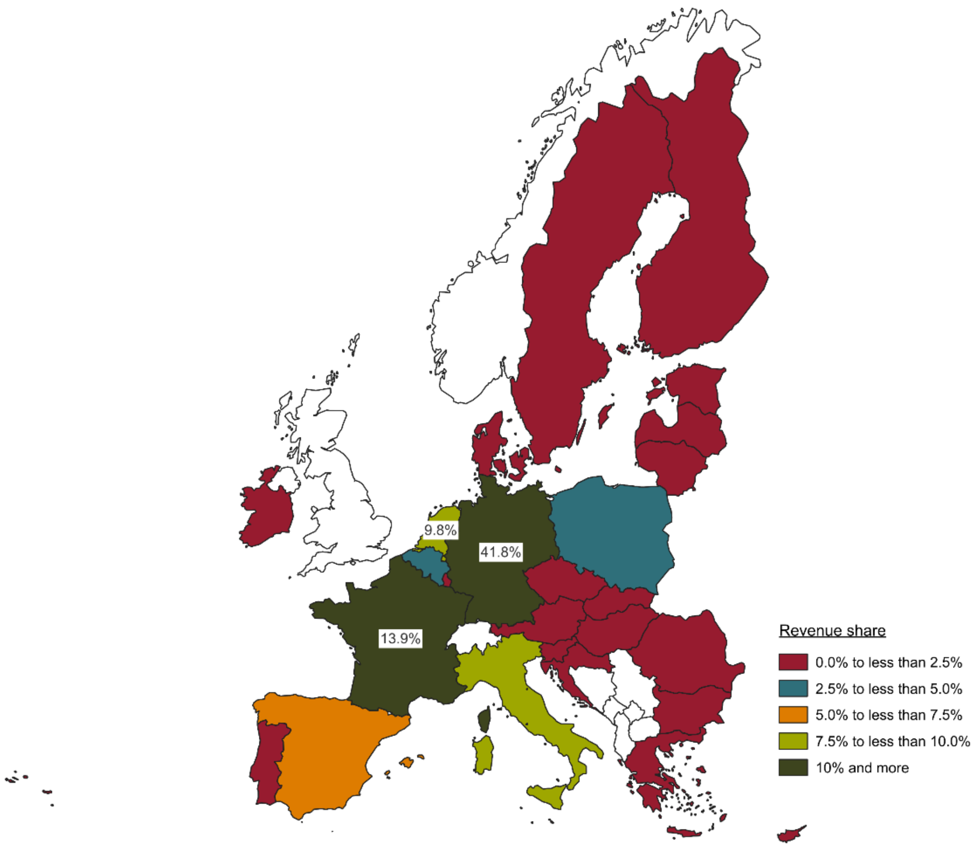
Figure 43 shows the revenue structure of the refining sector within the European Union. In 2023, the industry generated total revenues of approximately €586 billion across the EU27 (6.2% of revenue in the entire manufacturing sector) and employed more than 159 thousand people. Despite its relatively low employment compared to other manufacturing sectors, refining remains a strategically important and capital-intensive industry, supplying essential fuels and feedstocks for transport, industry, and chemical production. Germany holds the leading position in this sector, accounting for 22.2% of total EU revenue. This dominant share reflects the country's large refining capacity, advanced processing infrastructure, and central location within Europe's energy distribution network. Italy follows with a 9.7% share, benefiting from access to both domestic and imported crude oil, as well as a strong connection to the Mediterranean market. The Netherlands ranks third with 9.0%, supported by major port facilities and close integration with petrochemical hubs. Other notable contributors include France, Belgium, and Poland, each generating more than 7.5% of the sector's EU-wide revenue. These countries host strategically located refineries that serve both national markets and international trade routes. The data clearly show that refining activity in the EU is highly concentrated in a small number of member states. This reflects the sector's dependence on access to ports, energy infrastructure, and economies of scale. Unlike more labour-intensive industries, refining is shaped by technological complexity, regulatory compliance, and the need for continuous investment – factors that favour a limited number of highly specialised locations.

Healthcare

Healthcare is one of the most critical sectors for maintaining public well-being, ensuring access to medical treatment, and supporting population health across all age groups. It encompasses a wide range of services including hospitals, outpatient care, diagnostics, and emergency medicine. Statistically, the sector is captured under NACE division 86 – Human health activities. Beyond its social and ethical relevance, healthcare also represents a significant industrial sector with complex logistical and technical demands. In the context of the European market for industrial gases, the healthcare sector ranks sixth in 2024, accounting for approximately 7.1% of total gas consumption (see Figure 10). However, its importance goes far beyond this share, as it is a primary user of certain high-purity and medical-grade gases. The sector's strict regulatory requirements and need for uninterrupted supply further underline the strategic importance of industrial gases in healthcare infrastructure.

In the healthcare sector, industrial gases are essential to a wide range of medical and clinical applications, many of which are critical to patient care and hospital operations. Among the most important is medical oxygen, which is vital for respiratory support in both emergency and long-term treatments. It is used extensively in anaesthesia, intensive care units, and for patients with chronic respiratory conditions. The COVID-19 pandemic further highlighted the systemic importance of reliable oxygen supply in healthcare systems. Nitrous oxide, commonly known as "laughing gas," is widely used as an anaesthetic and analgesic, particularly in surgery, dentistry, and obstetrics. It provides fast-acting sedation and pain relief, often in combination with other agents. Medical air, a controlled mixture of gases – typically compressed, purified atmospheric air – is used for respiratory therapy and as a carrier gas in anaesthesia. Carbon dioxide is employed in minimally invasive procedures, such as laparoscopy and endoscopy, where it is used to inflate body cavities and improve visibility during surgery. It is also used in cryotherapy and dermatological treatments. Nitrogen plays several roles in healthcare. In its liquid form, it is crucial for cryopreservation of biological materials such as blood, reproductive cells, and tissues, especially in laboratories, fertility clinics, and biobanks. Gaseous nitrogen is also used for cooling during surgical procedures and in MRI systems. Finally, helium is sometimes used in breathing mixtures for patients with severe airway obstruction, due to its low density which reduces airway resistance. It is also a component in certain imaging technologies, such as superconducting magnets in MRI machines. Across all these applications, the healthcare sector requires ultra-high purity, pharmaceutical-grade gases with strict quality control. Industrial gases in this context are not only technical products, but essential components of life-saving treatments and diagnostics.

Figure 44 Market structure of healthcare in the EU27 in 2023



Source: Eurostat (2025b), ETR
Note: Percentages reflect each country's share out of total EU27 levels

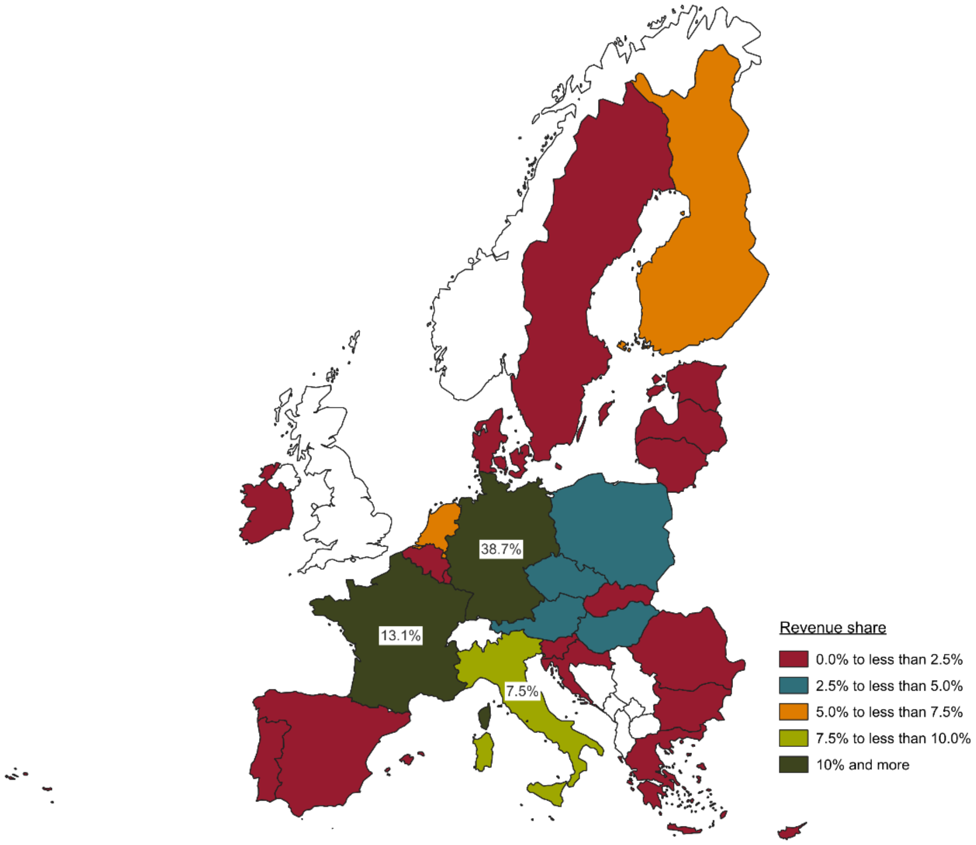
Figure 44 illustrates the market structure of the healthcare sector across the European Union. In 2023, the sector generated total revenues of approximately €724 billion in the EU27 and employed more than €8.2 million people, making it not only one of the largest employers in Europe but also a cornerstone of public infrastructure and social stability. Germany dominates the sector at the European level, accounting for 41.8% of total healthcare revenue and even 42.3% of total employment. This exceptionally high share reflects Germany's extensive hospital network, large population, high healthcare spending, and strong integration of public and private providers. France follows with a significantly smaller but still substantial share of 13.9%, supported by a well-developed public healthcare system and a broad range of specialised services. The Netherlands ranks third with a 9.8% revenue share, known for its efficient and innovative healthcare system with strong outpatient and preventive care. The data indicate a high concentration of healthcare revenue in just a few member states, particularly in western and northern Europe. This reflects not only demographic and economic differences, but also varying healthcare models, financing structures, and levels of medical infrastructure across the EU. While healthcare services are present in all member states, the revenue distribution underlines that the economic weight of this sector is not evenly spread, but rather concentrated in countries with large, well-funded health systems.

Electronics

The electronics sector is a cornerstone of modern industrial innovation, underpinning technologies in fields such as communications, mobility, healthcare, energy, and automation. Statistically captured under NACE division 26 – Manufacture of computer, electronic and optical products, the sector includes the production of semiconductors, microelectronics, sensors, imaging systems, and advanced computing hardware. It is defined by high-value manufacturing, rapid innovation cycles, and extreme precision requirements, making it one of the most technologically advanced branches of the manufacturing industry. In the context of the European industrial gases market, the electronics sector accounted for 3.3% of total gas consumption in 2024 (see Figure 10). Although relatively small in volume terms compared to other industries, its demand is highly specialised and purity-critical, reflecting the stringent technical standards of electronics manufacturing.

In the electronics sector, industrial gases are indispensable for the production of semiconductors, microchips, displays, and other high-tech components. Due to the extreme sensitivity of electronic devices to contamination, the industry requires ultra-high purity gases, often at “six nines” purity levels, and precise gas delivery systems. Nitrogen is one of the most widely used gases in electronics manufacturing. It provides an inert atmosphere in cleanrooms, prevents oxidation during wafer processing, and is used extensively in purging, drying, and packaging operations. Hydrogen is essential in processes such as annealing and reduction, as well as in certain deposition techniques where a reducing environment is required. Argon is used in plasma etching, ion implantation, and sputtering for thin film deposition – common steps in the fabrication of semiconductor layers and integrated circuits. Helium, due to its thermal conductivity and inertness, is used in leak detection, cooling, and some lithography processes. A wide range of specialty gases – including silane, phosphine, arsine, ammonia, and various fluorinated compounds – are crucial in chemical vapor deposition (CVD), etching, doping, and cleaning of process chambers. These gases enable the fine structural control needed to manufacture nanoscale features on chips and other electronic components. Because even the slightest contamination can result in costly defects, the electronics industry places exceptional demands on gas quality, purity, and supply reliability. As such, industrial gases are not only auxiliary materials but critical process enablers at every stage of electronics production.

Figure 45 Market structure of electronics in the EU27 in 2023



Source: Eurostat (2025b), ETR

Note: Percentages reflect each country's share out of total EU27 levels

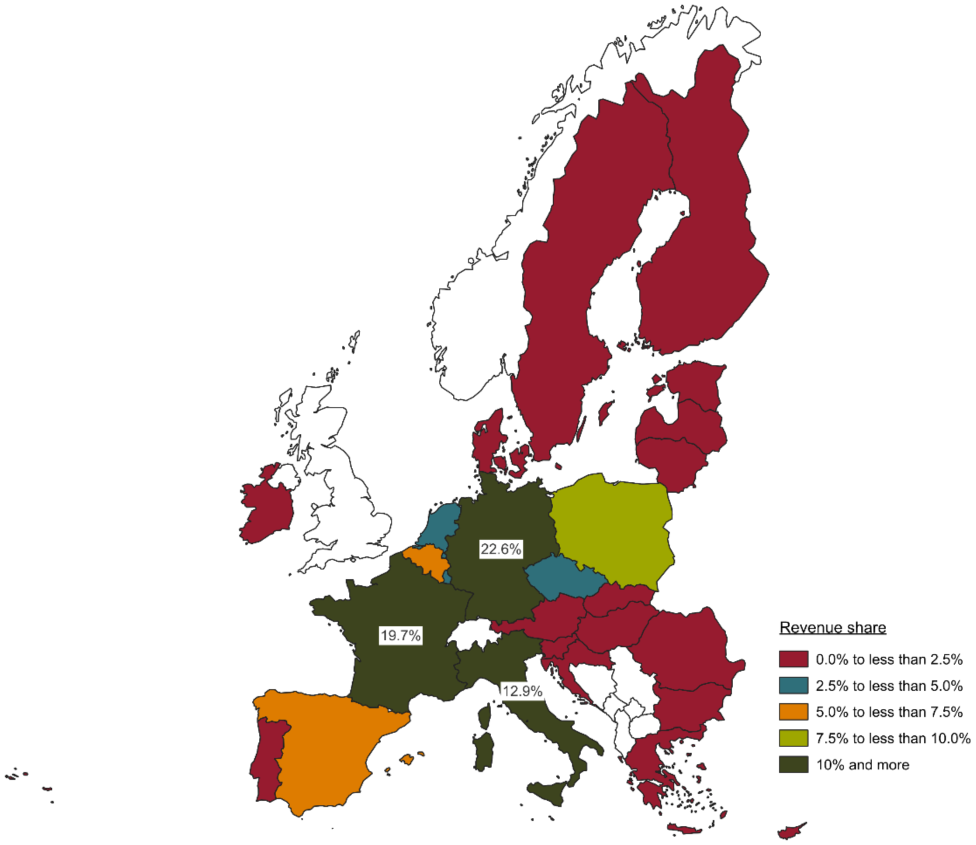
Unlike more traditional branches of manufacturing, the electronics sector is shaped by rapid innovation, high R&D intensity, and global value chains. In 2023, the sector generated approximately €333 billion in revenue across the EU27 (3.5% of revenue in the entire manufacturing sector), making it a crucial component of Europe's high-tech industrial base. In addition, the industry employed more than 1.1 million people with a high concentration of skilled technical and engineering roles. As Figure 45 shows, Germany holds a leading position in this field, contributing 38.7% of total EU revenue. Its dominance reflects strengths in industrial automation, semiconductor manufacturing, and metrology. France follows with a 13.1% share, supported by its activities in defence electronics, aerospace systems, and medical imaging technologies. Italy, accounting for 7.5%, plays a key role in consumer electronics, optical instruments, and electronics for the automotive sector. The geographic distribution of the sector highlights its tendency to cluster in regions with strong research ecosystems, specialised labour markets, and advanced production infrastructure. Compared to other manufacturing industries, electronics shows a particularly high degree of technological concentration, with a few countries generating the vast majority of value added in the EU.

Glass

The glass industry is a key component of Europe's manufacturing landscape, supplying critical materials to sectors such as construction, automotive, packaging, and advanced technologies. Statistically classified under NACE group 23.1 – Manufacture of glass and glass products, it encompasses the production of flat glass for windows and facades, container glass for food and beverages, glass fibre for insulation and composites, and specialty glass for optical, medical, and scientific applications. The sector is characterised by high energy intensity, continuous production processes, and stringent quality requirements. It also plays an important role in sustainability efforts, with increasing emphasis on recycling, resource efficiency, and the development of low-carbon production methods. In the context of the European industrial gases market, the glass sector accounted for 0.5% of total gas consumption in 2024 (see Figure 10), reflecting its relatively modest share in volume terms despite its strategic importance to multiple value chains.

In the glass industry, industrial gases are essential for both primary production and the processing of finished products. Oxygen is the most significant gas in this sector, used to enrich combustion air in glass melting furnaces. Oxygen-enriched combustion increases flame temperature, improves energy efficiency, and reduces emissions of nitrogen oxides (NO_x) compared to conventional air-fired systems. Natural gas and oxygen together enable precise temperature control, which is critical for achieving the desired clarity, strength, and uniformity of the glass. Nitrogen is often employed as a protective atmosphere in certain glass processing steps, particularly in the manufacture of coated or laminated glass, to prevent oxidation and contamination. Hydrogen, sometimes used in combination with nitrogen, serves in reducing atmospheres for specialty glass production, ensuring the correct optical and surface properties. Argon plays a role in the production of high-performance insulating glass units, where it is used as a filling gas between panes to improve thermal insulation. It is also applied in the manufacture of specialty optical glass to protect sensitive surfaces during processing. In addition, carbon dioxide may be used for surface cleaning, polishing, or cooling, especially in precision glass applications. Across all segments – whether container glass, flat glass, or specialty products – industrial gases contribute to higher product quality, lower energy consumption, and improved environmental performance in glass manufacturing.

Figure 46 Market structure of glass in the EU27 in 2023



Source: Eurostat (2025b), ETR

Note: Percentages reflect each country's share out of total EU27 levels

Figure 46 illustrates the distribution of revenue in the European glass industry by country. The data show a strong concentration of economic activity in a few member states. Again, Germany holds the largest share, accounting for 22.6% of total EU revenue in this sector in 2023, followed by France with 19.7% and Italy with 12.9%. These three countries together generate more than half of the sector's total revenue in the EU27. In 2023, the glass industry in the EU27 reached a total revenue of €70 billion (0.7% of revenue in the entire manufacturing sector) and employed approximately 300 thousand people.

Annex B – The input-output method as an analytical tool

Input-output analysis is a method of empirical economic research that maps and evaluates the supply relationships between individual economic sectors. Assuming that the supply relationships between economic sectors are in a constant linear relationship, they can be represented in an input-output table. This table shows the relationship between value-added components and final demand components at a detailed sectoral level. In Europe, the corresponding data is provided by the Eurostat. The input-output tables are estimated based on collected supply and use tables. They present the interconnections between 63 sectors (production areas) in total, as well as separated into domestic and imported goods. Input-output accounting is part of the national accounts.

Input-output analysis provides a powerful tool for estimating the overall economic impacts of changes in final demand in one or more industries. In conventional notation, *x* represents the output vector (production value) and *f* the vector of final demand. The matrix *A* represents the supply relationships between the sectors. The elements of this matrix are the input coefficients a_{ij}, which describe the share of intermediate products from sector *i* in the production value of sector *j*. The relationship between production value and final demand is therefore: $x = Ax + f$. A change in final demand directly triggers changes in production in at least one sector. To expand production, intermediate inputs must be obtained from other sectors, which in turn require inputs themselves. Altogether, this leads to the following production changes:

$$x = \underbrace{f}_{Direct\ effect} + \underbrace{Af}_{First-round\ effect} + \underbrace{A^2f + A^3f + A^4f + \cdots}_{Value\ chain\ effect}$$

The direct effect (***f***) is the effect that occurs immediately in the affected sectors – i.e., the immediate value-added and employment effects. The first-round effect (*Af*) describes the additional production, value added, and employment in the companies that produce intermediate goods for the sectors directly affected by the change in final demand. The value chain effect is observed along the entire upstream value chain, as each sector requires a certain number of inputs for the production of other sectors.

By rearranging the equation $x = Ax + f$, the relationship between production value and final demand can be expressed as:

$$x = (I - A)^{-1} f$$

From this, the Leontief inverse $(I - A)^{-1}$ yields multipliers that allow an estimation of the economy-wide production effects triggered by a change in final demand. Based on these, and assuming constant relationships, changes in gross value added and employment are derived.

An increase in employment goes hand in hand with an increase in incomes. Higher incomes allow for additional consumption spending, which in turn leads to further increases in final demand and thus further production increases. This additional chain reaction is referred to as the *induced effect*, which is also estimated within the framework of input-output analysis.

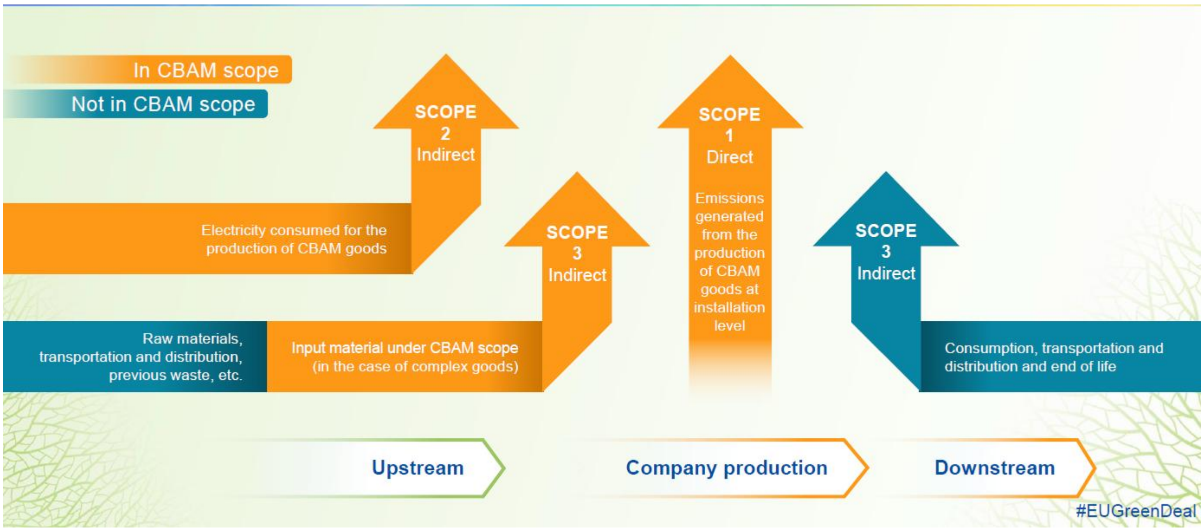
Annex C – Evolving Carbon Leakage Protection

The Carbon Border Adjustment Mechanism (CBAM)

The CBAM introduces carbon pricing to imported products whose domestic counterparts are subject to the EU ETS. During the initial transitory phase that began in October 2023 and the first years of the financial implementation, the scope of CBAM is limited to several selected products which can be described as relatively homogenous and that currently receive free allocation based on product benchmarks (with the exception of electricity, which is not eligible for free allocation): Iron & steel, aluminium, fertilizer, cement, hydrogen, electricity as well as selected pre-cursors and downstream products.

CBAM will cover scope 1, scope 2 and partially scope 3 emissions of upstream products as shown in Figure 47. Indirect emissions associated with the consumption of electricity is expected to be included in the scope. However, for those products that are currently eligible to receive indirect cost compensation, the scope has been narrowed to direct emissions.

Figure 47 CBAM Scope



Source: European Commission 2023

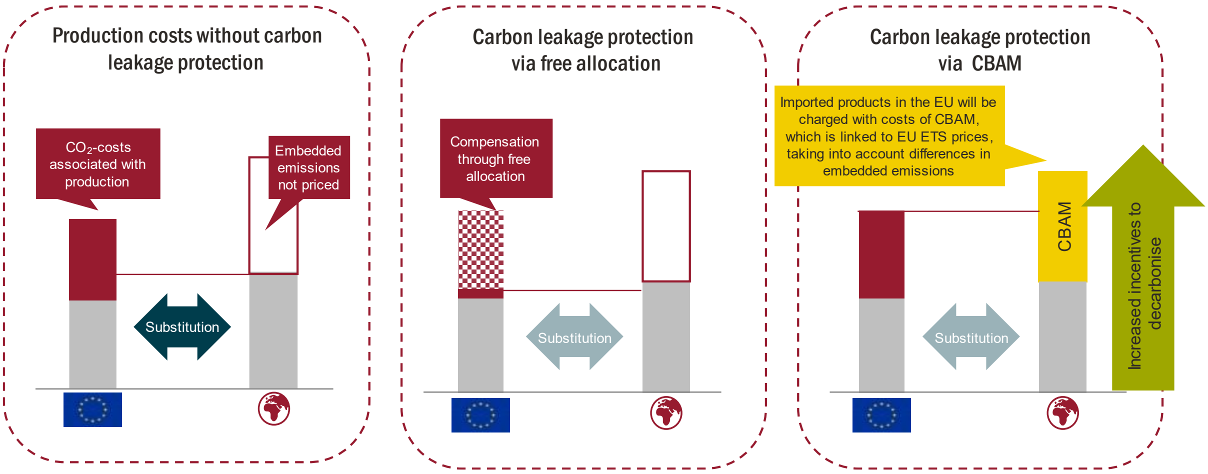
Compared to the current system of free allocation, the CBAM does not offer protection against carbon leakage by lowering the cost burden on domestic producers but by introducing additional cost for producers outside of the EU in jurisdictions with more lenient carbon regulation as shown in Figure 48. The current design of the CBAM, however, only covers imports to Europe and does not mitigate competitive disadvantages of EU producers exporting to global markets.

The effects of CBAM on EU producers of goods covered by CBAM or EU producers that use CBAM goods as inputs are the following:

- **Effect on production costs**: Firstly, the introduction of CBAM implies a phasing out of free allocation and hence an increase in effective carbon costs for their production processes. Depending on elasticity of demand of consumers and the ability to pass-on costs, the increase in carbon costs affects
  - profitability in domestic markets; and
  - competitiveness on global markets.
- **Effects through cost of inputs**: EU producers that consume CBAM goods as inputs for their own production will face higher costs due to the carbon tax on imports.

In addition to these two direct effects, the EU economy is indirectly affected through changing terms of trade and effects on relative prices.[30] For this analysis, however, we will focus on direct effects on **producers**.

Figure 48 Principles of CBAM vs. free allocation



Source: *Frontier Economics*

As described above, CBAM offers a partial carbon leakage protection: it acts as a tax on imports, increasing the costs of non-EU products on EU markets to the extent of the carbon cost difference between domestic EU and non-domestic goods. However, EU goods that are exported do not receive any form of carbon leakage protection under the current CBAM design.

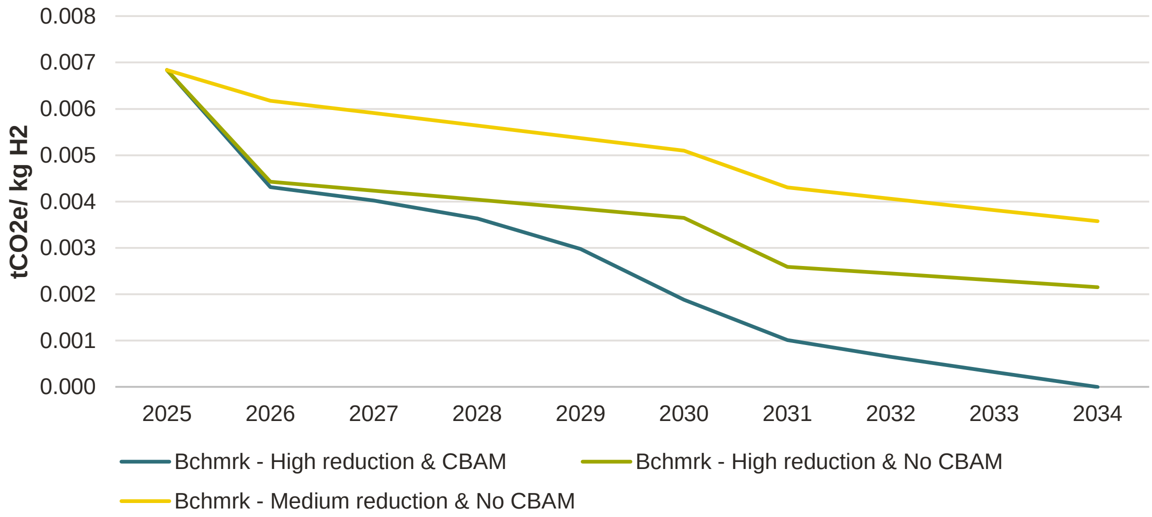
The European Commission is tasked to develop a solution for exports with the upcoming review of the ETS/CBAM guidelines. In its recent “Report on the functioning of the European

30 As is the case with standard tariffs, the main mechanisms through which the CBAMs effects economic growth play out are via changes to terms of trade and effects on relative prices. The two move in opposite directions. The CBAM improves the EU’s terms of trade, which in turn has a favourable, if limited, effect on its economic growth. At the same time, the CBAM increases the price of goods like cement, iron or steel that are primarily inputs into investment. This increases the cost of accumulating capital, which in turn reduces the capital stock, which reduces economic growth.

Carbon Market"[31] the Commission presents an initial assessment focusing on the emission and export intensity of CBAM goods.

Hydrogen Case Study: Results under the Medium Benchmark Scenario

Figure 49 Number of free allowances allocated (per unit of output) – Medium Reduction

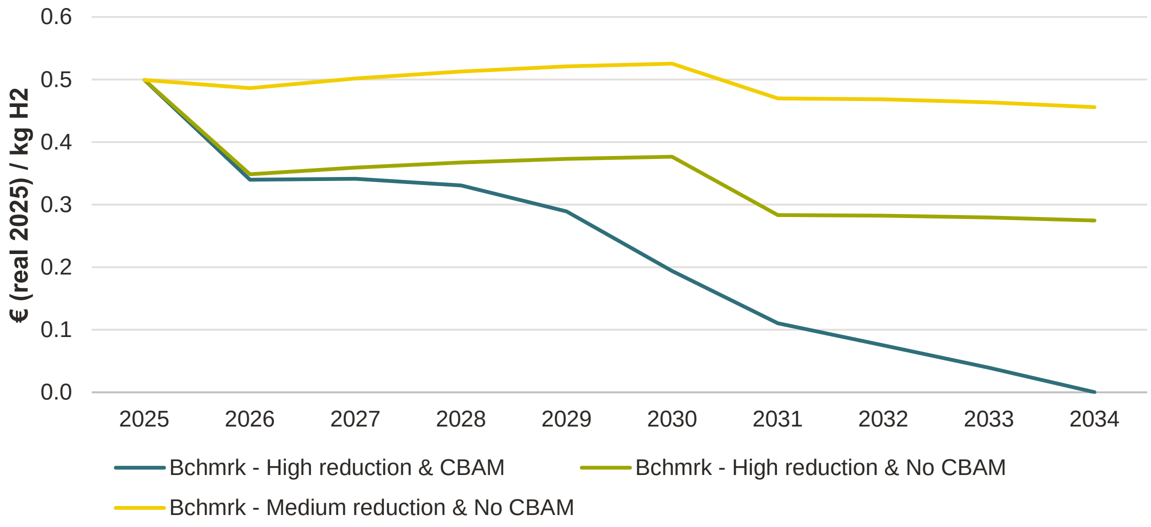


Source: *Frontier Economics*

Note: *A high reduction rate is assumed for outsourced hydrogen, while medium reduction scenario is applied for insourced hydrogen produced within refineries.*

[31] COM (2024) 538 final

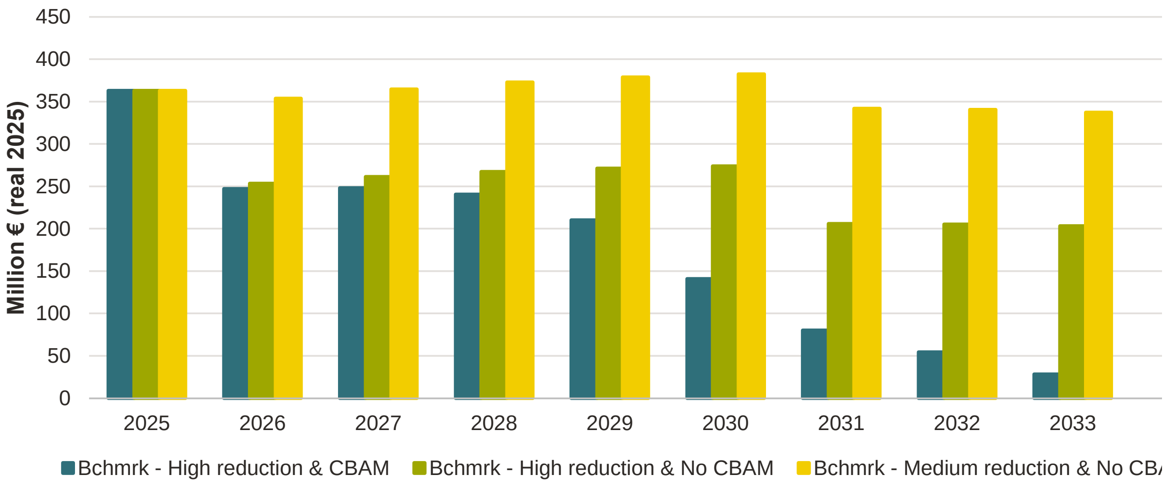
Figure 50 Value of free allowances (per unit) – Medium Reduction



Source: *Frontier Economics*

Note: *A high reduction rate is assumed for outsourced hydrogen, while medium reduction scenario is applied for insourced hydrogen produced within refineries.*

Figure 51 Total value of free allowances for H2 sold to refineries by the IG sector – Medium Reduction



Source: *Frontier Economics*

Note: *A high reduction rate is assumed for outsourced hydrogen, while medium reduction scenario is applied for insourced hydrogen produced within refineries.*

Annex D – Sources

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