3 Reaching climate neutrality in freight and industry

The port of Hamburg has taken a leading role in reaching climate neutrality by 2040. This chapter shows that Hamburg's strategic location can turn it into a major climate-neutral transport centre, building on its strong rail infrastructure. In this way Hamburg can deliver climate-neutral transport services client businesses need throughout Western and Central Europe quickly and at low cost. This includes harnessing its potential for a hydrogen hub. The transition to zero-emission fuels for international shipping therefore needs to be prepared now. This will raise costs by 2030 on account of initially higher fuel production cost and needed investment in zero-emission shipping, but an energy-saving fuel mix may help keep longer-term costs and trade flow impacts modest. Maximising the use of rail would deliver benefits beyond Hamburg. It requires addressing railway infrastructure bottlenecks and digitalization. Quick major steps towards electrified road transport are also needed, with electric charging infrastructure and continued efforts to improve logistics. Hamburg can play an important role in delivering imported green hydrogen and hydrogen-derived products, via pipelines or ships, to serve demand in local industry and shipping as well as in neighbouring industrial regions.

Freight and logistics through ports play a critical role in trade flows. Goods handled in ports account for 46% of the value of goods traded between the EU and the rest of the world, and 75% of its volume (ERA, 2022[1]). Hamburg hosts one of the four largest ports in Europe. Transport and logistics activity in and around the port reflect its importance as a major economic hub. Hamburg is home to a large number of industrial, wholesale and retail businesses, including in e-commerce, which depend on the port and its transport and logistics services. Preparing the Hamburg port for climate-neutral international shipping is therefore central to the Hamburg economy, as well as beyond, providing much-needed zero-carbon transport services to business on the continent. The first section of this chapter is devoted to this issue.

Land-based transport connections from and to the port are of equal strategic importance. The vast cargo turnover in Hamburg has fostered a high-frequency supply chain in the hinterland. The influence of Hamburg and its port reaches deep into this hinterland down transport chains, shaping economic and environmental performance in the Hamburg region, Germany and many parts of Europe.

The major ports in Europe often serve overlapping hinterlands: as the distance between the port and the hinterland grows, competition between ports and between transport modes increases. Yet, land-based freight services are, alongside maritime shipping, particularly difficult to decarbonise. The second section therefore discusses the implications of Hamburg hinterland transport and logistics, providing insights into actions to successfully manage the transition to climate neutrality while harnessing Hamburg's comparative advantage and its strategic position as one of Europe's major ports.

The port is closely integrated with the manufacturing of basic materials that are also particularly challenging to make climate-neutral. This applies in particular to basic metals production and oil refining. These sectors depend strongly on fossil fuels, both as energy carriers and raw materials. They often require high temperatures in production processes which do not easily lend themselves to electrification. The decarbonisation of key manufacturing sectors in Hamburg is discussed in the third section.

Hydrogen and hydrogen-derived products are important for the climate-neutral operation of international maritime shipping as well as for some of Hamburg's manufacturing activities. Some manufacturing might also require carbon capture and storage (CCS). The Hamburg port may also serve as a hub for the provision of hydrogen, CCS and related transport services. This is discussed in the fourth section of the chapter.

Anticipating the impact of decarbonising maritime transport

The Hamburg port has already adopted a strategy to reach climate neutrality for Scope 1 and 2 emissions in port operations by 2040. This includes all emissions in freight handling and transport. A consistent CO2 balance for the port will be used to monitor and control this process (Behörde für Wirtschaft und Innovation, 2023[2]). The first part of this chapter will therefore focus on the decarbonisation of international shipping. Preparing the Hamburg port for the major transformations this will bring is key for the Hamburg economy. This section will deploy transport and macroeconomic modelling for the port of Hamburg to provide insights about the implications, in terms of zero-emission fuel supply and impacts on trade (Halim et al., 2018[3]).

In July 2023 the International Maritime Organization (IMO, Box 3.1) adopted the revised 2023 IMO GHG strategy. This strategy sets objectives to reach net-zero GHG emissions by or around 2050 and reduce GHG emissions by at least 20% by 2030 while striving to reduce them by 30% and reduce GHG emissions by 70% by 2040, compared to 2008.

According to the revised 2023 IMO GHG Strategy, global shipping must lower its carbon intensity (CO2 emissions per transport service) by at least 40% by 2030.

Box 3.1. The role of the International Maritime Organization in decarbonising maritime freight

The International Maritime Organization (IMO) is a UN agency with 174 member countries. It is an intergovernmental consultative body which adopts policy measures to prevent and reduce environmental impacts as well as to improve the safety and security of international shipping. IMO has stated its aim to align with the 2015 Paris Agreement. It has revised the 2018 "Strategy on reduction of GHG emissions from ships" in 2023. A further review will be finalised when the IMO's Marine Environment Protection Committee (MEPC) meets in the autumn of 2028 to adopt the 2028 IMO Strategy. The MEPC handles environmental concerns such as the management and prevention of ship-sourced pollution, or ship recycling. As a technical body to create, review, and revise the IMO strategy, the Intersessional Working Group on GHG Emissions (ISWG GHG) proposes policy measures to the MEPC.

Source: (IMO, 2023[4])

Economic measures to decarbonise international shipping are under ongoing discussion. To meet the agreed targets, IMO member countries have proposed baskets of economic and technical measures that will need to be adopted by 2025. These measures will have the broadest coverage, in terms of the number of countries as well as the range of ship types regulated under IMO policy. This section takes the latest IMO agreement as the starting point of the analysis, as well as the proposed basket of measures from the European Commission (EC).

For most businesses involved with the trade of goods from and to the port, the emissions from international shipping are Scope 3 emissions. Climate neutrality for international shipping by 2050 may therefore be consistent with the 2040 HCC climate neutrality target, provided there is no strong reliance on international offsets to reach it. However, businesses operating vessels in international shipping headquartered in Hamburg should move ships to largely zero-emissions fuels by 2040.

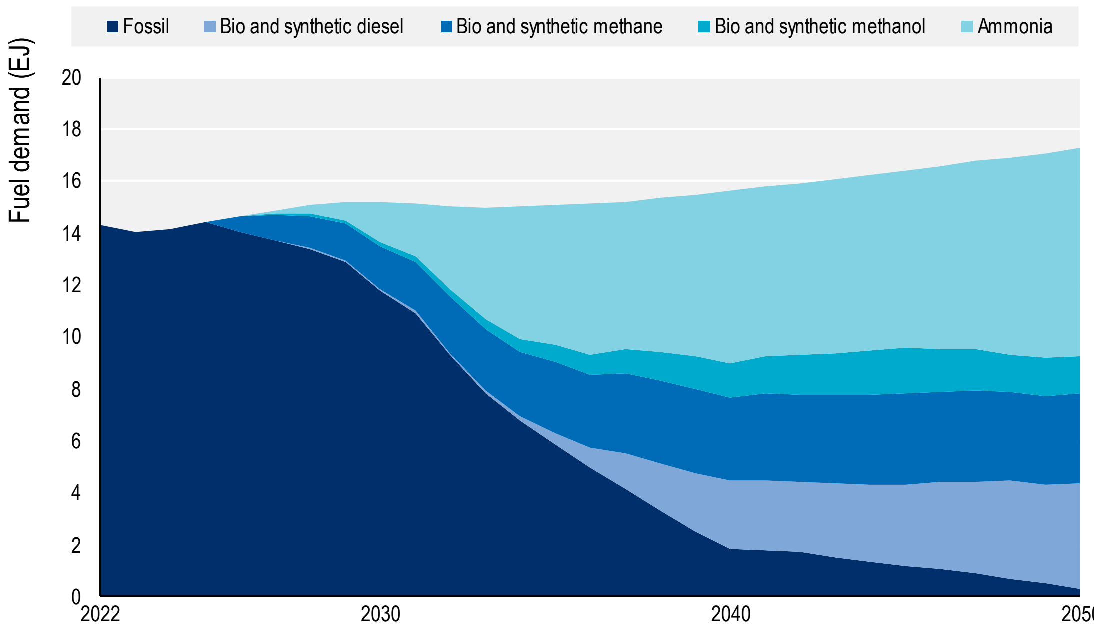
Preparing the port for zero-carbon fuels

The availability and the use of zero-emission fuels will be key to decarbonising international shipping according to the timeline that the revised IMO targets. Ports could play a strategic role as a logistics node in their supply, serving as bunkering stations for ships.

To estimate cost-minimising zero-carbon fuels, this section draws on the results of a modelling exercise carried out with the NavigaTE model (Mærsk Mc-Kinney Møller Center, 2021[5]). NavigaTe is a techno-economic shipping model developed by the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping to assess the most cost-effective decarbonisation pathways, taking comprehensive account of costs from adopting different fuel measures. It captures the entire energy value chain for powering the maritime vessel from raw materials and primary energy used in fuel production to the fuel combustion in the vessel. A description of this model can be found in the Annex. The model uses a cost-minimising approach to estimate the projected uptake of different fuel types in line with the 2023 IMO strategy. Figure 3.1 presents the results. Assuming the adoption of a carbon levy, discussed in detail below, which is expected to close the price gap to current fossil fuel types, proposed by the EU Commission, demand for ammonia is expected to increase from 2027. From 2035 onwards, ammonia may be the dominant zero-carbon fuel type. It may drive the decarbonisation of the sector thanks to its cost efficiency, higher volumetric energy density, simplified production, and existing well-developed infrastructure compared to other alternatives (Hoang et al., 2022[6]). Ammonia is emission-free in combustion and can also be produced emission-free with green hydrogen (Box 3.2).

Figure 3.1. Estimated fuel mix for decarbonising international shipping

Estimation based on the revised 2023 IMO strategy and proposed measures by the European Commission



Note: Ammonia includes blue ammonia produced from natural gas with carbon capture and storage as well as green ammonia from green hydrogen.
Source: (Equitable Maritime Consulting, 2023[7])

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Box 3.2. Ammonia may be the most promising zero-emission shipping fuels

Ammonia is a cost-effective zero-carbon bunker fuel that is easier to produce and store in large quantities than other zero-carbon fuels. "Green" ammonia is produced from hydrogen made by hydrolysis of water with renewable electricity. Research and development efforts are required to address potential air pollution of nitrogen oxides and nitrous oxide from ammonia combustion. Since ammonia is toxic to humans and aquatic life it needs to be stored and managed safely.

Green methane and methanol can also be produced and used emission-free. They require carbon, which can be sourced emission-free in two ways (World Bank, 2021[8]):

- from sustainable biofuels, in biofuel synthesis (biomethane, biomethanol),
- as a synthetic fuel, through recovering CO2 from carbon capture and combining it with hydrogen, in hydrogenation for alcohol synthesis (synthetic methane, synthetic methanol).

Their advantage is that they are similar to conventional fossil fuels and therefore require relatively minor changes in conventional fossil bunkers and engines. However, the production of synthetic fuels is energy-intensive. The climate-neutral sourcing of captured CO2 may also be a concern. In particular, sourcing it from CO2 emissions in industrial processes would not be fully climate-neutral. Sourcing it from direct air capture would be climate-neutral but would increase energy needs. Biofuels should also be sourced sustainably to ensure their use is emission-free. Another limitation is the high demand for biofuels in multiple sectors to reach climate neutrality, as well as competing land use for agriculture or biodiversity protection.

Next to ammonia bio and synthetic methane and methanol, as well as advanced biofuels are also expected to see some uptake to reach the 20%-30% GHG reduction target by 2030. Safety is another important aspect of zero-carbon fuels (Box 3.3).

Box 3.3. Safety of zero-carbon fuels: The role of the Clean Marine Fuels Working Group

The Clean Marine Fuels Working Group (CMF) plays a crucial role in facilitating and regulating the supply of new marine fuels by providing expertise and guidance. CMF has taken significant strides in ensuring bunkering safety and broader system safety. Initially, a bunkering safety toolkit for liquefied natural gas (LNG) was introduced, and subsequently, it has been adapted to encompass all low- and zero-carbon fuels. On the operational safety front, comprehensive safety bunkering checklists for liquid gases were released in 2022, followed by one for methanol in 2023. Ongoing investigations are developing safety protocols for ammonia. Regarding system safety, CMF is currently in the process of transforming the existing "audit tool for bunker facility operators" and "bunker-ready terminal tool" into universally applicable tools suitable for all existing and emerging marine fuels.

The port can provide incentives for shippers' voluntary emission reduction

Ports can voluntarily offer incentives to promote and reward shipping companies for surpassing legal emission standards. To facilitate this effort, the International Association of Ports and Harbors (IAPH) established the Environmental Ship Index (ESI), which quantifies environmental performance in terms of air pollutants, CO2 emissions and noise. This index has been universally adopted by ports worldwide as a tool to incentivise ships to lower emissions below the IMO emission standard. Currently, the ESI database includes around 7,000 commercial ships and more than 60 organisations, primarily consisting of port authorities. The Hamburg Chamber of Commerce could encourage shipping carriers to make use of the Environmental Ship Index (ESI) and monitor emission reductions in line with its 2040 climate neutrality target.

Measures by ports to schedule the arrival and mooring of ships (port call optimisation) lead to GHG emission reduction through lower energy use. Effective cooperation is vital. To that end, the International Taskforce on Port Call Optimization (ITPCO) aims to achieve optimised port calls through collaboration among relevant agents (international shipping, ports, terminals, and cargo owners) thanks to timely high-quality data sharing and standardisation.

Establishing green shipping corridors involves identifying specific trade routes between major hubs that support zero-emission solutions. This initiative depends on voluntary cooperation among ports, shipping entities, and other stakeholders. Successful implementation will require the participation of ports from developing countries. The Clean Energy Marine Hubs (CEM-Hubs) platform, a cross-sectoral public-private initiative involving energy, ports, finance, and shipping sectors, aims to accelerate the production and maritime transport of low-carbon-emission fuels, including those directly used for shipping.

Modelling the cost impact of potential decarbonisation measures

This subsection discusses the scenario design and the modelling method used to assess the economic impacts of measures proposed by the European Commission to reach the 2023 IMO emission reduction and climate neutrality targets. The assessed impacts include trade costs and on the value of trade flows in Hamburg. They include a global fuel standard (GFS) and a carbon levy on ships with a capacity above 5 000 gigatons (GT).

In the proposed GFS emissions are assessed “well-to-wake” (WTW) across the whole value chain of fuels. WTW refers to emissions in the entire process of fuel production, delivery and use on ships, so comprises Scope 1, 2 and 3 emissions in fuel use. A 16% reduction in the carbon intensity of ship fuel is applied in 2030. According to the EC proposal, the GHG reduction from the GFS is raised to 80% and 95% by 2040 and 2050, respectively. In addition, a carbon tax of 150 USD per ton is applied by 2030, to be increased to 200 USD by 2050.

Scenario design

The economic impacts are assessed comparing a policy scenario with the proposed measures against a business-as-usual (BAU) scenario, which includes climate action on international shipping only up to the measures introduced by IMO in 2021. Both policy and baseline scenarios assume that global climate action more generally will limit global warming to 2 degrees (Box 3.4).

Box 3.4. The Business-As-Usual (BAU) scenario

The Business-As-Usual (BAU) scenario applies the Shared Socio-Economic Pathway (SSP) 2 and Representative Concentration Pathway (RCP) 2.6 to reflect global socio-economic development and climate actions expected to be taken by countries worldwide. SSPs are pathways that describe how global society, demographics and economic developments might change over the next century and are used as a backdrop to model climate action. In SSP2 trends broadly continue historical patterns. RCPs refer to atmospheric GHG concentrations and other forces acting on climate, resulting from climate action. RCP 2.6 is consistent with 2-degree global warming. The economic projections rely upon DG-ECFIN for the European Union, while the IMF and OECD long-term projections inform the outlook for non-EU economies.

Furthermore, the BAU scenario takes into account the International Maritime Organization's (IMO) short-term measures in 2021 —including the Energy Efficiency Design Index (EEDI), Energy Efficiency Existing Ship Index (EEXI), and Carbon Intensity Indicator (CII)— to curtail shipping carbon intensity (IMO, 2021).

EEDI gauges the ship designs energy efficiency, with lower EEDI values as an indication of increased ship efficiency. This index, introduced in 2013, applies to new ships. EEXI applies to ships' operating emissions. These two indices oblige ship owners to adhere to specific energy efficiency standards. CII quantifies CO2 emitted by ships during transport activity on an annual basis. It is specified in grams of CO2 emitted per cargo-carrying capacity and nautical mile. The IMO has introduced a rating system ranging from A to E with an increasing stringency towards 2030. Ships with a D rating for three consecutive years are required to apply a corrective action plan.

Methodology

There will be a direct and an indirect impact of the GFS and of the carbon tax on transport costs, given the strong interdependencies between transport and trade systems (Halim, Smith and Englert, 2019[9]).

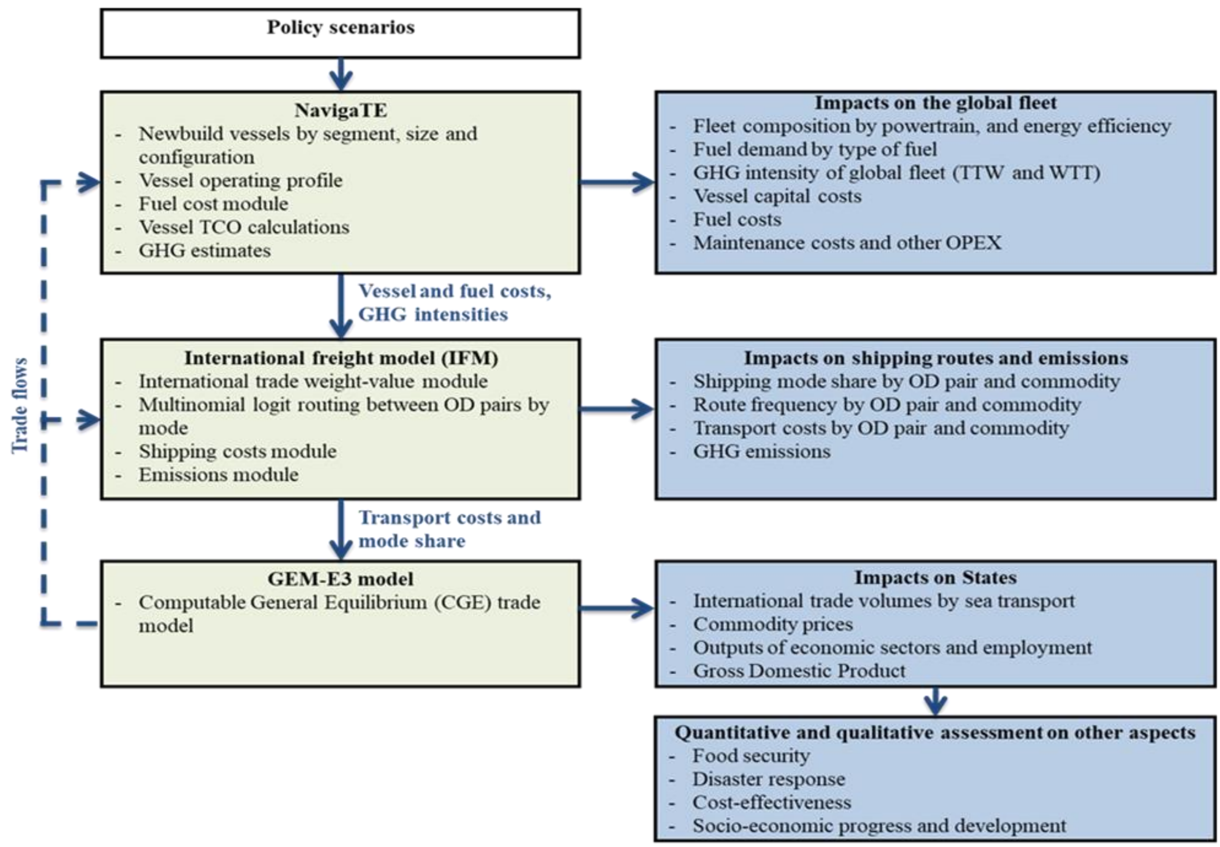
First, a direct impact will be on ship running costs on account of fuel and capital costs, as well as on account of the carbon levy on remaining emissions. This will increase transport costs. The increase in these costs impacts global trade. In turn, transport costs are sensitive to the change in trade volume, as unit transport costs could respond to the loss or gain in economies of scale in shipping. Scale economies can reinforce trade-cost-induced shifts in trade flows.

To assess the economic impacts on trade through Hamburg, this study focuses on the following indicators:

1. Change in transport costs by commodity for imports and exports (measured in percentage change), based on a comparison between BAU and policy scenario;
2. Change in trade values by commodity for import and export (measured in USD and percentage change) based on a comparison between BAU and policy scenario;
3. Change in trade values for the top 20 import/export countries (measured in percentage change).

To assess these impacts, the analysis is carried out using the output of NavigaTE, described above and in the Annex. The approach also deploys Equitable Maritime Company's (EMC) International Freight Model (IFM) to model cost-minimizing international freight transport choices, including transport mode choices, taking into account the quality of infrastructure and shipping services at a detailed network level (Halim et al., 2018[3]) This analysis is complemented by the output of the GEM-E3 model, a global computable general equilibrium economic model designed to project worldwide commodity trade under different scenarios (E3modelling). The modelling approach follows three steps, illustrated in Figure 3.2. A description of the 3 models and the 3-step modelling approach is in the Annex. This analysis is complemented by the output of the GEM-E3 model, a global computable general equilibrium economic model designed to predict worldwide commodity trade volumes under different scenarios (E3modelling). A detailed explanation of these three models can be found in the Annex and the cited references. The modelling approach follows three steps, illustrated in Figure 3.2. A description of the 3 models and the 3-step modelling approach is in the Annex.

Figure 3.2. Methodology Diagram



The impact of potential mid- and long-term decarbonisation measures: Modelling results

Impact on import and export costs by commodity

The GHG mitigation measures proposed by the EC may lead to higher ship running costs through higher fuel prices and higher capital costs. Users and producers of zero-emission fuels invest in new technologies and vessels, including advanced propulsion systems. Based on the assessment using NavigaTE, ship running costs are estimated to increase up to 20.37%, 17.78%, and 4.13% in 2030, 2040, and 2050 respectively, relative to BAU.

The estimations with the NavigaTe model suggest that the resulting increase in fuel costs due to the adoption of more expensive cleaner fuels is significantly higher than in vessel capital costs. However, this increase varies across ship types, routes, and commodities (Halim, Smith and Englert, 2019[9]). Even so, the measures will trigger a substantial increase in shipping company CAPEX around 2030 due to ship retrofitting and the purchases of ships with zero-carbon fuel capabilities.

While fuel costs may rise significantly initially, fuel costs are then projected to decrease gradually with the assumed improvement in the productivity of zero-carbon fuel production. Concurrently, lower emissions reduce costs on account of the carbon tax. Improvements in energy efficiency following regulation and technological progress, such as in hull shapes or propulsion systems, may also reduce costs. However, whether this benign long-term cost assumption materialises depends on many uncertain factors, including on the availability of renewable energy and green hydrogen world-wide, energy and hydrogen demand trends, as well as the choice of a cost minimising fuel mix, taking into account the needed energy inputs.

Table 3.1 presents the average impact on import unit transport costs of all commodities over time. By 2050, the increase in import transport costs across commodities may be relatively small. The changes in the top three commodities by import value for Hamburg are displayed in Figure 3.3 with broadly similar impacts. Across a broader range of commodity types (Annex Figure 3.A.1), import costs are estimated to increase between 20% and 32% in 2030. The highest costs concern raw materials which are mostly imported from developing countries.

Table 3.1. Projected average increase in unit transport costs across commodities imported in Hamburg

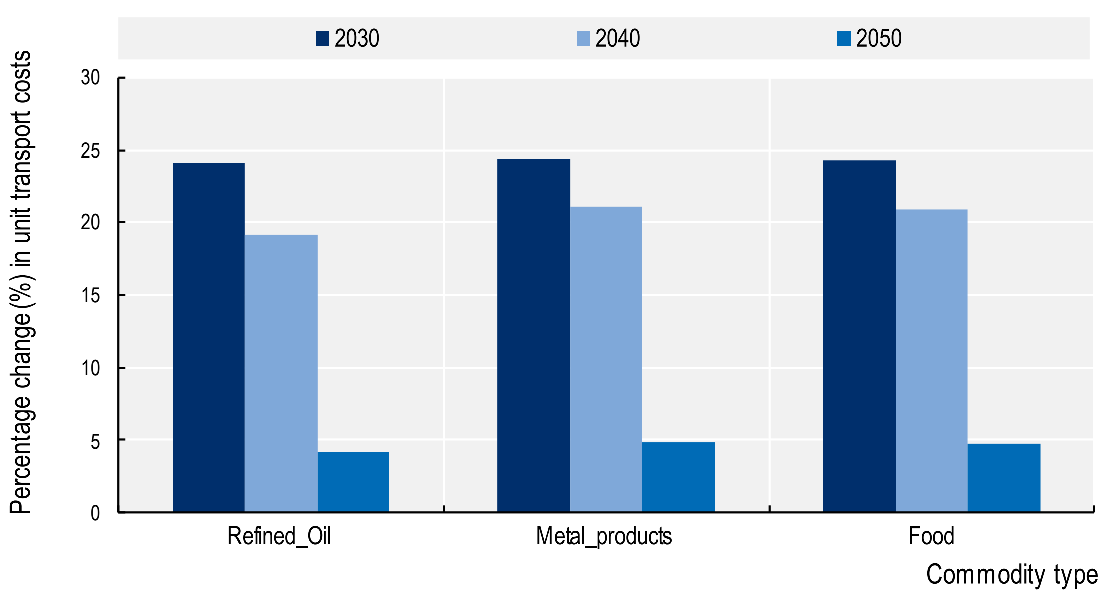
Impact of proposed IMO policy measures, relative to business-as-usual scenario

	2030	2040	2050
Average increase (%)	25,3	21,6	4,9

Source: (Equitable Maritime Consulting, 2023[7])

Figure 3.3. Projected increase in unit transport costs for top 3 commodities imported in Hamburg

Percent change in import unit transport costs (USD/ton-km), relative to business-as-usual scenario



Note: Estimation based on the revised 2023 IMO strategy and proposed measures by the European Commission
Source: (Equitable Maritime Consulting, 2023[7])

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A similar pattern over time emerges for export unit transport costs (Table 3.2). Among the top 3 export goods for Hamburg increases in unit transport costs are bigger in the export of metal products and food than in transport equipment (Figure 3.4). They may also be somewhat bigger than in the case of unit import costs.

Table 3.2. Projected average increase in unit transport costs across commodities exported in Hamburg

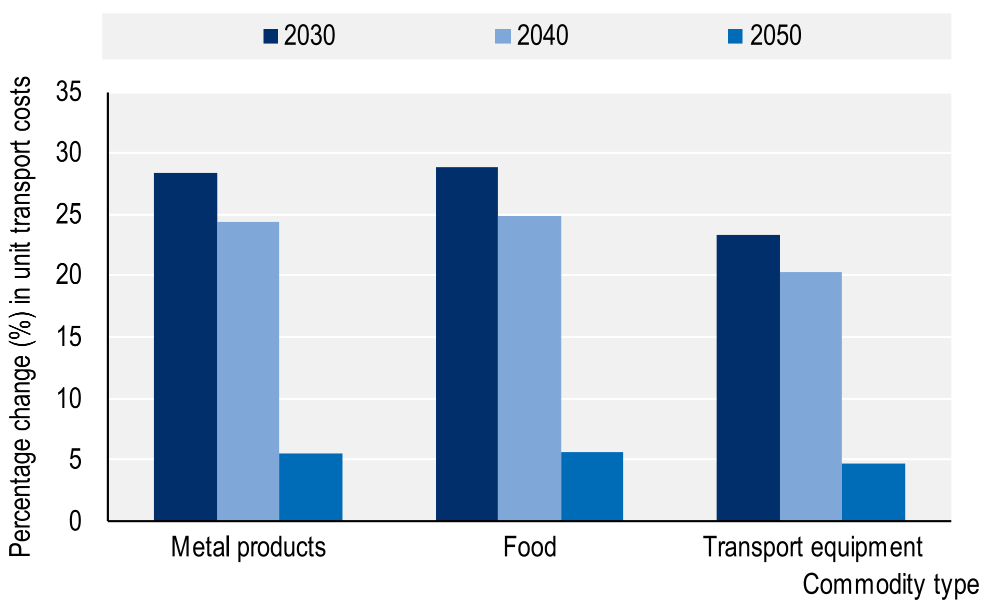
Impact of proposed IMO policy measures, relative to business-as-usual scenario

	2030	2040	2050
Average increase (%)	28,5	24,5	5,5

Source: (Equitable Maritime Consulting, 2023[7])

Figure 3.4. Projected increase in unit transport costs for top 3 commodities exported in Hamburg

Percentage change in export unit transport costs (USD/ton-km), relative to business-as-usual scenario



Source: (Equitable Maritime Consulting, 2023[7])

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Impact on import and exports by commodity

Higher transport costs could lower trade flows, for example as a result of firms relocating production. The projected impact on Hamburg trade flows is small (Tables 3 and 4). With its diversity of trading partners, Hamburg may have more potential to accommodate and adjust to changes in origins and destinations than other ports. Indeed, the port serves as a major hub in the maritime network, supporting this flexibility.

Table 3.3. Projected total Hamburg import values

Billion USD

Import value	Baseline	Policy scenario	Difference (%)
2030	63.4	62.8	-0.9
2040	67.4	66.9	-0.7
2050	71.7	71.6	-0.2

Source: (Equitable Maritime Consulting, 2023[7])

Table 3.4. Projected total Hamburg export values

Billion USD

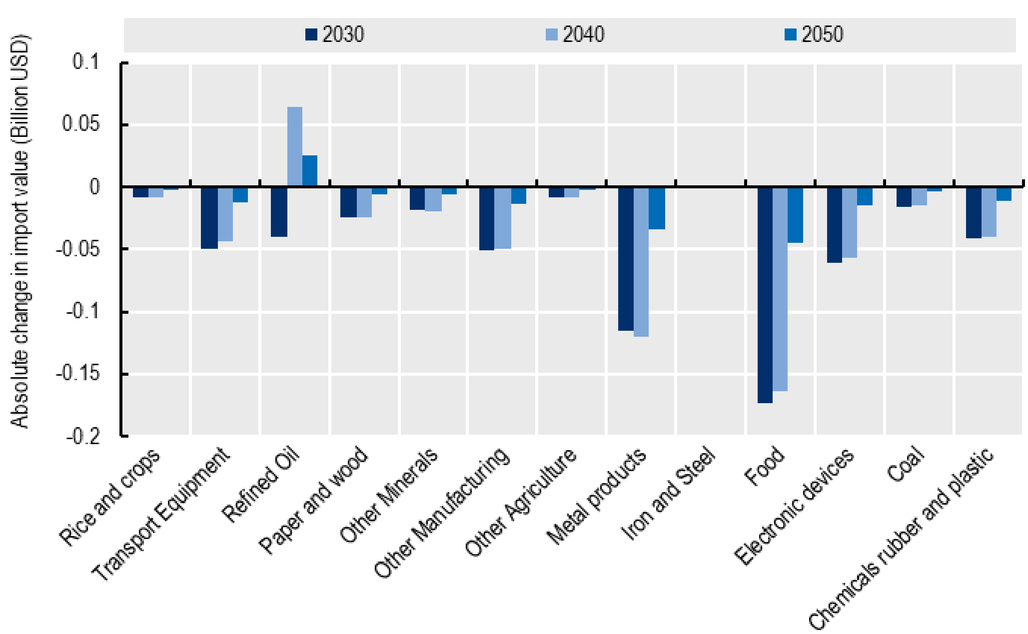
Import value	Baseline	Policy scenario	Difference (%)
2030	54,9	54	-1,7
2040	59,6	58,8	-1,4
2050	66	65,7	-0,4

Source: (Equitable Maritime Consulting, 2023[7])

Food commodities may be subject to the most substantial decrease in both import and export values in absolute terms (Figure 3.5, Figure 3.6). Figures in the Annex present the percentage change in import and export values by commodity.

Figure 3.5. Projected change in import value of each commodity in Hamburg

Absolute change in import value (Billion USD), relative to business-as-usual scenario



Source: (Equitable Maritime Consulting, 2023[7])

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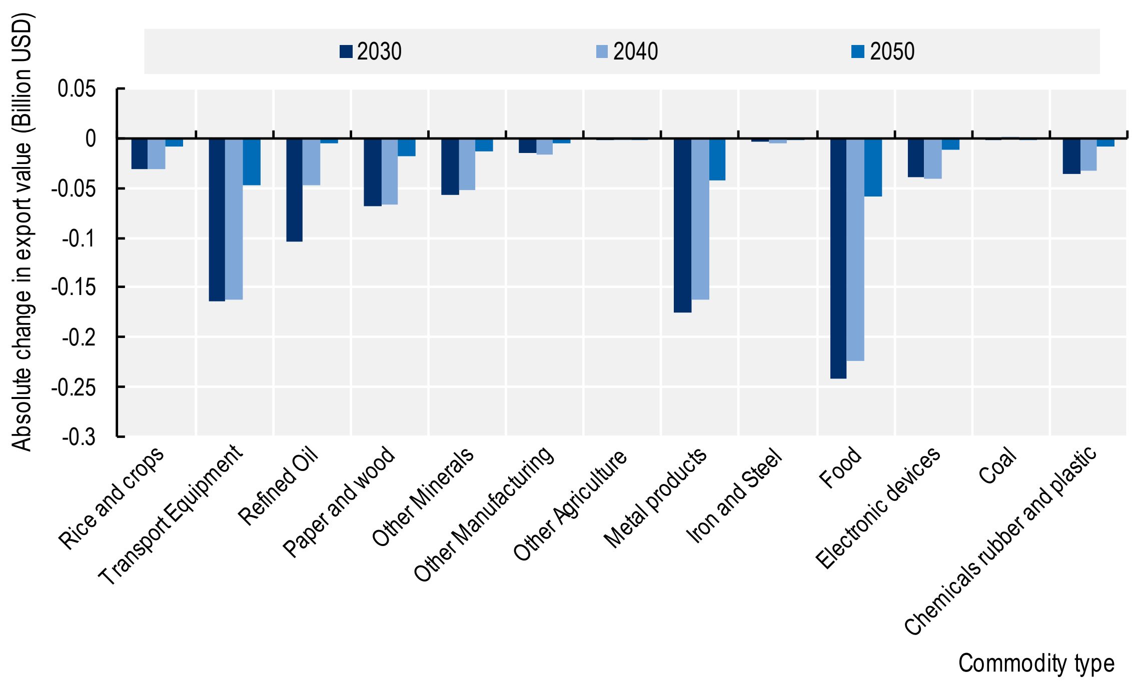
Figure 3.6. Projected change in export value of each commodity in Hamburg

Absolute change in export value (Billion USD), relative to business-as-usual scenario



Source: (Equitable Maritime Consulting, 2023[7])

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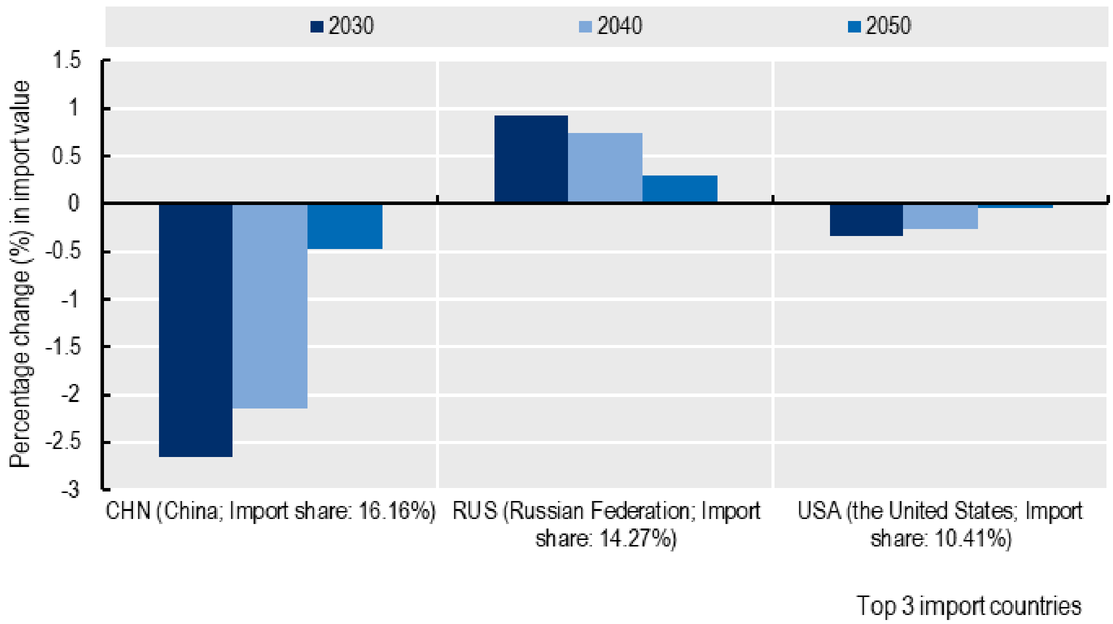
Impact on import and export value by country

Figure 3.7 displays the projected differences for the top three Hamburg trading partner countries in terms of import values, along with their respective shares in total import value in the base year (2022). The results suggest China may experience a relatively substantial decline. Figure 3 in the Annex shows the impact for the 22 countries from which Hamburg consistently imports the highest values of commodities.

Figure 3.7. Projected change in imports to Hamburg from the top 3 trading countries

Percent change in import from the top 3 countries, relative to business-as-usual scenario



Source: (Equitable Maritime Consulting, 2023[7])

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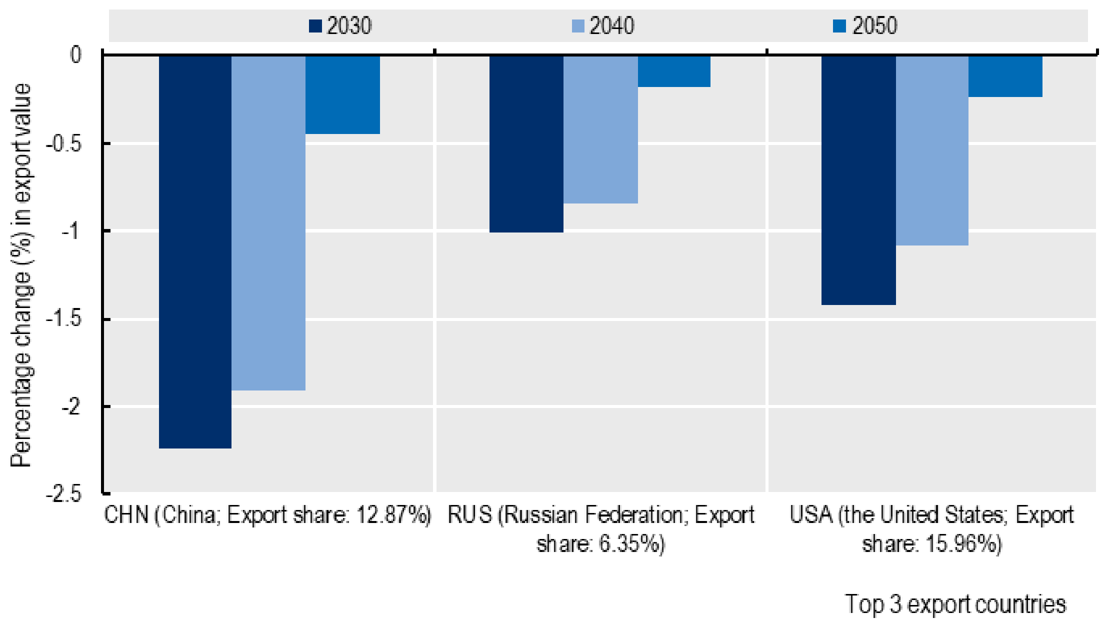
Figure 3.8 displays the changes in export value for the top three countries in the base year. The results suggest all of them experience a decline, notably China. Figure 4 in the Annex presents the analysis for the top 20 countries.

Figure 3.8. Projected change in exports from Hamburg to the top 3 trading countries

Percentage change in export of Hamburg to top 3 countries, relative to business-as-usual scenario



Source: (Equitable Maritime Consulting, 2023[7])

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Key actions

Immediately

- The Hamburg Chamber of Commerce could, together with the port authority, key shippers in Hamburg, as well as researchers, and in coordination with other major ports, assess advances in the deployment of zero-emission fuel and ships, with a view to promoting fuels likely to do best in terms of system-wide low cost and resilience.
- The Hamburg Chamber of Commerce could encourage shipping carriers to make use of the Environmental Ship Index (ESI). It could provide incentives for shippers' voluntary emission reduction, by rewarding companies that surpass legal emission standards.
- All new ships should run on, or be able to run on, zero emission fuels, ideally anticipating a long-term system-wide low-cost fuel mix.

By 2030

- Shipping companies could augment zero-carbon fuel use, such as ammonia. Ensuring safe production, transport and delivery of zero-carbon fuel will be key to that end.
- The Hamburg port could cooperate with other major ports and shipping entities to establish green shipping corridors to identify specific trade routes between major hubs that support zero-emission solutions.
- The Hamburg Chamber of Commerce could continue assessing the impacts of transport costs on trade flows through Hamburg.

By 2040

- Broadly complete the replacement of fossil fuels with zero-emission fuels in international maritime shipping.

Climate neutrality in transport logistics and transport from and to the port

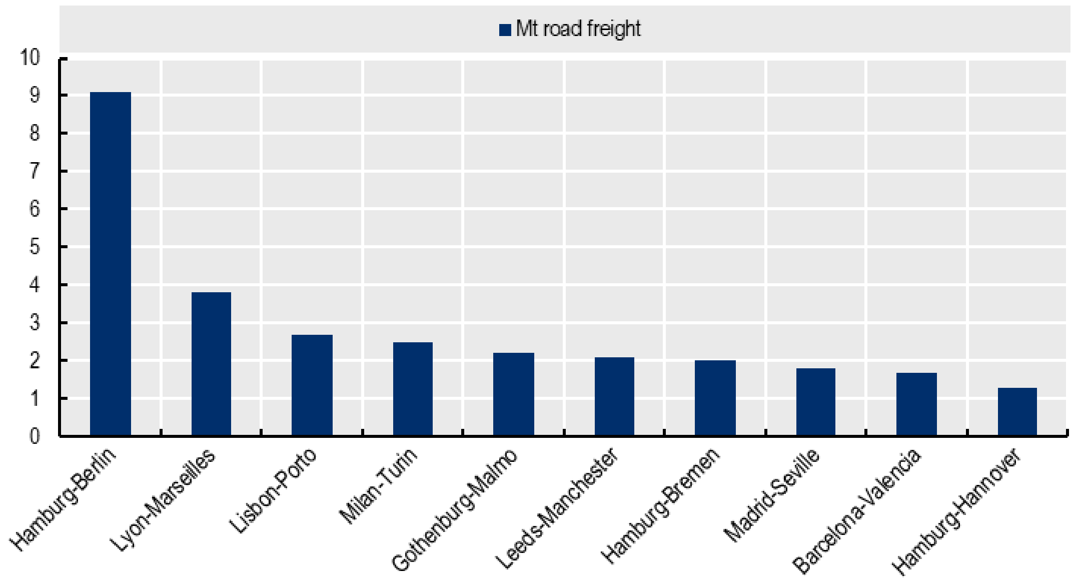
Hamburg is the largest rail port and the busiest road freight transport node in Europe, and the third largest inland water transport (IWT) port in Germany. One in seven of all rail freight journeys in Germany start or finish in Hamburg, carrying 15% of Germany's rail freight. Some 200 freight trains use the port daily. Hamburg is the largest rail container transhipment centre in Europe. Three out of nine major European road freight transport routes – the TEN-T corridors, which account for 80% of EU road freight transport – intersect in Hamburg, which is by far the busiest node, with the Hamburg-Berlin route alone accounting for over 9 Mt annually (Figure 3.9). Hamburg is one of the largest road freight loading regions in Europe (OECD, 2021), with 40 000 trucks driving into the port daily. With good connections to the pan-European canal and river network, the port also attracts 11 000 calls annually from inland vessels travelling essentially to Berlin, Hannover and the Czech Republic.

Just over half of containers were transported by rail (50.5%), road accounting for 47.3%, and inland water transport for 2.2%. Some 53.9% of freight tonnage was by rail, 37.6% by road and 8.5% by inland water transport (Port of Hamburg Marketing, 2023[10]). In other large ports, the share of rail ranges from 7% (Le Havre and Antwerp) to 11% (Rotterdam) (Figure 3.10). Only two smaller ports reach a higher share. Inland water transport covers 9% of hinterland freight transport (mainly bulk cargo) and 2% of container transport out of Hamburg, whereas in the ports of Rotterdam or Antwerp, inland water transport accounts for half of freight tonnage and 40% of container transport.

The Port of Hamburg stands out among European ports because of the large share of rail in hinterland transport, which has almost doubled over the last 20 years, largely at the expense of road. Four main factors have helped this increase:

- Hamburg has been able to leverage its position as a gateway for long-distance trade thanks to good rail connections (2 000 offered daily out of the port) and a hinterland network that could handle a large number of trains with segments with third tracks and sidings for longer trains.
- An extensive railway system within the port gives rail a head start from the moment of unloading. Ports that have high shares of rail for hinterland transport, such as Gothenburg, Trieste and Koper, share this characteristic. Over half the HPA rail track is electrified, a higher share than other major ports in Europe (for instance Antwerp and Rotterdam).
- There have been major investments to remove infrastructure bottlenecks within and through the port, such as the Kattwyk railway bridge, one of the largest in the world.
- The governance structure of the port and a high degree of vertical integration have supported rail choices, for instance opening up HPA tracks to all 57 railway operators.

Figure 3.9. Road freight traffic over the main Ten-T corridors (2020)



Source: (T&E, 2021[11])

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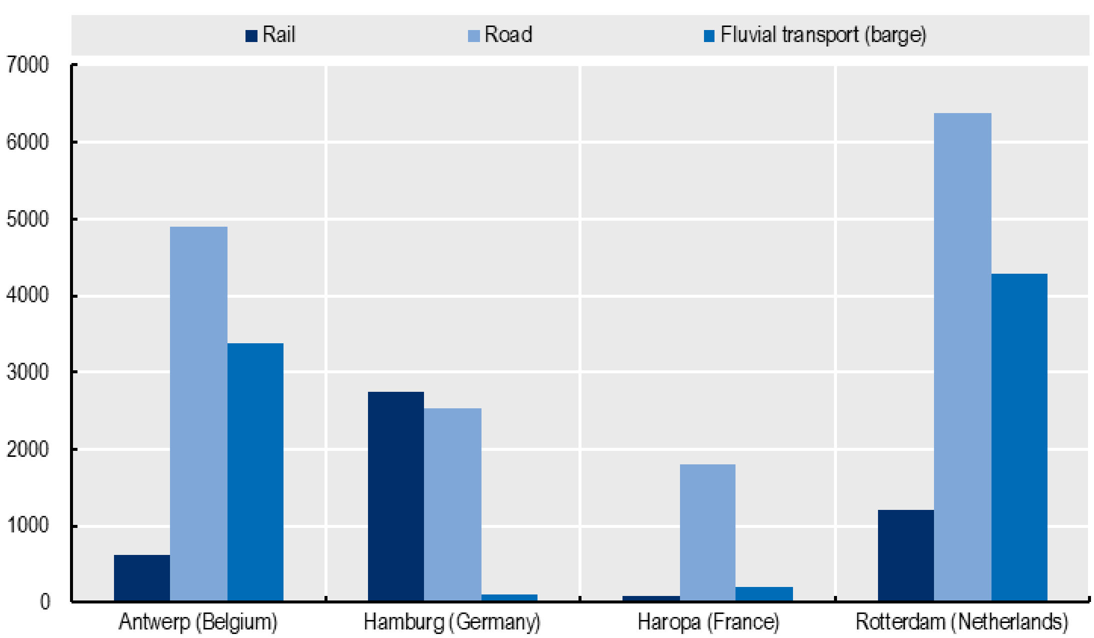
Figure 3.10. Hinterland container transport from European ports by modal share

Thousand twenty-foot-equivalent container units (TEU), 2022 or the latest available date



Source: Port authority reports

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The high share of rail in hinterland transport places Hamburg in a favourable position to work towards climate neutrality since much of its freight transport is already zero-emission. This share is concentrated in long-haul transport (up to 80% of long-haul freight is transported by rail) so that much of road transport takes place on shorter trips, a segment more amenable to electrification.

Hamburg is also a major logistics hub, combining short, medium and long-range transport with warehousing and storage services. The logistics industry occupies a significant part of Hamburg's commercial real estate, covering one-third of its total warehousing and storage area. Urban freight logistics are a growing segment of the logistics business, bolstered by Hamburg's high population and value-added density. In 2019, the average number of courier, express and parcel items per inhabitant in Hamburg was a third above the national average, with related traffic already accounting for about 10% of inner-city traffic.

Acting on Hamburg's competitive advantage: governance, vertical integration and interlinkages in hinterland transport and logistics

The Port of Hamburg is an intermodal hub serving shippers and freight forwarders who are clients of a multitude of hinterland transport and logistics companies. Transport choices are often part of multimodal supply chain strategies, especially as containerisation has reduced the time and cost of transferring cargo.

The port, city transport and logistics businesses are closely interlinked through cross ownerships, partnerships and long-term commercial relationships that support the use of rail for hinterland transport:

- The City of Hamburg is the majority shareholder of the HPA and of the largest port terminal operator HHLA.
- Both terminal operators (HHLA and Eurogate) hold substantial equity shares in railway operators (Metrans and EUROKOMBI respectively) and rail terminals in the hinterland. EUROKOMBI is Germany's largest intermodal railway terminal. Metrans links its port terminals to inland rail terminals in Germany, Poland, Hungary, Slovakia and the Czech Republic.
- The Port of Hamburg is one of Deutsche Bahn's largest customers. In addition to Transfracht International (TFG), companies such as Railion, Intermodal, HHCE, Interconainer-Interfrigo or Kombiverkehr also transport goods straight from the port to the hinterland by rail.
- Some rail freight operators, such as DB Cargo, are also active as third-party logistics companies and freight forwarders.

The actors in road hinterland transport are more dispersed, with 1 700 road haulage companies operating 45 000 trucks registered with the Hamburg Chamber of Commerce. Over 120 courier services are available in Hamburg for the transport of small and urgent consignments across Germany and beyond. Some are also active in the urban logistics business in Hamburg.

In addition to these specialised trucking and freight rail operators, combined transport operators offer intermodal services. For instance, the Hamburg-based Zippel Group has a fleet of 200 trucks and operated 2 000 block trains in 2019. Third-party logistics service providers offer storage, packaging and customs brokerage, and a range of door-to-door hinterland transport services. Container lines such as Maersk, CMA CGM, Cosco and NYK, have their own freight forwarding subsidiaries. Some freight forwarders (such as Kühne+Nagel) hold shares in shipping companies (in this example, Hapag Lloyd). DB Schenker, a division of Deutsche Bahn, is a global logistics provider.

Altogether, about 12 600 companies employ 400 000 people in the local logistics industry. Shippers range from small businesses to huge multinationals. Retail contributes to a large part of containerised shipping and procures considerable amounts of freight transport services directly or via freight forwarders. Larger retailers can own warehouses, vehicles for last-mile transport, or even their own freight forwarding companies, such as Hermes, which belongs to the Hamburg-based retailer the Otto Group, one of the world's largest e-commerce businesses.

Breaking the link between growing freight activity and CO_2 emissions

At 3 602 Mt and 417.2 billion tonne-kilometres, German freight transport is by far the largest in Europe, accounting for almost one-quarter of total EU tonnage, and twice as much as the next largest (France and Spain). The share of rail has grown from 16% to 19% over the last twenty years because the fall in traditional bulk cargo has been more than compensated by an increase in container transport, thanks to substantial investment at key connection points such as ports (BALM, 2023[12]). By contrast, in Europe, the share of freight transported by rail has halved to about 15% in the last 40 years, prompting a downward cycle of increasing fixed costs, loss of competitiveness and loss of volume.

Road freight transport in Germany reached 303.50 billion tonne-kilometres in 2022, 89% of which was national transport. Over half of road tonnage is transported less than 50 km. The German fleet of trucks numbers about 2.7 million, with close to one million vehicles over 3.5 tonnes. Some 85 000 heavy-goods vehicles (HGVs) are newly registered every year.

At 5.1% of total freight transport, Germany has one of the largest modal shares of inland water transport in Europe. Some 182.45 Mt of goods were transported on German inland waterways in 2022, of which over 75% was international transport. Around 80 % is transported on the Rhine for at least part of its journey.

Projections of the effect of current policies agree that inland freight transport will grow by at least 30% into the 2040s, and that road transport will grow more strongly, reinforcing its dominant position in the modal mix:

EU forecasts show an increase of 31% in inland freight transport by 2030 compared with 2015, and of 55% by 2050, with road freight transport growing by 35% by 2030 (ITF, 2021[13])

In Germany, a recent forecasting exercise for the Federal Ministry of Digital Affairs and Transport (BMDV) sees freight transport grow by 30% and road freight transport by 34% by 2051 compared with 2019 (Intraplan Trimode, 2023[14]).

In 2019, transport accounted for 23% of Germany's greenhouse gas (GHG) emissions. Road transport represents 80% of total transport emissions (196 MT of CO_2 equivalent), of which around 28% are from heavy-goods vehicles (UBA, 2023[15]) If projections for freight activity turn into reality, without decarbonisation, freight transport would continue to contribute substantially to CO_2 emissions. EU and national emission reduction objectives therefore appear relatively ambitious:

- The EU aims for a 55% reduction in GHG emissions by 2030 compared with 1990 and climate neutrality by 2050, with a 90% reduction in CO2 emissions from transport, and a 50% increase in the share of rail in freight transport by 2030 and a doubling by 2050.
- Germany aims to reduce its GHG emissions by at least 65% by 2030 compared with 1990 levels, reach net-zero emissions by 2045, electrify 30% of HGV vehicle-kilometres and increase the share of rail in freight transport to 25% by 2030.

The HPA is aligned with the Hamburg Chamber of Commerce's objective of climate neutrality by 2040. The ports of Antwerp and Rotterdam have set this objective for 2050. The HPA has also set a target of 65% for hinterland freight transport by rail by 2040, as well as a target for train container capacity utilisation of 80 TEU in 2025 (BWI, 2023[16]). HHLA has signed up for climate neutrality by 2040 concerning its operations (scope 1 and 2) and aims to reduce its emissions by 50% by 2030, compared with 2018 (HHLA, 2023[17]). Some larger transport operators have formulated emission reduction targets. For example, Deutsche Post DHL Group has set itself a 2050 climate neutrality objective, with a 2025 target to increase carbon efficiency by 50% compared with 2007. Several large shippers have carbon emission reduction targets that cover both their own operations and those of their transport and logistics service providers. For instance, the Otto Group aims to be carbon-neutral by 2030 for its transport and logistics, and IKEA aims to reduce its carbon footprint from freight transport by 70% and from logistics by 80% by 2030.

Opportunities and barriers on the way to climate neutrality

Reconciling the projected growth of freight transport with ambitious climate neutrality targets will require a major effort to decarbonise and improve energy efficiency in freight transport and logistics. Options relevant to Hamburg and its hinterland include the following:

- Modal shift from road to rail
- Modal shift from road to decarbonised inland water transport
- Options for the decarbonisation of road transport
- Energy efficiency improvements in hinterland transport and logistics

Their potential contribution to making Hamburg's economy climate-neutral by 2040 is evaluated in this section, in terms of their costs, their effectiveness and their timeframes.

The potential for further modal shift to rail

Shifting freight from road to rail depends on two factors: making rail more attractive on the one hand and securing additional rail capacity to handle the increased demand on the other.

Distance is one of the main differentiators in mode choice: longer distances bring economies of scale and flow bundling opportunities, and reduce intermodal handling cost relative to total cost. Weight and volume are also key factors, with small volume and low-weight goods such as textiles and food products frequently shipped by road, but over 80% of coal and crude oil transported by rail or inland water transport. Rail is the most competitive transport mode for high volumes and weight, long shelf life and low sensitivity to transport conditions, over longer distances, the sweet spot being generally beyond 300 km to 500 km. Ports such as Hamburg have the advantage that they can generate the critical mass of cargo needed to operate high-frequency large-capacity shuttle trains to the hinterland.

A recent ITF study found that because rail is already very cost-effective for long-distance freight transport, when it already accounts for a large share of freight transport as is the case for hinterland transport out of Hamburg, generating modal shift is difficult (ITF, 2022[18]). The main factor blocking change is inelastic demand for road transport: the reach, speed, and flexibility of road transport are generally superior to rail, so price changes do not always alter the mode-choice decisions of shippers. Modal shift efforts therefore need to focus on increasing attractiveness beyond cost considerations, notably by encouraging multimodal transport and reducing intermodal dwell time. The modal shift requires better information so users can make the appropriate choices. Digital technology is critically important in this respect, starting in ports. The Port of Hamburg's EVITA/TransPORT Rail digital platform includes rail information and plays an important part in supporting rail hinterland transport.

If demand for rail shifts from road transport, rail capacity will need to grow. Resolving rail bottlenecks around Hamburg involves substantial investment with long lead times. For instance, the Hamburg to Hannover corridor is at full capacity and in need of renovation, and the Hamburg to Bremen connection needs upgrading and a third track. Dry ports or extended gates have reduced bottlenecks and increased rail use in ports such as Gothenburg and Antwerp, but are not an option for Hamburg due to spatial constraints and lead times beyond 2040 (Merk and Notteboom, 2015[19]). A further issue is that in Europe, passenger rail transport is prioritised over freight, restricting access to daytime slots, especially close to critical nodes. Increasing freight capacity would require dedicated freight lines, many of which have been dismantled to cut costs. Recreating such redundancies would be a lengthy and, in some cases, an impossible task, since land has long been sold off.

It is generally considered that the most realistic solution to capacity constraints is to focus on making the best of currently available routes through large-scale digitalisation: advanced train control and signalling systems using wireless communication to supervise trains could increase capacity by more than 20% on many network lines without additional tracks (ITF, 2022[20]). The 2000 European Rail Traffic Management

System legislation has led to technological improvements, but progress has been slow, partly because digitalisation requires transformation rather than a step-by-step change. Except for a few countries, the pace of digitalisation has been slow, including in Germany. The Digitaler Bedienplatz should update a portion of the system, though completion is only scheduled for 2033 to 2035.

Modal shift to decarbonised inland water transport

Cargo transport by barge emits up to ten times less CO_2 per tonne than by road (and up to 5 times less than rail). However, reaching climate neutrality requires switching from barge diesel engines to zero-emission propulsion, which is a big challenge. Inland water transport shares structural characteristics with rail in terms of cost, time and flexibility. It also suffers from infrastructure restrictions, notably the bottleneck in the Scharnebeck ship lift south of Hamburg, as the new lock will not be completed until the early 2030s. The Elbe and the Rhine regularly struggle with low water levels, which are affected by climate change. In addition, within the port itself, access to barges will need to be expanded to increase capacity.

Zero-emission barges are being tested in Hamburg. A hydrogen fuel cell-powered pusher boat and a battery electric powered workboat are being tested in the port (Port of Hamburg Marketing, 2023[10]). A feasibility study for the City of Hamburg of an electrified barge for last-mile transport did not show significant energy use and emission reductions compared with electric trucks for loads under its maximum tonnage (108 tonnes), thereby reducing its usefulness for urban short-range transport of small loads (Fraunhofer Institute, 2022[21]).

The inland water transport industry is small and fragmented. The technological leap needed to move to zero-emission inland water transport is likely to require progress made with electric propulsion in sea shipping and road haulage. The uptake of new technologies will be slowed by the large variety and long lifespan of vessel hulls and engines, which exceeds 30 years. Options for totally decarbonising inland water transport therefore appear currently limited.

Decarbonising road freight transport and logistics

According to the BMDV, reducing transport CO_2 emissions by up to 48% by 2030 will entail one-third of the mileage of road freight transport being zero-emission, and one-third of semi-trailer trucks (about 145 000 vehicles) being zero-emission vehicles. These are transformative challenges. The main options for decarbonising road freight transport in the 2020s and 2030 are generally considered to be:

- Battery electric vehicles (BEVs)
- Electric road systems (ERSs)
- Hydrogen-powered fuel cell electric vehicles (FCEVs)

Though these options have been extensively analysed, major uncertainties remain as to their potential, if only because scaling up involves overcoming many technological, market and policy barriers.

Battery electric vehicles

With over one million electric cars on the road, the German electric passenger vehicle market has matured. BEVs are now also progressing in the light commercial vehicles (LCV) segment: according to the German Association of Automotive Industry, there were over 180 000 battery electric light commercial vehicles in Germany in 2021, up 6% from 2020 (VDA, 2022[22]). Much of this increase is attributable to last-mile delivery vehicles and short-haul trucks, which have predictable daily range and payload, return-to-base operations and charging.

Trips over 400 km make up around 5% of all trips in Europe but represent 40% of the EU truck activity (in tonne-km) and 20% of truck emissions, with similar figures for German road freight. BEVs with up to a 500 km range are entering the market. Charging during the driver's mandatory rest period (generally

45 minutes every 4 and a half hours) can extend the range to cover over 90% of road freight activity in Germany (T&E, 2021[11]).

The electrification of vehicles above 7.5 tonnes will require a high-power charging infrastructure. Battery electric trucks that use high-power fast charging need smaller batteries, shifting the economics of battery electric heavy-goods vehicles (ITF, 2022[23]). The numbers for the infrastructure needed are large: the European Automobile Manufacturers Association (ACEA) has estimated that heavy-goods vehicles would require up to 279 000 charging points across Europe by 2030, of which 84% would be in fleet hubs and the rest mostly public high-power points along highways and in overnight charging points (ACEA, 2022[24]).

As part of the EU "Fit for 55" package of regulation, the 2023 revision of the Alternative Fuels Infrastructure Directive mandates that 15% of the entire TEN-T be equipped with fast-charging stations at least every 120 km by 2025, increasing to 50% by 2027, and 100% by 2030, when the maximum distance between stations will be 60 km in the core TEN-T and 100 km in the comprehensive TEN-T (ICCT, 2023[25]). In Germany, the 2022 Federal Master Plan for Charging Infrastructure II proposes 10 measures to accelerate the expansion of HGV charging infrastructure, primarily information-sharing for mapping demand and grid requirements, but also tendering for a HGV fast-charging network along main transport axes (BMDV, 2022[26]). Business initiatives include a partnership of 20 research institutions and businesses, including MAN and ABB, which is working on the publicly funded "HoLa" megawatt high-performance charging system. Daimler Truck, the Traton Group (Volkswagen) and the Volvo Group have also come together for the Milence project, which is building two-megawatt charging systems along the A2 highway.

Electric road systems

An alternative to static charging is an electric road system (ERS) with an overhead catenary line which can also recharge a truck's battery, storing enough power to drive short distances. In Germany, Electric road systems (ERSs) are being tested with Federal funding on two short highway sections and a national road, with results expected at the end of 2024. Siemens, which is testing the concept in Germany and Sweden, estimates that 4 000 kilometres of ERS could accommodate about 60% of German truck traffic on the busiest routes.

Despite high energy efficiency, the high upfront cost of overhead cables (about EURO 10 billion for 4 000 km) appears to be a major barrier to adoption (Fraunhofer Institute et al., 2022[27]). The risk is that uptake might be limited by market inertia, or that ERS technology be rendered obsolete by BEV improvements. There are also major organisational obstacles to be overcome, such as reaching a Europe-wide agreement on technical standards.

Hydrogen-powered fuel cell electric vehicles

Hydrogen-powered FCEVs are less energy efficient than BEVs, but for heavy-goods vehicles driving long distances, weight is a game-changer: hydrogen is significantly more energy-dense. For an 800 km range truck, the weight difference can reach 2 tonnes. FCEVs can travel further with heavier payloads with shorter layover time since refuelling is generally faster than recharging. The range advantage means FCEVs would be suited for trips over 1 200 km, though such trips make up less than 9% of tonne-kilometres in Germany.

There is considerable interest in Hamburg around the hydrogen economy. A 100 MW electrolysis plant is being built on the site of the former Moorburg coal-fired power station. By 2026, it will provide green hydrogen for industrial processes, and transport and logistics (REH, 2023[28]). Ultimately it could be scaled up to 800 MW. A study for the logistics company Dachser identified Hamburg as one of 4 strategic locations where FCEVs could initially operate due to the availability of hydrogen and favourable location (Dachser, 2022[29]). The regions of Hamburg and Lower Saxony have launched an EUR 32 million project to replace diesel trucks with FCEVs. The Clean Cargo Connect project will build five hydrogen refuelling stations and two mobile refuelling facilities, as well as an electrolyser close to Oldenburg.

According to a recent ITF study, the key challenges are energy conversion losses, high vehicle cost (over EUR 400 000 compared with around EURO 250 000 for battery electric trucks and EUR 130 000 for diesel trucks), refuelling infrastructure and the price of hydrogen (ITF, 2023[30]). Fuel cells and hydrogen will likely not see substantial cost reductions from scaling up this decade. Other fuel cell markets such as maritime shipping might not start growing significantly before the 2030s.

Improving energy efficiency in hinterland transport and logistics

Energy efficiency improvements will be essential during the transition to climate neutrality and beyond, since demand for sustainable electricity will increase for a broad range of energy uses. For instance, charging the 40 000 heavy-goods vehicles that arrive in the Port of Hamburg daily would require as much as 16 GWh (for 40-tonne trucks with a battery capacity of 400 kWh). While they would not be charging simultaneously, this would require careful capacity planning. The upper-bound estimate of fuel efficiency improvements expected from the recent revision of European standards would reduce truck fuel consumption by 21% by 2030 compared with 2020. This level of efficiency would require an optimised aerodynamic tractor design, which would also reduce the electricity consumption of electric heavy-goods vehicles.

Reducing the energy intensity of freight transport also relies on route optimisation and reducing empty runs. In 2022 in Europe, 20% of all road freight kilometres were travelled by empty vehicles, with a higher share for national transport (24%) than for international transport (13%). About 20% of trucks had suboptimal loads (European Commission, 2022[31]). In Germany, the LKW Maut highway toll is estimated to have reduced empty runs by 2% (T&E, 2017). There remains scope for optimisation, especially for smaller transporters and for light commercial vehicles that will start paying the LKW Maut in 2024.

The Port of Hamburg is positioning itself as a major hub for e-commerce freight flows. E-commerce brings the challenge of managing urban logistics, with consignments in Hamburg expected to grow by 71% to 163 million by 2030. Hamburg's 2020 Sustainable Mobility Plan includes a strategy for decarbonising urban logistics, with a 40% emission reduction target for the last mile by 2030 compared with 2017. Hamburg is a testbed for innovative solutions to handle the sharp increase in deliveries with decarbonisation and efficiency improvements. Initiated by Logistics Initiative Hamburg (LIHH), efficient delivery networks include micro-depots instead of large storage centres, floating depots on unused canal sections and shared depots, vehicles and lockers (LIHH, 2023[32]). A trial with UPS found that 100 micro-hubs in the city centre could shift 40% of last-mile deliveries to cargo bikes. Other initiatives include Digital Hub Logistics Hamburg (one of 12 digital hubs chosen by the Federal Ministry of Economics and Energy to support digitalisation), which connects companies, startups, investors and researchers. The Hamburg Ministry of Economic Affairs and Innovation is assessing the feasibility of shifting courier traffic to urban waterways with support from the EU DECARBOMILE project. LIHH and nine partners are also testing inland water transport as part of the European sustainable urban freight AVATAR project.

Logistics is more than mobility: it includes warehousing and storage, where the main measures to improve energy efficiency and reduce emissions are equipment electrification, LED lighting and adapting the layout to reduce forklift and truck movement. For instance, all the forklifts operated in Kühne+Nagel warehouses are now electrified, and 75% of lighting is LED. With the growth of e-commerce, logistics real estate is expanding, providing opportunities to build sustainably, as for a new 53 300 m2 logistics centre in Hamburg Wilhelmsburg, with geothermal heating, 6 000 m^2 of solar panels to power BEVs, and state-of-the-art insulation, heating and air exchange systems to minimise energy use.

Moving faster towards climate neutrality: The effect of policy measures

"Peak internal combustion engine" for passenger cars is in sight and the electrification of road freight is underway: battery electric light commercial vehicles produced at scale can already be cost-competitive with diesel vehicles, given current battery prices (ITF, 2020[33]). The electrification of larger vehicles, because they are heavier and travel longer distances, requires expensive high-power chargers. According to ITF analysis, battery electric heavy-goods vehicles are not likely to reach total cost of ownership parity with diesel trucks until 2037. As for FCEVs, they would only be cost-competitive with hydrogen priced below EUR 2.5/kgH_2 (at the pump), down from the current EUR 11/kgH_2, which represents a major challenge (ITF, 2022[18]).

The cost-competitiveness of zero-emission technologies depends largely on economies of scale over the coming decade. Batteries are experiencing a self-reinforcing dynamic driving down costs in the passenger car market. This dynamic is spilling over into the urban and regional delivery truck segment. If it takes another 15 years to do so into long-haul trucking, it would be too late. Competitiveness parity should be reached before 2030 because of slow fleet turnover: in Germany, the average age of light commercial vehicles is 8 years, and 9.5 years for heavy-goods vehicles (Eurostat, 2023[34]). According to ITF's 2023 Outlook, assuming battery electric light commercial vehicles are already competitive with diesel vehicles and that battery electric heavy-goods vehicles become so in 2030, their share of the fleet by 2040 would only be 30% to 60% for light commercial vehicles and 15% to 30% for heavy-goods vehicles (ITF, 2023[35]).

Germany has introduced one of the highest purchase subsidies for zero-emission trucks in Europe, covering up to 80% of additional vehicle costs and/or charging infrastructure, with an EUR 500 000 cap, but take-up has been small. The 2023 revision of the European HGV CO_2 standards raises targets for manufacturers of zero-emission trucks to 45% of their sales from 2030, 65% from 2035 and 90% from 2040, in line with the EU Green Deal objective to decarbonise by 2050. They are designed to incentivise manufacturers to ramp up production to avoid supply bottlenecks in the zero-emission vehicle market.

The 2022 amendment to the EU Eurovignette introduces a tax of EURO 200 per tonne of CO_2 for HDVs in Member Countries with public distance-based tolling, with an optional higher external-cost charge for CO_2 emissions limited to 16 cents/km in all or part of their highway network. Germany's highway toll system, the LKW Maut, introduced in 2005, applies to all vehicles over 7.5 tonnes (extended to vehicles over 3.5 tonnes in 2024), except zero-emission vehicles. Its rate ranges from 9.8 cents/km to 35.4 cents/km, depending on vehicle weight, axle number and EURO emission category (Toll Collect, 2023[36]).

Taking action for the Hamburg economy in the lead-up to climate neutrality

Achieving climate neutrality by 2040 requires a proactive attitude on the part of all stakeholders in the Hamburg economy. This calls for a dedicated plan of action by the Chamber of Commerce and by businesses active in hinterland transport and logistics.

Actions for the Hamburg Chamber of Commerce

The first step towards climate neutrality is to shift from an emission reduction strategy based largely on transition fuels, with an energy mix centred on LNG and CNG, biofuels, and grey or blue hydrogen, to one focused on zero-emission solutions relying on renewable electricity. Renewable electricity generation has long been a major feature of the city-state: 28 offshore wind farms now dot the North Sea and Baltic Sea, several of which are managed from Hamburg. The city already prioritises deep geothermal and waste heat for thermal uses so that valuable renewable electricity can be directed to transport and other hard-to-abate uses. All stakeholders should integrate the need to manage this electricity efficiently into their climate neutrality strategies.

The Port of Hamburg has been remarkably successful in promoting rail for hinterland freight transport, contributing to a virtuous circle that helped preserve the overall share of rail in Germany's freight transport: according to a study by McKinsey, targeted rail infrastructure investment such as that by the Port of Hamburg have triggered larger shifts to rail than investments dispersed across European rail networks (McKinsey & Company, 2022[37]). The City of Hamburg has voiced support for the Federal goal of increasing the share of rail freight transport from 18% to 25% by 2030 and is keen to address the bottlenecks on railways out of Hamburg. This will require coordination with different tiers of government, including in non-transport policy areas such as spatial planning.

The city and the port benefit from a major competitive advantage in the transition to climate neutrality, since so much of hinterland freight transport is already zero-emission thanks to rail. The large share of rail, especially for long-haul trips, will provide a further advantage in decarbonising road freight transport: battery electric trucks are moving fast to cost parity with diesel in the short to medium-distance segment; for long haul trucks, this might not happen before the 2030s. In the case of Hamburg, with rail well established on long-haul routes, decarbonisation will concentrate on routes up to 300 km to 500 km where battery electric trucks are currently entering the market. This presents Hamburg with an early opportunity to position itself as a climate-neutral transport hub within the timeframe of its 2040 objective.

All zero-emission technologies require new infrastructure and investment. Now is the time for stakeholders to lay the ground, given that achieving the 2040 climate neutrality objective will require 10 to 20 years of infrastructure development. Uncertainty is amplified for long-distance freight transport since different jurisdictions could make diverging choices, making it essential to coordinate infrastructure planning along major routes out of ports into the hinterland well ahead of final technological choices.

A 2021 ITF study on zero carbon supply chains in Hamburg recommended that the HPA play a more proactive role in driving the decarbonisation of transporters by leveraging its position as a key transport node (ITF, 2021[38]). The Chamber of Commerce is well placed to encourage hinterland transport and logistics businesses to develop targets in line with the 2040 neutrality objective and support them in developing relevant strategies. This should include setting up networks and thematic committees within the Chamber so that all stakeholders coordinate and share knowledge as well as resources.

The challenge of reaching zero emissions over global supply chains is daunting: encouraging route-specific cooperation among transporters and jurisdictions makes it more manageable. Such efforts can reduce uncertainty and mobilise infrastructure investment, giving Hamburg a head start. This could involve promoting hinterland freight transport “green corridors”, similar to the zero-emission maritime green corridor route agreed in 2022 between Hamburg and Halifax (Port of Halifax, 2023[39]).

Businesses could also benefit from immediate practical help in choosing zero-emission solutions for trips using tools such as the Port of Barcelona’s “eCOcalculator” to evaluate CO_2 emissions generated by transporting a container into the hinterland (Port of Barcelona, 2019[40]). This service could be extended to in-depth analysis, assessing more complex transport chains and exploring emission reduction solutions.

Hamburg is, like many other ports, deeply embedded in a metropolitan area with a densely populated hinterland. While zero-emission vehicles will eliminate CO_2 emissions and tailpipe pollutants, and halve traffic noise, other impacts such as braking emissions and traffic congestion will remain and indeed grow along with the projected rise in freight transport. The future importance of BEVs also points to the need to associate decarbonisation efforts with energy and transport demand management.

Experience shows that businesses benefit from information exchange and networking to make transformations and reach financial decisions - they help find cost-effective solutions and lower transaction costs. Generally, business-based energy-intensive solutions are more readily considered than changing habits or processes to reduce energy inputs, even though energy savings are in fact the first “zero-emission fuel” (IEA, 2021[41]) and are of critical importance in view of the difficulties to expand renewable energy production to the required scale. Coordinated logistics harness such savings.

The ITF Hamburg case study also recommended stronger involvement of the city administration in zero carbon freight by initiating a coordination group for port cities in Europe and across the world to develop common policies. Coordination with jurisdictions that could be considered freight transport competitors is particularly relevant for the Chamber of Commerce to avoid carbon leakage. The city and its port are ideal backdrops to test and demonstrate zero-emission solutions. Effective policy advocacy requires a technological and policy watch of the issues involved should be formally established as soon as possible, so that relevant information can be shared in a timely fashion.

Actions for Businesses

The main obstacle for shippers is the lack of zero-emission transport solutions offered by transport operators. The large share of rail in freight transport out of the port of Hamburg provides carriers and forwarders with a head start in working towards zero-emission supply chains, compared with many other large ports. At the moment, the only zero-emission freight transport chain possible would combine rail transport with last-mile transport by BEVs, though in practice there are still unavoidable CO_2 emissions because road transport has not been entirely decarbonised.

Businesses can accelerate the climate neutrality transition by investing early in zero-emission solutions, even if they initially come at a “green" cost premium which some customers are willing to pay. To succeed in these new markets, companies should design market strategies that target green segments of their business.

Many stakeholders in freight transport are interrelated. Strategic partnerships between shippers, logistics providers and their transport partners can provide a collaborative environment supportive of supply chain decarbonisation. Long-term shipping contracts that include climate neutrality criteria in contract bidding can also provide an opportunity to decarbonise transport and logistics operations.

Transport and logistics businesses with large fleets could pilot zero-emission truck adoption in clusters or along transport lanes, as a first step towards decarbonisation. Networking could help deploy private depot chargers which will be central to fleet charging needs, with access encouraged through collaboration between fleet owners, truck manufacturers, utilities and infrastructure providers.

Financing and leasing companies should turn their attention to innovative business models to overcome the upfront costs associated with zero-emission trucking, particularly for smaller operators. Solutions such as trucking-as-a-service and charging-as-a-service can facilitate the transition to zero-emission trucking for fleet owners, as they are less capital-intensive (ICCT and ECTA, 2022[42]).

The larger businesses have dedicated research and innovation centres focused on preparing for the logistics of the next decade and beyond. Hamburg, as a major industrial and transport hub, has the critical mass of knowledge and resources to support these efforts. The Chamber could work towards linking small businesses with these efforts and combining them with local scientific advice.

Key actions

Immediately

- The Hamburg Chamber of Commerce could prepare hinterland freight transport green corridors through cooperation among transporters, vehicle manufacturers and infrastructure providers.
- The Hamburg Chamber of Commerce could provide "ecocalculator" tools to evaluate CO_2 emissions generated by transporting goods, considering emission options for individual trips and routes.
- The Hamburg Chamber of Commerce could establish a technological and policy watch for monitoring and sharing information related to zero-emission options in freight transport and logistics.
- Shippers should introduce decarbonisation and energy efficiency criteria in bidding processes for shipping contracts to incentivize carriers to adopt greener practices.
- Transport and logistics businesses should pilot the adoption of zero-emission trucks in clusters or specific transport lanes as a step toward full decarbonisation.

- Transport and logistics businesses should design a green/climate-neutral service proposition, identify target markets and create a pricing strategy for zero-emission services.

By 2030

- The Hamburg Chamber of Commerce could promote leveraging Hamburg's position as a clean energy hub, taking into account the shift from transition fuels to decarbonisation.
- The Hamburg Chamber of Commerce could promote coordinated energy-saving logistics by providing information and networking.
- Shippers should form strategic partnerships with logistics providers and transport partners to collaboratively work toward supply chain decarbonisation.
- Transport and logistics businesses should collaborate to deploy private depot chargers for electrified heavy-goods vehicles, especially where public infrastructure is lacking.

By 2040

- The Hamburg Chamber of Commerce could monitor and coordinate with other jurisdictions, notably on railway renovation and other infrastructure improvements.
- The Hamburg Chamber of Commerce could continue taking account of the urban environmental impacts of freight transport, including PM emissions, traffic congestion and noise.

The transition to climate neutrality in key manufacturing sectors

As discussed in Chapter 1, manufacturing employs more than 100 thousand people in Hamburg and generates around 12% of value added. It is the most productive economic sector in the Hamburg economy. Some manufacturing sectors will be particularly hard to make climate-neutral (OECD, 2023[43]), mostly those producing basic materials, including basic metals and oil refining. They employ around 8000 workers in Hamburg. In addition, cement is produced close to Hamburg.

These sectors have depended particularly strongly on fossil fuels as inputs, both as energy carriers and as raw materials. They require high temperatures in production processes which do not easily lend themselves to electrification. Long-lived fixed capital assets characterize production in the sectors. Replacement of existing equipment may therefore need to be net-zero consistent starting in 2025 even to reach climate neutrality in 2050 (Material Economics, 2019[44]).

The manufacturing activities producing basic materials are located within the port. The port helps better integrate production in global value chains. Indeed, the production of basic materials permeates the value chains of a wide range of manufacturing products. It also depends on imports of materials and energy inputs. For example, in the EU the manufacture of basic iron and steel alone employs 375.000 workers. Upstream and downstream jobs could be 5 times as many (Oxford Economics, 2019[45]). Aluminium production employs about 230.000 workers and about 1 million workers when including indirect employment (European Aluminium, 2015[46]). Successful decarbonisation of basic materials production is therefore important beyond Hamburg on a European scale.

Transformations towards the circular economy are particularly important in manufacturing industries producing basic materials. Reducing demand for raw materials saves energy and other resources and avoids process emissions. (Sun, Lettow and Neuhoff, 2021[47]). Circular economy approaches, for example, could reduce CO_2 emissions in plastics, steel, aluminium, and cement by 56% in developed economies by 2050 relative to a baseline with no further climate action and no major shift in materials intensity or industry structure (Johnson et al., 2021[48]; Sharmina et al., 2021[49]; Material Economics, 2019[44]).

Beyond climate, raw materials extraction and processing also account for substantial water, soil and air pollution and ecosystem destruction worldwide. These environmental impacts are particularly severe in basic metals production, notably steel and copper. Most global environmental impacts of extraction and processing of these key materials are projected to at least double between 2017 and 2060 if recent materials use and policy trends continue (OECD, 2019[50]). These trends need to be reversed to address the global interrelated challenges from climate change, biodiversity loss and the degradation of land.

The circular economy requires exchanging and reprocessing materials or shared-use assets among manufacturing plants or their customers. It also requires moving towards producing goods that can be used for longer, be reused, or be available for shared use. Reducing transaction costs is therefore important, for example, to ensure the precise composition of materials or the repairability of components is known. Digitalisation and industrial symbiosis can contribute:

- Digitalisation can support the circular economy practices in the industry through improved tracking of product and materials composition. Major opportunities include marking technologies, low-cost sensors, and real-time tracking to provide better information on materials composition as well as automation, for example in sorting (Material Economics, 2018[51]). Other opportunities are geolocation technologies to indicate asset locations or blockchain to store information (OECD, 2020[52]). Digital technologies also reduce transaction costs in innovative circular economy business models, such as in the provision of capital goods as a service (Barteková and Börkey, 2022[53]).
- Industrial symbiosis, or closed-loop recycling as it is sometimes called, involves the use of by-products from one firm as inputs for another. Industrial symbiosis reduces intermediaries and is most common in industries that produce pure and homogeneous materials, such as the chemicals industry. Some of these relationships may develop organically or are the result of carefully planned industrial parks (OECD, 2019[54]). The partnership of industrial establishments across sectors, sharing infrastructures and their material inputs and outputs (including waste) can also optimise resource use.

Decarbonising manufacturing is a particular challenge in view of global competition and different climate policy ambitions across countries. In principle, the pricing of environmental footprints in value chains could address this challenge. The EU carbon border adjustment for steel, aluminium and cement products addresses this challenge to some extent but may expose domestic producers to deteriorated competitiveness in third markets, where such rules do not exist. Broad international alliances for the taxation of environmental footprints would therefore be useful.

The remainder of this section will take a closer look at manufacturing activities in Hamburg that are difficult to decarbonise, in particular, steel, copper, aluminium and oil refining.

Steel manufacturing

Steel is essential in the global economy for its wide manufacturing and construction applications such as automobiles, industrial machinery, buildings, railways, and bridges. Steel is also vital for capital goods and infrastructure in the net-zero transition, such as for electric vehicles and wind power. The demand may overall remain stable or slightly increase in Europe, while global demand may increase by more than a third (IEA, 2020[55]). Among heavy industries producing basic materials, iron and steel production is particularly dependent on freight services, relative to value-added, alongside non-metallic minerals (OECD, 2023[43]).

Hamburg has three installations in steel manufacturing in the EU ETS, all owned by ArcelorMittal. In 2019, emissions of the three installations summed up to 346 thousand $MtCO_2$. ArcelorMittal is one of the world's leading integrated steel and mining companies. Globally, they produce 69.1 million tonnes of crude steel, of which 0.9 million tonnes in Hamburg. In Hamburg, the company also produces billet and high-quality wire rods, and its production is mainly sold to automotive and engineering customers in the European market.

In the long term, decarbonisation will require the adoption of new technologies for steel production on the basis of mined raw iron (primary production). The main option without relying on Carbon Capture and Storage (CCS) is hydrogen-based direct reduction with “green” hydrogen (H-DR) (IEA, 2020[55]; Material Economics, 2019[44]). The H-DR route for making steel may be more attractive in regions with access to low-cost green hydrogen. Green hydrogen produced with renewable electricity replaces coal or natural gas as the reducing agent. Steel production in Hamburg could therefore benefit from a hydrogen hub in Hamburg to obtain access to hydrogen at the lowest possible cost, an issue taken up below. Hydrogen needs can also be avoided by outsourcing the production of iron pellets to locations with cheap hydrogen production. Iron pellets are easily transported.

Currently, most steel worldwide is produced with a combination of blast furnaces and basic oxygen furnaces (BF-BOF). Another method to produce steel is through direct reduction and electric arc furnaces (DRI-EAF). DRI-EAFs have the potential to be fully decarbonised, in terms of Scope 1 and Scope 2 emissions, using green hydrogen and climate-neutral electricity sources (Wang et al., 2021[56]; Bataille, 2020[57]) without large-scale replacement of production equipment (Box 3.5).

Steel in Hamburg is produced using Europe’s only DRI-EAF furnace (Eurofer, 2022[58]). Hamburg steel production is therefore relatively well-placed for decarbonisation. Even so, the new production processes will have wide implications for infrastructure such as raw materials storage and processing, transport and supply of energy, power and steam distribution and generation (Material Economics, 2019[44]). As elsewhere, steel manufacturing in Hamburg is particularly energy-intensive.

ArcelorMittal is preparing to make the switch to hydrogen instead of natural gas in the iron ore reduction process. A project is underway to test hydrogen DRI for iron production on an industrial scale, integrating it into the EAF steelmaking process (Reuters, 2021[59]). The objective is to reach industrial commercial maturity of the technology by 2025, initially producing 100,000 tonnes of climate-neutral iron a year. The German government has expressed its intention to provide €55 million of funding support towards the plant’s construction (Box 3.6).

Box 3.5. Steel production methods worldwide

The ironmaking and steelmaking phases are the most emissions- and energy-intensive phases in the making of steel products minerals. Currently, most steel worldwide is produced with a combination of blast furnaces and basic oxygen furnaces (BF-BOF). Another method to produce steel is through direct reduction and electric arc furnaces (DRI-EAF).

- **BF-BOF:** Iron ores are heated with highly purified coal in a blast furnace (BF). The carbon in the coal binds with the oxygen of the iron ore as CO and CO_2, leaving the elementary iron in a melted state. Then, various other elements, such as carbon, chromium, zinc and nickel, are added in a subsequent alloying process in a separate basic oxygen furnace (BOF) to produce steel.
- **DRI-EAF:** In direct reduction (DR), the iron ore reacts with hydrogen (H_2) combined with carbon monoxide (CO) in syngas, now usually made using methane (mostly from natural gas) and water. The elementary iron is then melted in an electric arc furnace (EAF) and alloyed as necessary to produce steel (Wang et al., 2021[56]; Bataille, 2020[57]).

Steel products can be made from iron ore or scraps, or a combination of both. Recycled secondary steel is usually made using the EAF method. On average, the BF-BOF method emits 2.3 tonnes of CO_2e per tonne of steel produced. Natural gas-driven DRI-EAF plants emit 0.7 tonnes of CO_2 per tonne of steel produced (Wang et al., 2021[56]; Bataille, 2020[57]).

Source: (OECD, 2023[43])

Production costs and investment

Based on current estimates of the levelised costs of production for commercial-scale plants, producing one tonne of carbon-free primary steel (i.e. without using recycled materials as inputs) is at least 8-9% more expensive than today's main commercial production routes. However, this is based on CCS-equipped DR, with hydrogen produced from natural gas, and innovative smelting reduction processes. Deploying CCS at scale is subject to major uncertainty. All other options for decarbonising steel, except for recycling, cost at least 30% more. The hydrogen-based DR route typically raises costs by around 35-70% for bulk steel (IEA, 2020[60]), with energy efficiency and electricity price being determining factors. The costs can also vary depending on access to green hydrogen. In downstream products, metal parts may perhaps cost 10% more and would only add $300-400 to a car for example (0.5-2%) (Bataille, 2020[57]). Falling costs of green hydrogen production will lower this gap.

The viability of emission-free production of primary iron and steel in Hamburg will depend on electricity and hydrogen prices. A more granular distribution of electricity prices over time and space would result in more efficient energy markets and would give energy-intensive industries in Northern Germany, including Hamburg, a better chance. The overall regional balance of energy supply and demand in Hamburg is therefore also likely to influence prices at which electricity will be delivered to industry.

Integrating circular economy practices in steel and other basic metals production is key to lowering Scope 3 emissions. While ArcelorMittal does not publish Scope 3 emissions, emissions from copper production in Hamburg suggest they can be a high multiple of Scope 1 and 2 emissions. Beyond climate, the extraction of raw iron and its processing are among the most environmentally damaging materials processing activities, with a broad range of strong, adverse impacts on energy use, climate, human toxicity as well as terrestrial and ecosystem degradation, that would be set to rise further on current world-wide materials use trends (OECD, 2019[50]). Integrating circular economy practices is therefore of strategic interest especially in steel.

The use of steel scrap mainly uses electricity and therefore entails much lower GHG emissions (Wang et al., 2021[56]). It can be fully decarbonised without resorting to hydrogen and with substantially lower energy input. Expanding steel production on the basis of scrap processing can also be an interesting option if electricity or hydrogen costs are locally too high. There are at present limitations to relying on scraps for recycling (IEA, 2020[61]) both in terms of availability of scraps and quality hence, mitigation strategies for steel cannot rely solely on recycling (Material Economics, 2019[44]). In particular, copper contamination in steel scrap limits high-value recycling.

Box 3.6. Steel companies with net zero targets and EU initiatives

In the steel industry, there are industry-wide and firm-specific initiatives to reach climate neutrality. Several EU steel companies have plans to start piloting H-DR, including Salzgitter, SSAB, ThyssenKrupp, and Voestalpine (Material Economics, 2019[44]). Some companies that have net zero emissions ambitions include ArcelorMittal, Thyssenkrupp, Acerinox and Posco. Companies mention technology levers such as green hydrogen, direct reduction and renewable electricity. Also, the use of CCUS is included to keep current assets running, and thus reduce stranded asset risk, and make more short-term progress. To reach these goals, companies highlight the importance of the provision of affordable clean energy, circular economy infrastructure, sustainable finance for developing climate-neutral steelmaking and a global level playing field. (Acerinox, 2021[62]; ArcelorMittal, 2021[63]; Posco, 2021[64]; Thyssenkrupp, 2020[65])

The EU Ultra Low Carbon Steel program (ULCOS) is a cooperative R&D initiative on CO_2 emissions reduction solutions in steel production between the European Commission, major EU steel companies and other research partners (Quader et al., 2016[66]). One technology that was explored is the Hisarna process, which produces a more concentrated CO_2 waste gas than BF-BOFs, facilitating carbon capture. The Hisarna process could also be installed next to existing steel facilities but would need to be used with carbon capture and storage (CCS). It would not disrupt existing supply chains and labour forces (Bataille, 2020[57]).

In Sweden, a Hydrogen Breakthrough Ironmaking Technology (HYBRIT) project was launched in 2016 in cooperation with SSAB. The Swedish HYBRIT hydrogen DR-EAF project uses hydrogen, produced by electrolysis using fossil-free electricity, to produce primary iron ore pellets. Electricity prices are a main production cost parameter (Pei et al., 2020[67]). The project delivered its first carbon-free steel to Volvo in August 2021 (SSAB, 2021[68]). Although volumes are still small, SSAB plans to lift production to an industrial scale by 2026. The company also plans to convert a production plant in Sweden by 2025.

In Germany, ArcelorMittal supports this ambition by operating a hydrogen DR-AEF facility in Hamburg. With partial funding from the German government, it is building a commercial-scale demonstration plant that will use either green hydrogen and carbon monoxide or pure green hydrogen for direct reduction (ArcelorMittal, 2021[69]).

Other projects to produce green steel using pure green hydrogen instead of natural gas currently being developed in Europe include GrInHy and SALCOS-MACOR by Salzgitter in Germany and SuSteel and H2Future by Voestalpine in Austria. ThyssenKrupp is planning on eventually converting its Duisburg plant In Germany to produce steel with hydrogen.

One promising alternative to hydrogen is using electricity to reduce iron ore through electrolysis. This method is being explored by Boston Metal in Massachusetts, and Luxembourg-based Arcelor Mittal (Fennell et al., 2022[70]).

Source: (OECD, 2023[43])

Copper manufacturing

Copper is an indispensable metal for decarbonisation. With its high electrical conductivity and corrosion resistance, it plays a significant role in electrification, the deployment of renewable energy and electric car production. The global copper demand could, on account of these demands and on account of income growth, triple in 2050 compared to the 2010 level (Elshkaki et al., 2016[71]).

70% of the total GHG emissions from the entire copper production value chain occur in mining sites, 23% are from smelting and refining, an activity carried out in Hamburg, and 7% in transport and the recycling of sold products (International Copper Association, 2023[72]). This is reflected in high scope 3 emissions of primary copper production in Hamburg (Box 3.7). Other negative impacts of copper mining and processing on the environment include water pollution, soil contamination and ecosystem degradation. While less wide-ranging than for iron processing, these impacts could increase particularly strongly for copper by 2060 on recent policy and economic development trends (OECD, 2019[50]).

Circular economy practices can contribute substantially to reducing Scope 3 emissions and other environmental impacts along the value chain, especially from copper mining. Copper production from recycled materials (secondary production) involves only 35% of the carbon footprint production that results from the use of raw materials from copper mines ("primary production") (Grimes, Donaldson and Grimes, 2015[73]). The total environmental impact of secondary copper is only 1/8 of the primary copper production process. This entails initiatives to advance sorting methods, enhance fabrication yields, prolong the lifespans of products, and more efficient use of the existing copper stock (Watari et al., 2022[74]). At present, 50% of copper products are recycled, and 30% of global copper demand is met by recycled inputs (OECD, 2019[50]). Even 100% recycling rates will not be able to end the need for primary supply by 2050 (Hund et al., 2023[75]).

Energy intensity is high in both primary and secondary production. A mix of electrification, green hydrogen and ammonia, produced from green hydrogen, as well as the reuse of waste heat can decarbonise the energy use. The energy density of ammonia, produced emission-free from green hydrogen, is higher than for hydrogen itself (Valera-Medina et al., 2018[76]) and therefore serves for achieving elevated process temperatures (The Royal Society, 2021[77]). The planned ammonia terminal may enhance the competitive edge of business in Hamburg. Electricity prices will also be an important determinant of competitiveness.

As in the case of steel, process CO2 emissions result from the use of natural gas in the reduction process. Hydrogen can serve as a substitute for natural gas as a reducing agent in both primary and secondary production. Hydrogen can remove oxygen from the copper mineral melt, generating water vapour instead of CO2 (Luidold and Antrekowitsch, 2007[78]). GHG emissions also come from the separation of organic chemicals from secondary copper materials (Chen et al., 2019[79]). These processes entail the intricate separation of over 50 materials, each with distinct thermodynamic and metallurgical characteristics, from a single product (IEA, 2021[80]). Carbon Capture and Storage (CCS) can help to decarbonise the secondary production where CO2 is generated when separating copper from other materials, such as plastics.

Box 3.7. The decarbonisation strategy of Aurubis AG in Hamburg

Aurubis, a metal manufacturing company headquartered in Hamburg, specialises in producing copper cathodes and related other copper products in several production sites. In 2021, Aurubis reported 559,000 tonnes of Scope 1 emissions, 1,047,000 tonnes of Scope 2 emissions, and 6,181 000 tonnes of Scope 3 emissions across their business sites. Out of their Scope 1 emissions, 165 000 tonnes originated from the Hamburg plants. The Hamburg site of Aurubis is taking the lead in the group on decarbonisation and carries out research and development for the group.

Aurubis is working towards decarbonising its value chain and aims to reduce Scope 1 and 2 emissions by 50% by 2030. It is expanding its long-term power purchase agreements with energy companies that have a large share of renewable energy in their portfolios. Additionally, Aurubis generates its own electricity through on-site solar plants and utilises waste heat to generate electricity. Waste heat also plays a role in supplying heat and processing steam as well as feeding district heating for buildings in Hamburg.

Supported by the Federal government's hydrogen supply strategy, Aurubis has conducted trials replacing natural gas with hydrogen as a reducing agent in anode furnaces. The use of ammonia in rod plants is also being explored as part of a collaborative effort on hydrogen between Germany and the United Arab Emirates (UAE). In the initial stages of the production process, an ammonia co-firing trial is set to replace 20% of the natural gas fuel for six to eight weeks this year.

To reduce Scope 3 emissions, Aurubis aims to achieve a recycled content share. Its Hamburg facility specialises in recycling raw materials. In 2022, it decided to invest € 190 million to enhance recycling in the Hamburg recycling operations. Aurubis closing material loops through customer collaborations and product marketing. The company offers tailored solutions for customers to recycle copper and other metals. This includes selling copper scrap back to Aurubis and receiving refined copper in exchange.

Source: (Aurubis AG, 2023[81]); (Carbon Disclosure Project, 2022[82])

Decarbonising aluminium

Demand for aluminium may increase as it can displace other materials to reduce weight and thereby energy use (Pedneault et al., 2021[83]). For example, replacing steel with aluminium reduces energy consumption in cars, a key consideration for more sustainable car production. In aluminium production primary production from mined raw materials has on average a greenhouse gas emissions footprint twenty times higher than secondary production from scrap. Secondary aluminium production also boasts a lower environmental footprint more generally and much lower energy use. (Liu and Müller, 2012[84]; Liu, Bangs and Müller, 2013[85]). Primary and secondary aluminium cannot be substituted with the given equipment. The Hamburg production of aluminium consists of primary aluminium only.

Secondary aluminium production represents over half of world aluminium production. Aluminium is quasi-infinitely recyclable. However, scrap availability still limits recycling, reflecting long product life and the short history of mass aluminium production (IAI, 2021[86]). Circular economy strategies also need to overcome alloy inter-contamination in recycling and to further reduce transformation and fabrication losses (Pedneault et al., 2021[83])

Primary aluminium producers are large electricity consumers (IEA, 2020[61]). The price of electricity is hence a major production cost determinant. The Hamburg aluminium production plant reports it can respond flexibly to variable renewable energy supply. Aluminium production would therefore benefit from the granularity of electricity pricing, so its positive role in system stability can be valued. Even so, aluminium production also requires some baseload electricity to ensure continuity of production, which offshore wind could supply. The extent to which electricity prices need to incorporate network costs may be key. Reflecting high electricity needs and the significant share of coal in German electricity Scope 2 emissions are about 3 times higher than Scope 1 emissions in Hamburg aluminium production. No information on Scope 3 emissions is available.

Climate-neutral technologies, in particular inert anode smelting, need to reach significant market penetration in the next two decades (Liu, Bangs and Müller, 2013[85]) and are not yet deployed in Hamburg. Replacing carbon anodes with inert anodes eliminates direct emissions, including process emissions (IAI, 2021[86]). Following this route makes CCS redundant. The electricity requirement for inert anode smelting may be 50% higher than for the current smelting process (Pedneault et al., 2021[83]), although this may come down with technological developments. Moreover, stranded asset risks are substantial as it is currently unclear whether it is feasible to retrofit existing installations, which have an economic life of at least 20 years (Pedneault et al., 2021[83]).

Employment effects of decarbonising basic metals

Employment in the manufacture of basic metals, including aluminium, copper and steel, in the EU-27 may slightly increase until 2030, according to Cedefop's European Green Deal (EGD) scenario (Cedefop, 2021[87]). The OECD ENV Linkages model finds that the effect of decarbonisation policies will cause a slight decrease in employment in aluminium and a slight increase in steel by 2040 across OECD and most EU countries, though the large EU countries may lose some employment.

Decarbonised steel production may have significant employment potential, particularly for science, technology, engineering and mathematics graduates (University of Cambridge Institute for Sustainability Leadership (CISL), 2020[88]). As part of the shift towards the circular economy, workers will be expected to possess strong digital skills as well as an understanding of environmental management and knowledge to support circular business models (University of Cambridge Institute for Sustainability Leadership (CISL), 2020[88]). A major challenge for the sector is the ageing workforce which may slow skills renewal and green skills.

Oil refining

Refined petroleum products have two uses: energy use (fuels) and non-energy use (raw material or "feedstock" for petrochemical products). Direct emissions from the manufacture of refined petroleum products are among the highest, relative to value-added, across manufacturing sectors, but the Scope 3 emissions, notably from using final oil products, are substantially higher than direct emissions (Jing et al., 2020[89]). With the electrification of road transport, global demand for fuel oil products will decrease strongly (IEA, 2021[90]).

Where electricity cannot substitute energy provided by fossil fuels, new fuels, including biofuels, hydrogen and synthetic fuels will substitute crude oil. Of these, only biofuel production can be based on existing oil-refining production assets. Oil refineries converted to biofuel plants can reduce the stranding of assets and reduce capital costs of biofuel production (Karka, Johnsson and Papadokonstantakis, 2021[91]). Other benefits include using shared infrastructures, such as for transport, and logistic networks from the oil refining infrastructure.

Demand for oil products as "feedstock", such as to produce plastics, may by contrast increase at a global scale for some time. Overall, the IEA (2021[90]) expects a decrease in global oil demand by around 70% by 2050 in a net-zero-emissions scenario but still expects some oil to be produced in 2050 at a global level. Even so, meeting the EU climate neutrality target may reduce fossil fuel use substantially even as feedstock by 2050, especially if CCS is avoided. This could also concern petrochemical production in Hamburg (Box 3.8).

One possible replacement is with biofuels. Green hydrogen combined with carbon capture and use (CCU) to produce synthetic hydrocarbon fuels as well as chemical plastics recycling can be alternatives but are energy-intensive. Another possible replacement is biofuel. Biofuel is likely to face high demand, for feedstock and fuel use. Its production will compete with other land uses, notably for food production, biodiversity protection and carbon sinks. Its sustainable sourcing is necessary for climate neutrality. The demands on biomass therefore risk exceeding sustainable supply substantially. Sustainable biofuels will have unavoidable priority uses. These include aviation and shipping fuels, as well as feedstock to produce petrochemicals and plastics or fibre-based substitutes for plastic products (Material Economics, 2019[44]).

According to the EU ETS, there are six oil refining installations in Hamburg. The bulk of emissions arise in the production of diesel transport fuels which do not serve priority use. Unless this production can be repurposed to produce biofuels, the production is likely to cease in the transition to climate neutrality. Biofuel processing is thus far particularly strong in countries with high biofuel production potential, such as in Brazil or Sweden. This suggests biofuel processing may not play an important role in Hamburg. On the other hand, Hamburg’s economy depends on sectors where biofuel use will be a priority, notably in transport, as well as in the production of some petrochemical products (Box 3.8).

Box 3.8. Decarbonising oil refining: The example of Hywax in Hamburg

Hywax in Hamburg produces waxes, petroleum jellies and wax emulsions for different types of products, such as insulation materials, cosmetics, coated paper, adhesives for cardboard, food products, etc. The raw materials used are to a large extent by-products from crude oil refining and more specifically from the production of base oils, which are for example used for motor oils. Hywax in Hamburg is one of the leading companies in wax production in Europe. It employs around 350 people and is an important activity for the port. It loads about one ship (barges and larger vessels) per day with waxes.

Hywax used to produce their finished products 99% from raw materials derived from crude oil. Nowadays it uses 70-80% of crude-oil-derived raw materials and the rest are natural and synthetic waxes. Waxes are then kept in tanks at high temperatures (60-80°C) to remain liquid.

Hywax aims to be **climate-neutral by 2040** through three main measures:

1. **Optimisation:** the company plans to replace older tanks and pipes with newer, better-isolated ones to reduce heat loss. It also plans to invest in newer, more energy-efficient machines.
2. **Electrification:** the company plans to switch from natural gas (which is mainly used in a co-generation unit to produce steam and electricity) to a) heat pumps to provide heat for wax production and storage, and b) external sourcing of renewable electricity as the main energy source.
3. **Harnessing variable renewables:** As waxes only lose around 1°C in temperature per day if the tank heating is interrupted, the variability of renewable energy sources is not an issue but an opportunity. Waxes in the storage tanks can be heated up to 95°C during periods of high availability of renewables. Wax production is thus well placed to benefit from low-cost intermittent renewables supply.

Nevertheless, for fully climate-neutral wax production, feedstocks need to be further replaced by natural-based and synthetic waxes. For synthetic waxes, the options are ‘green’ hydrogen combined with carbon capture and use (CCU). The processing is similar to the production of synthetic sustainable aviation fuel (SSAF).

Source: (OECD/Hywax, 2023[92])

Employment effects of decarbonising oil refining

A substantial reduction in this employment can be expected. According to Cedefop’s European green deal (EGD) scenario, direct employment in manufactured fuels in the EU-27 will decrease by about 10% until 2030 (Cedefop, 2021[87]). This is additional to an already expected decline of 4% in this sector in Cedefop’s baseline scenario. A substantially bigger decline is expected beyond 2030, as activity needs to be phased out.

A study on the transferability of skills in the UK offshore energy workforce found that soft skills, business skills and other non-technical skills in the oil sector tend to be highly transferable to adjacent clean energy sectors such as offshore wind, carbon capture and storage, hydrogen or other industrial sectors (de Leeuw and Kim, 2021[93]). However, transition training and upskilling will be required.

Key actions

Immediate action

- Businesses should replace long-lived capital assets in a way that is consistent with climate neutrality.
- The Chamber of Commerce could seek to support broad international alliances for the taxation of environmental footprints in basic materials production, extending them beyond the EU.
- Scope 3 emission accounting should be provided and included in climate neutrality targets and action plans of all Hamburg basic material producers.
- The HCC could assess, with key businesses, employment and worker skills implications from the transformations in manufacturing, in particular in oil refining, and identify actions to maintain attractive job prospects for affected workers.

By 2030

- Key businesses in basic materials manufacturing should define circular economy strategies for the decarbonisation of value chains.
- The Chamber of Commerce and key businesses in basic materials manufacturing could assess the key determinants of making climate-neutral production viable in Hamburg, including the cost of hydrogen and electricity.

By 2040

- Key businesses in basic materials manufacturing should largely eliminate direct missions in Hamburg production sites, with the remainder to be offset with the purchase of carbon credits.

The potential for a green hydrogen hub in Hamburg is large

Green hydrogen is an essential tool for reducing emissions in all sectors that are difficult to electrify (IRENA, 2020[94]) (IEA, 2023[95]) (IEA, 2022[96]). Several of these are present in Hamburg, including steel and copper production. Hydrogen-based fuels for shipping are also particularly relevant for Hamburfg The European Union’s hydrogen strategy (European Commission, 2022[97]), as well as RePowerEU (European Commission, 2022[98]) place green hydrogen as a major instrument to lower CO2 emissions, as well as the German National Hydrogen Strategy and the Hydrogen Strategy for Northern Germany (Federal Ministry for Economic Affairs and Energy, 2020[99]).

As a key European industrial port, Hamburg holds a comparative advantage. The IEA emphasizes the pivotal role of "*mak(ing) industrial ports the nerve centers for scaling up the use of clean hydrogen*" (IEA, 2019[100]). Hamburg’s strategic plan involves establishing itself as a prominent green hydrogen hub in the North Sea region (Box 3.9), with multiple industries in the area already demonstrating a strong inclination toward procuring green hydrogen (Future Hamburg, 2022[101]).

Box 3.9. The Hamburg green hydrogen hub

German green initiative for hydrogen

Initiated by the Northern German Chamber of Industry and Commerce, the green initiative for hydrogen gathers Hamburg, along with Bremen, Schleswig-Holstein, Mecklenburg Western Pomerania and Lower Saxony, with initial subsidies of 9 billion euros. It aims at turning Northern Germany into the strongest region for green hydrogen in Europe. Nearby the port of Hamburg, the Helmholtz Centre gather scientists working on a new kind of storage facility for hydrogen.

Hamburg Hydrogen Network

The "Hamburg Hydrogen Network" (*Wasserstoffverbund Hamburg*), composed of Airbus, Arcelor Mittal, Gasnetz Hamburg, GreenPlug, Hamburger Hafen und Logistik AG, Hamburg Port Authority and the Green Hydrogen Hub (Luxcara and Wärme Hamburg) are all developing projects to use green hydrogen. For example, Airbus announced that it will commercially offer hydrogen-powered aircraft by 2035; Arcelor Mittal plans to use hydrogen to produce around 100 000 tons of sponge iron per year for steel production as of 2024 and Hamburger Hafen und Logistik AG aims to use heavy-duty vehicles with hydrogen fuel cells on its terminals and last mile container traffic.

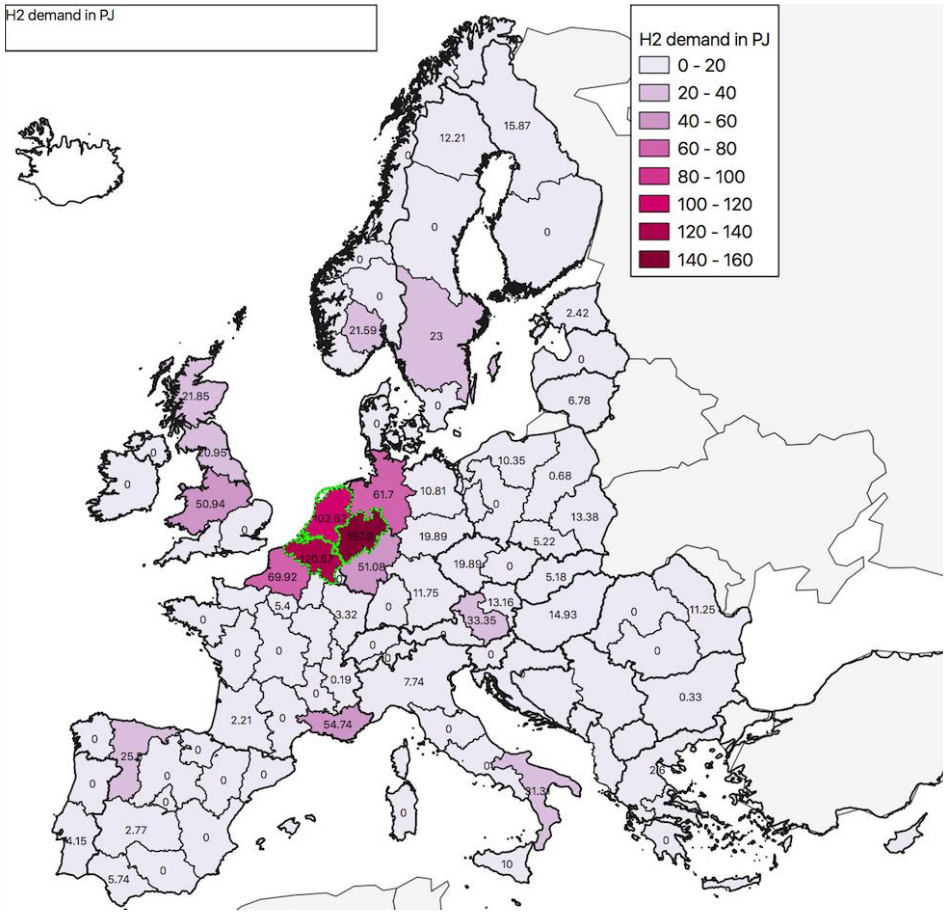
Source: (Hamburg Invest, 2022[102]) (Hamburgnews, 2020[103]) (Future Hamburg, 2022[101]) (Future Hamburg, 2022[104]) (HHLA, 2022[105])

Hamburg can contribute to satisfying hydrogen demand beyond its borders

Global hydrogen demand may rise by around 50% by 2031 even in the IEA's Announced Pledges Scenario. Announced pledges will need to be reinforced to reach Paris Agreement climate targets, which should raise hydrogen demand further. In the industry sector the demand comes mainly from the chemical and steel industries (IEA, 2022[96]). Given the presence of steel and copper production as well as some petrochemical production within the oil refining industry in Hamburg, the demand for local green hydrogen is anticipated to be substantial. Hydrogen-based fuels hold potential for maritime shipping, including ammonia. In heavy-duty road transport, hydrogen fuel cell vehicles may be an option, especially for heavy-duty transport over the longest distances, though electric solutions appear likely to be predominant because they are lower-cost. This especially applies to Hamburg, where rail takes on most long-distance land-based transport from and to the port. Germany has initiated trials of fuel cell trains and is working on a project to incorporate hydrogen in aviation.

Meeting local hydrogen needs requires infrastructure to transport, store and process hydrogen. This infrastructure will be subject to scale economies. Unit costs may be lower with higher demand. The port's potential could therefore serve as a hub for the use of hydrogen beyond local needs. Hamburg is close to regional industrial hubs with large green hydrogen demand. Figure 3.11 illustrates the projected spatial distribution of hydrogen demand in 2050, considering the current production sites are maintained. Nearby regions in Belgium, the Netherlands and North Rhine-Westphalia, account for the highest green hydrogen demand, more than 50% of European demand, although they can also be served by the Rotterdam, Antwerp and Dunkerque ports.

Figure 3.11. Spatial distribution of hydrogen demand for decarbonising chemicals and steel production



Note: assumes a development according to the "New Processes"-pathway (ENTSO-E, 2014[106])
Source: (OECD, 2023[43])

Most hydrogen will need to be imported

Germany is a leader in the development of green hydrogen production projects, but they fall short of near-term demand. The largest is the AquaVentus project in which Hamburg participates (Box 3.10). In addition, Germany has launched the Power-to-X (International PtX Hub, 2023[107]) and H2Global (H2 Global Stiftung, 2023[108]) initiatives to provide knowledge platforms which connect stakeholders from politics, business, science and civil society in order to discuss scale-up. Power-to-X helps identify market potential and funding. It organizes training and technical advice, while H2Global participates in the development of infrastructure that turns electricity into carbon-neutral fuels (PtX), market models and supply chains for green products. H2Global is a competition-based market instrument that aims at promoting a timely and effective ramp-up of the PtX market on an industrial scale.

The projected installed capacity falls short of demand (Figure 3.12) (IEA, 2022[96]); therefore, importing green hydrogen into Hamburg will be essential.

Box 3.10. Green hydrogen production projects – selected examples

AquaVentus project

The AquaVentus project will be developed in the German North Sea area to use electricity from offshore wind farms to operate electrolysers installed in the North Sea on an industrial scale. The aim is to set up electrolysis units with a total capacity of 10 GW by 2035, enough to produce 1 million metric tons of green hydrogen.

Moorburg power plant site

The site of the former coal-fired power plant Moorburg aims at decarbonising the entire port economy thanks to a 100 MW electrolyser project and the conversion of the coal power plant in the Moorburg Quarter. According to estimates, the plan can produce 2 tons of hydrogen/hour. The Moorburg site will be connected to local companies by a pipeline system to supply the port's big industrial companies: the HH-WIN (Hamburg's hydrogen-industrialism-network) will be 45 km long and will provide green hydrogen by 2030 for the steel, copper and aluminium industries. It will also be connected to the national hyperlink pipeline system.

Figure 3.12. National hydrogen targets of Germany

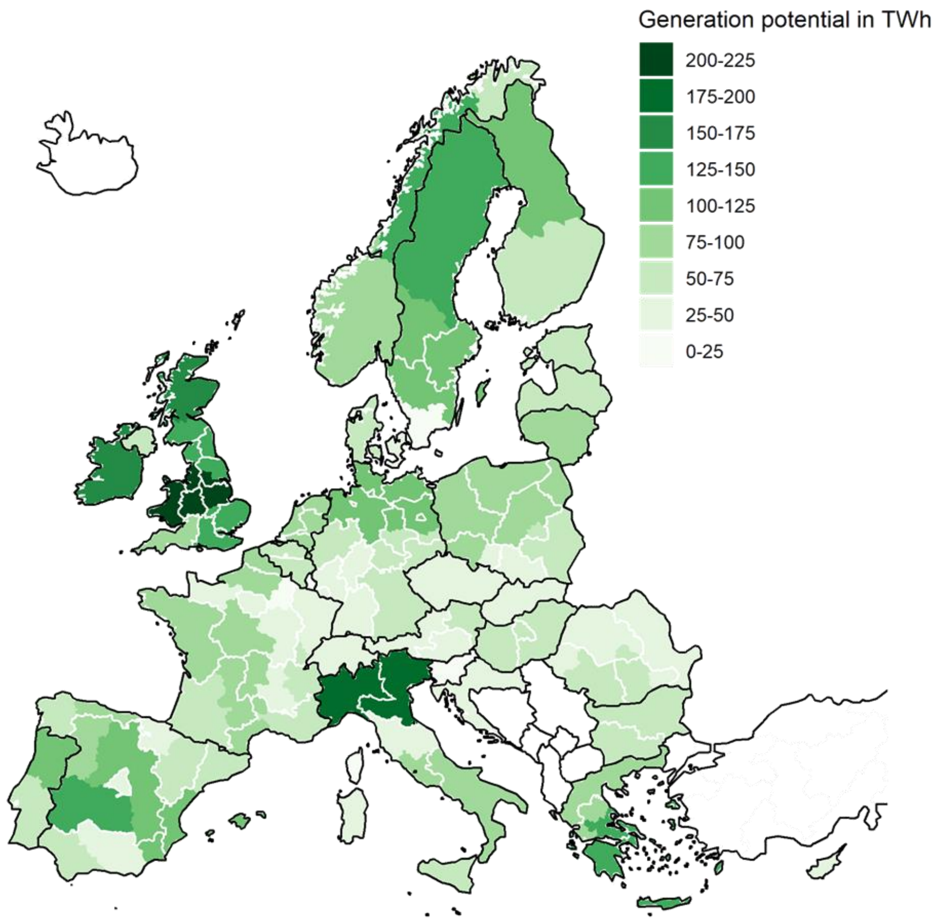
Sector		Target volume and time horizon
Renewable hydrogen production	Electrolysis capacity	5 GW (2030); 10 GW (2035-2040)
	Renewable hydrogen production	14 TWh/a (2030); 28 TWh/a (2035-2040)
	Renewable power consumption	20 TWh/a (2030); 40 TWh/a (2035-2040)
Overall demand	Hydrogen demand	55 TWh/a (2020); 90-110 TWh/a (2030)
	Power-based energy carrier consumption	110-380 TWh/a (2050)
	Hydrogen consumption in industry	55 TWh/a (2020); at least 65 TWh/a (2030)

Source: (Weltenergierat, 2020[109])

Producing green hydrogen requires an important amount of renewable electricity sources (solar, wind or hydropower) representing more than half of hydrogen production costs. The renewable power production potential in northern Germany, while substantially stronger than in the south, is modest even if compared to European regions (Figure 3.13). The lower renewable power production potential increases the cost, which is likely to be higher than the cost of imported hydrogen (IRENA, 2022[110]).

Beyond the potential for wind and solar power which are the highest in the Middle Eastern and African countries, the cost of imported hydrogen depends also on soft factors such as government support, and political stability. Spain, Australia, Chile, and Morocco stand out as countries with the greatest potential to emerge as net hydrogen exporting nations (IRENA, 2022[111]). Importing green hydrogen from these countries will be more economically attractive compared to local production by 2030 (Hydrogeninsight, 2023[112]).

Figure 3.13. Renewable electricity technical potential from wind and solar vary across regions



Note: Includes existing renewable electricity generation, including from other sources than wind or solar, and solar and wind technical potential
Source: (OECD, 2023[43])

Infrastructure is vital to importing green hydrogen and providing a hydrogen hub

Since production and transport distances are expected to increase to meet demand, there is a need to scale up infrastructure development to connect areas of production, import and demand.

Repurposing natural gas pipelines to transport hydrogen can cut investment costs by 50-80% compared to the building of new pipelines (IEA, 2022[96]). Hamburg could be part of a repurposed hydrogen pipeline network connected to nearby storage (Figure 3.14). However, repurposing existing natural gas pipelines may be a challenge over long distances where no multiple pipes exist. In this case, it may only be done when natural gas is out of use which could delay long-distance transport over existing pipelines. This would raise the importance of hydrogen import by ship.

Additional transport and storage capacity along the pipeline's network will be needed, as three times more volume of green hydrogen will be necessary to supply the same amount of energy as natural gas. New pipelines for ammonia (NH3, liquid) are cheaper than new pipelines for hydrogen (IEA, 2019[100]).

In May 2023, the German cabinet approved the creation of a national hydrogen core pipeline network, to become law in 2023 (Collins, 2023[113]). The network will target energy-intensive industries and connect all regions of Germany. The European Hydrogen Backbone initiative (group of 32 gas network operators) has already introduced a plan for a European-wide H2 network. Hamburg's geographical proximity to salt caverns is an advantage for integration into the network because it offers storage potential.

Figure 3.14. Repurposed pipelines can connect Hamburg to a European hydrogen network by 2040

Source: (OECD, 2023[43])

For longer distances, demand for imported hydrogen creates a need for expanding shipping and port infrastructure. Hydrogen can be transported as liquefied hydrogen (LH2), ammonia (NH3), LOHC or converted into a synthetic hydrocarbon fuel (IEA, 2022[96]). Due to the inability to transport pure hydrogen by ship, the existence of conversion and reconversion facilities is essential at both the loading and receiving terminals. By 2026, a terminal for importing green ammonia to Germany will be constructed at the port of Hamburg. It can also serve ammonia needs from future emission-free international shipping.

The Hamburg port can play a key role in importing hydrogen

Pipelines are currently the least costly way to transport hydrogen up to a distance of 2 500-3 000 km, for capacities. Hydrogen may therefore be transported to Europe via pipeline from the Middle East, through Southern Europe, as well as from Denmark and Norway. Repurposing existing gas pipelines to transport hydrogen from North Africa or the Middle East takes time, in part because natural gas will remain in use. Shipping also provides flexibility, helping to deal with any geopolitical risks. Hamburg already has existing cooperation projects with Chile, Uruguay, Argentina and Scotland, and some promising hydrogen export regions such as the United States can also export green hydrogen to Europe via shipping, making Hamburg a suitable place to deliver their products. Since shipping hydrogen is yet not developed at scale, there is a potential to invest in research, development, and deployment to lower costs. As a green hydrogen hub, Hamburg could invest to scale up technology in this field.

Shipping hydrogen gives more options on the different forms under which it will be transported. Some hydrogen-derived products, such as ammonia, organic compounds and iron pellets, offer more cost-effective transport options. Once delivered, ammonia can be converted back into hydrogen.

Hydrogen requires ambitious yet low-cost green certification

Certified green hydrogen allows industrial producers to market their products as having been produced using low or zero-carbon emission hydrogen. Certificates improve the supply chain carbon accounting (IRENA and RMI, 2023[114]). However, a cumbersome certification framework could increase costs, as some green hydrogen exporters might choose to send their product to a place with a less stringent framework. Costs could be transferred to importers of green hydrogen in Hamburg. The risk will be greater with a lack of harmonization of certification worldwide.

Currently, there are 11 voluntary or mandatory schemes worldwide. Their criteria for defining the sustainability of green hydrogen vary in scope, emissions threshold, and accounting methodology. With the growing number of certification schemes, the European Commission will probably update a list of national or voluntary internationally recognised certification schemes (Erbach and Svensson, 2023[115]), as it already does for biofuels. The CertifHy scheme, which applies only in the EU, recently submitted its RFNBO Voluntary Scheme for recognition by the European Commission (CertifHy, 2023[116]).

The IRENA Coalition for Action’s ten criteria to ensure that tracking systems meet green hydrogen demand could represent an interesting basis for achieving a global system of green hydrogen certification (Box 3.11).

Box 3.11. The IRENA Coalition of Action's 10 criteria for green hydrogen tracking systems

- Develop a harmonised definition of green hydrogen
- Certify the renewable origin of the energy used to produce hydrogen thanks to technological correlation (1), geographical correlation (2), temporal correlation (3), additionality (4)
- Ensure that certificates contain sufficient information for consumers and policymakers
- Simplify the green hydrogen tracking system to avoid administrative burdens
- Implement a cost-effective tracking system
- Put in place appropriate control systems to avoid misuse or lack of transparency
- Consider interactions with existing tracking systems
- Avoid double counting
- Use taxonomy and green finance criteria to encourage compliance with green hydrogen certification requirements
- Promote international co-operation to establish globally accepted rules and requirements

Source: (IRENA coalition for action, 2021[117])

Key actions

Immediate action

- The HCC could continue to assess, with businesses concerned, as well as with regional and national government, the need for infrastructure to transport, store and process hydrogen and hydrogen-derived products, including ammonia to satisfy local needs for climate neutrality, notably in shipping, long-distance heavy-duty road transport steel production, copper production and as a feedstock in petrochemicals production.
- The HCC could assess, with businesses concerned, as well as with regional and national government, the potential for Hamburg to contribute to hydrogen demand beyond the Hamburg region, notably in North Western Europe, following up on assessments across European regions (OECD, 2023[43])
- The HCC and key businesses could quantify the local potential for green hydrogen production. They could evaluate the competitiveness of locally produced green hydrogen compared with imports.
- The Hamburg Chamber of Commerce could participate in national or international discussions to develop green hydrogen certification schemes aligned with the European Union standards

By 2030

- Increase local potential to produce renewable electricity for the supply of green hydrogen
- Scale up infrastructure development to connect areas of production, import and demand.
- The HCC could assess, with businesses concerned, as well as with regional and national government, research, development and deployment of technologies to lower costs for shipping hydrogen.

Carbon Capture and Storage in the North Sea to reduce hard-to-abate CO2 emissions from heavy industries

Carbon Capture and Storage (CCS) may be a "last step technology", that may be useful for a few hard-to-abate heavy industries (IPCC, 2022[118]; IEA, 2020[60]). One approach is to limit CCS to process emissions in industrial production, as climate-neutral options for energy-related emissions are available, as favoured in the European Union (OECD, 2023[43]). In situations where emission-free technologies are not readily available, CCS becomes a necessary requirement to achieve Net Zero Targets (NZT). Consequently, CCS is most likely to be necessary in cement production and, perhaps, in copper production, both present in the Hamburg metropolitan area. modest.

The North Sea offers major advantages for CCS storage. Indeed, several projects, mostly small-scale, have been launched around the North Sea or are planned (Box 3.12). However, a major potential for CCS development in the Hamburg region appears unlikely. As outlined below costs are high, including those for transportation. Moreover, large-scale transportation of CO2 may not require Hamburg's port infrastructure. Even so, the availability of space or transhipment facilities and compatibility with other transformation developments (such as hydrogen imports) would need to be examined.

Box 3.12. CCS projects of European countries bordering the North Sea

- In Norway, the Northern Light project is one of the most important CCS projects in Europe. The Longship project, the transport and storage component of Northern Light, is the first trans-European hub opened to all European emitters. Transport and storage capacity is up to 5 million (Mt/year) CO2, for a total storage capacity estimated around 100 Mt.
- In the Netherlands, the Porthos project is being developed in the Rotterdam port. This joint project between the Port of Rotterdam Authority, EBN and Gasunie will allow various companies to supply their CO2 emissions to a collective pipeline running through the Rotterdam port area. Only a very limited share of CO2 emissions will be captured and stored in the North Sea. Indeed, industries around the port emit around 25 Mt/year CO2 (45 chemical companies and 5 refineries), and the Porthos' project initial capacities will be limited to 2 Mt/year CO2, with a possible increase to 5 Mt/year CO2 by 2030.
- In Denmark, the Greensand project is led by a consortium of Danish and international companies, research institutes, universities and start-ups. It aims at storing 1,5 Mt/year CO2 in 2026 and up to 8 Mt/year CO2 in 2030. This corresponds to 13% of Denmark's annual CO2 emissions.
- In Belgium, the Antwerp port aims at capturing 50% of its emissions by 2030, which represents around 9 Mt/year CO2 to be stored in the North Sea.
- In France, the D'Artagnan project in Dunkerque is planned as an export hub opened to everyone to store CO2 in the North Sea from Dunkerque's harbour. The initial capacity is set at 3 Mt/year CO2 and will be increased up to 12 Mt/year CO2 in the final phase. Similar projects are proposed by Haropa Port for the Havre Port, to capture and store 7 Mt/year CO2.
- The UK still does not have any CCS projects but is aiming to develop them by 2030 to help reach climate neutrality. Indeed, the UK has considerable potential to store carbon under the North Sea. In the Net Zero Strategy, it is planned to capture and store between 20 Mt and 30 Mt/year CO2 from 2030; with capacity to be increased to 47 Mt/year CO2 from 2050.

Source: (Northern Lights, 2023[119]), (Porthos, 2023[120]), (Greensand, 2023[121]), (Port of Antwerp Bruges, 2023[122]), (Cornot-Gandolphe, 2021[123]), (Wettengel, 2023[124])

Demand for CCS is widely spread

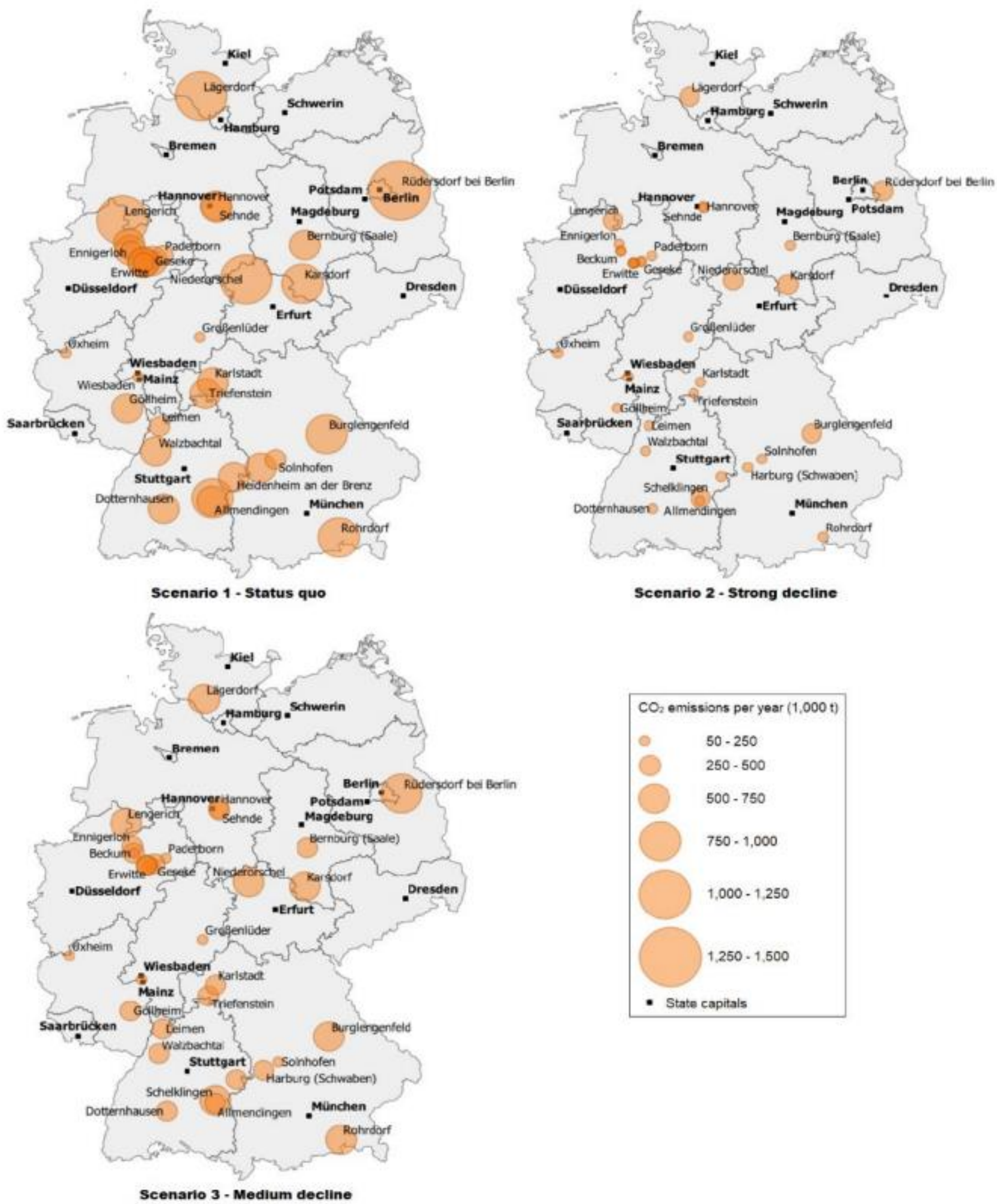
Looking for potential CCS demand beyond Hamburg's immediate vicinity, European cement plants are geographically dispersed across the continent. Given that CCS infrastructure benefits from economies of scale, the wide distribution of cement facilities poses transportation challenges and raises costs. It may be that steel producers, with more concentrated production sites, are interested in joining cement production in CCS. Unit costs decline markedly as CO2 transport capacity increases.

Demand for CCS (Carbon capture and storage) in the Hamburg metropolitan area will come mainly from a cement plant nearby Hamburg in Lägerdorf. Copper production within Hamburg may add somewhat to local CCS demand (Table 3.5). Only part of these emissions would require CCS, as most are energy-related and more efficient production processes can reduce emissions.

The North Rhine-Westphalia region includes Europe's largest cement production clusters (Bellona Europa, 2016[125]), for a total CO2 emissions estimated at 35 Gt/year (IEA, 2020[60]). While CCS is still seen as a technology to be developed to limit the industrial emissions of the region beyond cement production

(Ministry for Economic Affairs, 2021[126]), uncertainties and the high cost of transporting CO2 over long distances make a role for Hamburg unlikely.

Figure 3.15. Scenarios for CO2 emissions of cement plants in Germany in 2050



Note: Scenario 1 - No reduction in emissions until 2050, and cement demand and clinker-cement factor remain constant; Scenario 2 - 70% reduction in emissions until 2050, and use of alternative production processes and products; Scenario 3 - 35% reduction in emissions until 2050, and a smaller reduction in cement demand or CO2 emissions.
Source: (Winter, Schröter and Fidaschek, 2022[127])

Table 3.5. Cement and chemical CO2 emissions registered in the EU ETS for Hamburg

	Aurubis AG	Holcim (Deutschland) GmbH – Werk Lägerdorf (cement clinker)	Holcim (Deutschland) GmbH – Werk Höver (cement clinker)
Verified emissions (ETS) in 2022 (in tons)	154 294	961 548	555 043

Source: (EU ETS, 2022[128]), Aurubis AG.

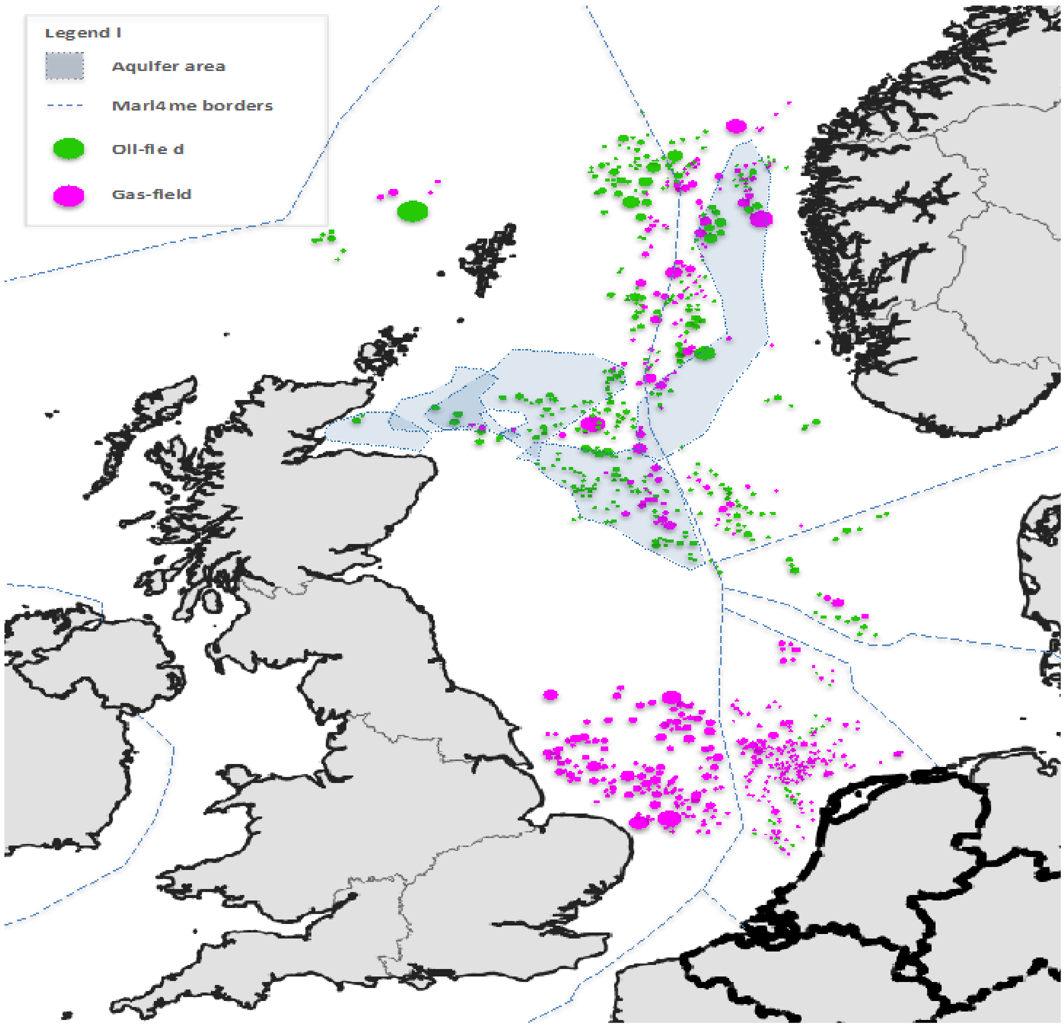
The North Sea appears to be a preferred location for CCS

The IEA estimates theoretical storage capacity in the North Sea to be very large, around 300 Gt, equivalent to around 400 times German annual CO2 emissions, with almost half of them located in the Norwegian and British areas (IEA, 2022[129]) (Figure 3.16). Indeed, the North Sea is a mature oil and gas extraction area (Nakhle, 2016[130]), making available many pipelines and geological reservoirs that have been empty after decades of oil and gas development. These infrastructures could be restructured to carry CO2 emissions.

In addition to its substantial storage capacity, the oil and gas infrastructure in the North Sea presents key advantages over alternative storage locations. When considering the two primary options for CO2 storage saline aquifers and depleted oil and gas fields, it becomes evident that utilising oil and natural gas fields not only ensures long-term safeguards against the risk that CO2 re-emerges from storage sites (which would undo storage efforts) but also provides significantly more precise capacity estimates, allowing to assess the economic viability of each storage site. The North Sea region thus enhances the overall viability and reliability of carbon capture and storage efforts (OECD, 2023[43]).

One key factor favouring offshore storage is social acceptance. The German government will soon unveil its carbon capture and storage strategy (BMWK, 2022[131]). There are plans to introduce a reform project in 2023 that will enable the construction of commercial infrastructure for CCS. While onshore storage remains prohibited in all *Länder*, offshore storage in the North Sea is permitted. For now, in Germany, no storage or pipelines have been applied for, approved or built (Wettengel, 2023[124]).

Figure 3.16. Potential offshore CCS storage sites in North Sea hydrocarbon fields vary in storage capacity



Source: NLOG. (2020). Interactieve Kaart. https://www.nlog.nl/ NPD (2020). Interactive map — Norwegianpetroleum.https://www.norskpetroleum.no/en/interactive-map-quick-downloads/interactive-map/ . OGA. (2020). Interactive maps and tools. https://www.ogauthority.co.uk/data-centre/interactive-maps-and-tools/

High costs and uncertainty make a major role of Hamburg in CCS unlikely

CCS is an exceptionally expensive procedure. At present, based on data from the interactive tool created by the Clean Air Task Force, the cost of CCS in Germany varies significantly, ranging from EUR 70 to EUR 280 per ton of CO2, with an average cost of EUR 211 per ton for the cement industry (Clean Air Task Force, 2023[132]). In contrast, the current market price for a ton of CO2 hovers at approximately EUR 80, making CCS economically unfeasible.

Research and development efforts have the potential to significantly decrease costs associated with large-scale CCS implementation (Budinis et al., 2018[133]). The areas of CCS research are vast, ranging from reducing energy requirements and using innovative solvents to standardising capture units and increasing plant size. They could reduce costs by 80% (IEA, 2020[60]). Furthermore, costs are expected to fall as the market expands (Baylin-Stern and Berghout, 2021[134]). Overall, the cost of CCS should decrease, but it is heavily contingent on research and development efforts, which introduce a significant level of uncertainty.

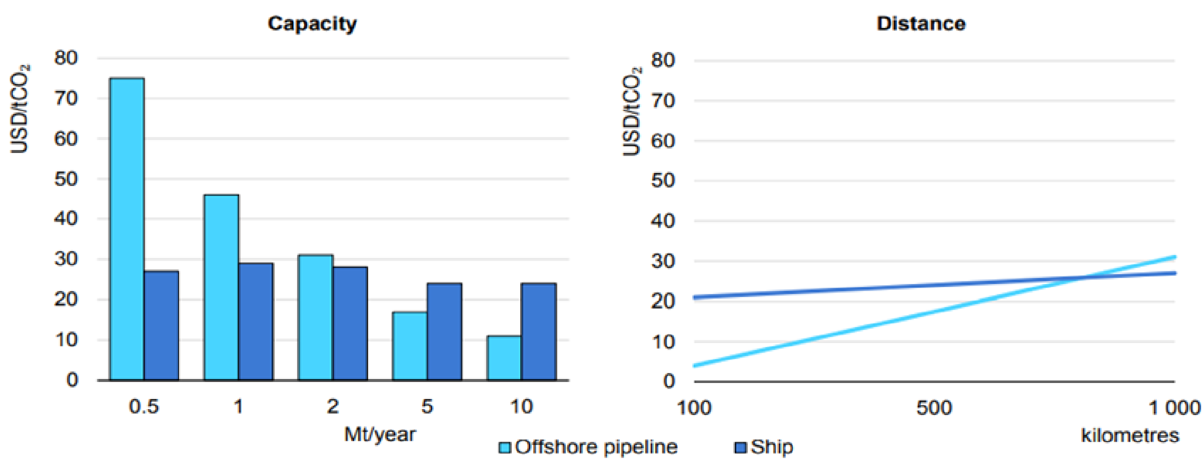
Transportation of CO2 emissions is complex and may not require port infrastructure

Emission sources that could potentially utilise CCS are often located at a considerable distance from the North Sea, particularly in the case of widely dispersed cement production facilities, raising two main transportation challenges: onshore transport for CO2 collection and offshore transport to deliver the CO2 to storage sites.

First, with respect to onshore transportation, the most likely economically viable transportation is an onshore pipeline. Only when the quantity or distance of CO2 transported is limited, CO2 emissions can be transported over land via train or truck. Presently such a pipeline network does not exist; if a pipeline network is built to connect emission sites with the North Sea, it may not go through Hamburg. Contrary to hydrogen, the transport of CO2 cannot easily use repurposed natural gas pipelines. It requires new infrastructure which is time-consuming and costly (OECD, 2023[43]). Building an onshore pipeline for CO2 emissions transport can present big challenges and high costs, particularly due to the potential for land use conflicts.

For beneath the North Sea, in terms of cost-effectiveness, offshore pipelines are well-suited for large quantities and relatively short distances, whereas shipping emerges as a more financially viable choice for conveying smaller quantities of CO2 across extended distances (Figure 3.17) (IEA, 2020[135]).

Figure 3.17. Shipping and offshore pipeline transportation costs



Note: Mt denotes million tons. The left-hand chart assumes a distance of 1 000 km. The right-hand chart assumes a capacity of 2 Mt/year.
Source: (IEA, 2020[61])

Several initiatives are emerging to connect with North Sea storage facilities via offshore pipelines. They enable the industrial-scale transportation of CO2, are less vulnerable to disruptions caused by extreme weather conditions, and do not necessitate any additional technological advancements. Offshore pipelines may not require a dedicated port facility such as Hamburg's (OECD, 2023[43]).

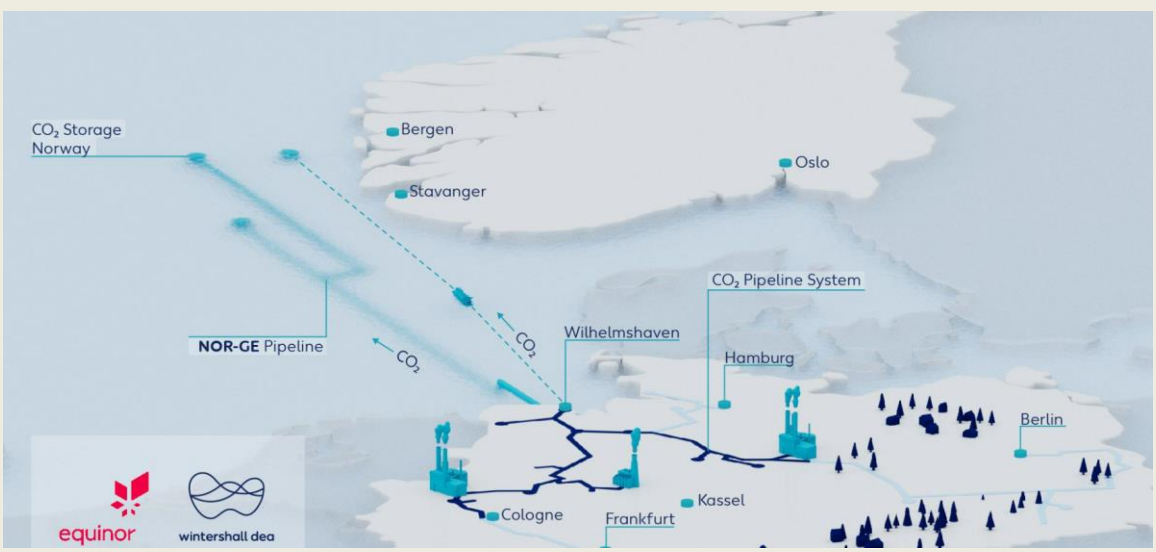
Several CCS projects in Europe are planning to use shipping as the primary form of transport, which is more flexible (IEA, 2022[129]). Equinor plans to build two ships that can transport liquefied gas: it will collect CO2 industrial emissions from Northern Europe areas close to ports like Hamburg and will go afterwards to Oygarden, an offshore storage site on the Norwegian coast (Joeres, 2021[136]).

Instead of being stored, CO2 can be used locally in a number of industries, notably in basic chemical manufacturing, such as the production of plastics, lubricants or waxes, which are produced also in Hamburg. In combination with hydrogen, CO2 could replace fossil fuel feedstocks in these production processes. It could for example be employed in the production of green methanol, which is likely to play a role as a fuel in maritime shipping. To limit cost, the plant using the CO2 would need to be close to the CO2 capture site while supply and demand of CO2 would need to match closely to remain consistent with climate neutrality. Moreover, to be fully consistent with climate neutrality, captured CO2 emissions would need to be used in products that do not themselves emit CO2 in use or disposal. Otherwise, the CO2 would need to come from non-emitting CO2 sources, such as the firing of sustainable biomass or direct air capture (DAC). CCU and DAC are energy intensive, which could undermine the energy transition (OECD, 2023[43]). Overall, the potential for CCU may be limited.

Box 3.13. Current offshore CO2 pipeline systems in Europe connecting the mainland to North Sea storage sites

In Norway, the Hammerfest is 153 km long and has a capacity of 0,7 Mt/year. In the Netherlands, the Rotterdam system is 85 km long with a capacity of 0,4 Mt/year (IEA, 2020[60]). Germany's proximity with south Norwegian EOR fields is an advantage to store CO2 in the North Sea (Global CCS institute, 2007[137]). A third CO2 pipeline may be built between Germany and Norway, to store CO2 in the North Sea, and may not be built from Hamburg (Figure 3.18). This subsea pipeline would be 900 km long, with a capacity between 20 and 40 Mt/year by 2037, equivalent to around 20% of Germany's annual industrial emissions (Offshore, 2022[138]). It may compete with other locations, such as Rotterdam.

Figure 3.18. Pipeline project to transport CO2 between Germany and Norway



Notes: EOR stands for Enhanced oil recovery, a process for extracting oil. Wintershall Dea is a German gas and oil company and Equinor is a Norwegian gas and oil company.
Source: (Wintershall Dea, 2022[139])

The port may support local industries with CCS needs

To conclude, Hamburg's potential to establish itself as a prominent hub for CO2 collection appears, at best, uncertain and, at worst, improbable. Rotterdam would be a closer location as a hub for storing CO2 from North-Western Europe below the North Sea. Hamburg's port infrastructure is more likely to offer CCS-related services to the relatively modest emissions in the Hamburg region which may require CCS, notably for cement production nearby Hamburg and copper production in Hamburg. Hamburg's direct access to the North Sea presents opportunities for directly sending locally produced CO2 to storage sites.

Key actions

By 2030

- Businesses should identify needed CCS-related services, notably from local cement and copper production

By 2040

- Businesses should develop any needed port CCS-related services to local industry and local businesses bearing in mind the availability of space or transhipment facilities, as well as the compatibility with other transformation developments.

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Annex 3.A. Description of models and further modelling results

The NavigaTe, IFM, and GEM-E3 models

NavigaTE model: Techno-economic model to assess potential decarbonisation pathways for shipping, which captures the entire maritime energy value chain for powering the vessel from feedstock/primary energy to the wake of the vessel. The NavigaTE model consists of two main elements: A Total Cost of Ownership (TCO) model and an Industry Transition model. These are used to estimate the fleet fuel uptake over time and energy efficiencies leading to an overall estimate of the required energy demand, fuel split and GHG emissions.

International freight transport demand model (IFM): a freight transport model specifically designed to project international freight transport activities (in tonne-kilometres), maritime transport costs and modal share until 2050 under different trade and policy scenarios. EMC hosts one of the leading international freight transport models that has been validated, published in a scientific journal1 and applied to project transport activities in different maritime decarbonisation projects, including IMO impact assessments. The model is built on the four-step freight transportation modelling approach and it takes the global trade projection from the GEM-E3 model as an input. The IFM is designed to be able to estimate the weight of commodities traded between countries, the choice between modes and transport routes used to transport these commodities based on transport network characteristics, and relevant socio-economic variables such as transport costs and time. The model consists of the following components:

1. Trade flow disaggregation model;
2. Value-to-weight model;
3. Mode choice model; and
4. Route choice model.

The model is highly granular with spatial resolution that covers more than 120 countries, 333 regions, and 4000 ports worldwide. Trade flow disaggregation and value-to-weight sub-models allow the model to convert international trade values (typically presented in USD in various global trade databases) into trade volume (in tonnes) and assign them across global maritime routes using the route choice model and assignment procedure. The mode and route choice sub-models are also capable of analysing the potential shift to other available modes and routes as an impact of changes in transport costs.

The output generated by IFM is the bilateral trade value of each commodity at the centroid level (i.e., city-level) by each transportation mode. This means that in order to evaluate the impact on an individual city (i.e., Hamburg) in terms of its maritime imports/exports per commodity and its maritime trade relationship with important trading partners at the country level, there's a need to gather and summarize information at both the product and country levels. As a result, both disaggregation and aggregation processes are conducted.

In the step of computing Hamburg's imports/exports maritime unit transport costs per commodity from/to all trading partner countries, we apply a weighted average approach to aggregate information.

In this procedure, the maritime unit transport cost of each import/export to/from Hamburg is assigned a weight corresponding to the ratio of that import/export flow to the total import/export volume of the port, distinguished by commodity and year. The weighted average value is then obtained by summing the weighted unit transport costs of all imports/exports. The Formula (1) is given to measure the weighted average export unit transport costs for Hamburg. The approach to calculating the weighted average for import unit transport costs is similar, by only considering all the origins to Hamburg.

$$W_{dcy} = \frac{V_{dcy}}{\sum_{d=1}^{D} V_{dcy}}$$

$$WUTC_{cy} = \sum_{d \in D} (W_{dcy} * UTC_{dcy}) \qquad (1)$$

In Equation (1):

V_{dcy} = Trade value from Hamburg to destination centroid *d* for commodity *c* in year *y,*

W_{dcy} = Weight of trade from Hamburg to destination centroid *d* for commodity *c* in year *y,*

UTC_{dcy} = Unit transport cost between Hamburg and destination centroid *d* (US$/ton-km),

$WUTC_{cy}$ = Weighted export unit transport costs for Hamburg for commodity *c* in year *y.*

GEM-E3: A global economic model designed to simulate the operation of the economic system (by country) with a particular focus on the representation of bilateral trade transactions by origin-destination, product and transport model. Focus is placed on the global trade volume of commodities transported using maritime transport. GEM-E3 is a state-of-the-art model (accumulating knowledge of over 20 years of model development – it is continuously used to support impact assessment of a range of policies) which is capable of simulating the interdependencies of markets and economic agents' decisions at a global scale. The model captures changes in global trade that are driven by competitiveness, policies/regulations/standards, infrastructure, prices, and supply/demand constraints. The representation of commodity trade includes numerous factors that are relevant for policy analysis such as maritime and international transport costs, market-based instruments such as carbon tax, and the characteristics of different countries in producing supply and demand for commodities globally.

A 3-step modelling approach

First, NavigaTe estimates the increase in total capital expenditures (CAPEX) and operational expenditures, (OPEX) taking into account the Well-to-Wake life cycle costs of production and deployment of zero-carbon fuels such as green methanol, and ammonia for different types of vessels due to the implementation of the GFS and the carbon levy in 2030, 2040, and 2050.

Second, based on the estimated increase in vessel costs, IFM translates this impact to the increase in maritime unit transport costs across all commodities and shipping routes globally. The computation takes into account the volume of freight transported across different routes and different cost components across the intermodal transport chain including hinterland and sea transport, to estimate the increase in maritime transport costs.

Third, GEM-E3 takes the increase in maritime transport costs to estimate the shift in trade patterns between countries, as reflected in the change in import/export values of all commodities by maritime mode into/out of Hamburg. Changes in values include both changes in volumes as well as changes in relative prices. The impact of the EC proposals for the IMO decarbonisation measures can be inferred from the changes in sea trade value by comparing the change in the import/export values between BAU and policy scenarios for each commodity.

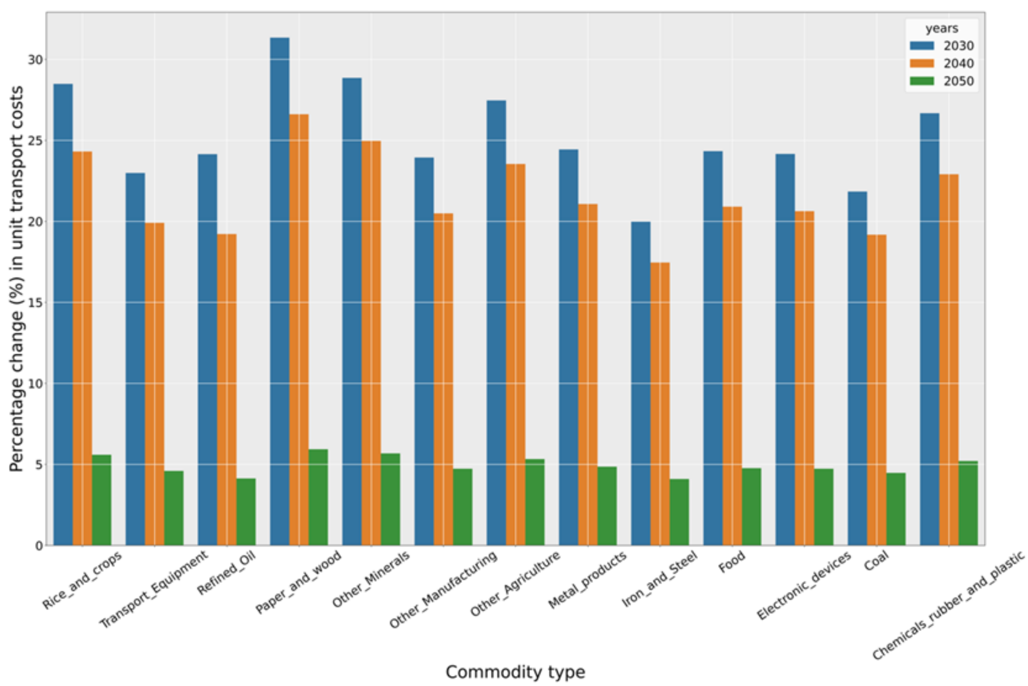
Because GEM-E3's results are presented at a broader regional scale, combining multiple countries within a single region, it is necessary to break down these regional trade patterns into trading relationships of countries and port cities. To achieve this, the trade disaggregation module of IFM is utilised.

To assess the potential second-order feedback effect of change in trade value on maritime unit transport costs, for example, due to economies of scale, the analysis deploys this change in trade volume to adjust the transport costs estimated by IFM. Specifically, a trade transport cost elasticity as specified in the study of (Camisón-Haba and Clemente-Almendros, 2020[140]) is applied.

Further modelling results

Annex Figure 3.A.1. Projected increase in unit transport costs of each commodity imported to Hamburg (%)

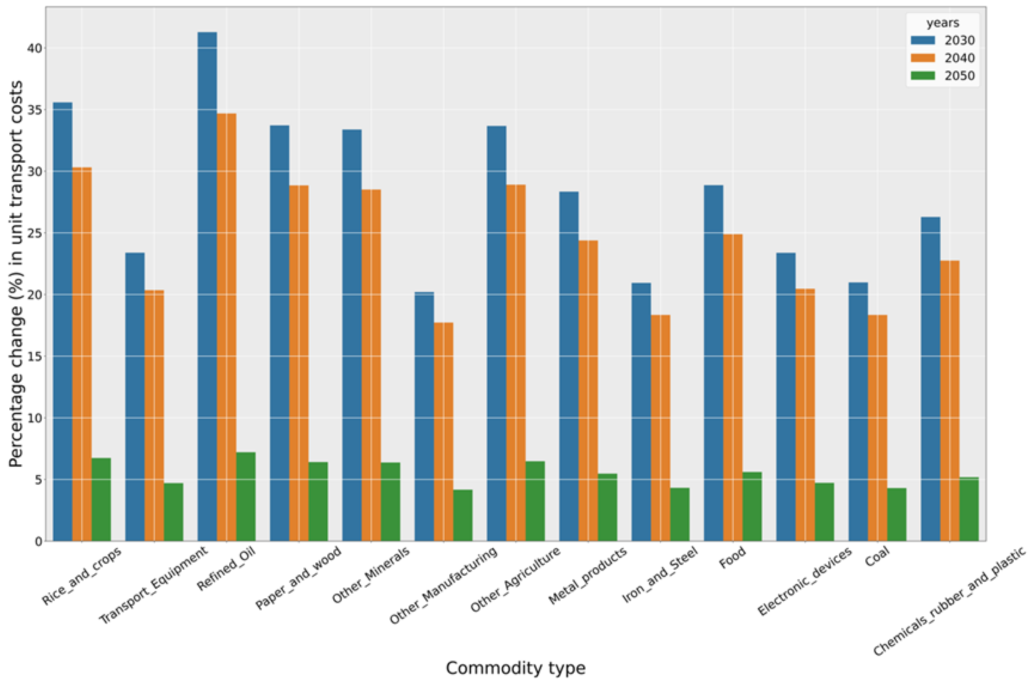
Percent change (%) in import unit transport costs (USD/ton-km), relative to business-as-usual scenario



Source: (Equitable Maritime Consulting, 2023[7])

Annex Figure 3.A.2. Projected increase in unit transport costs of each commodity exported from Hamburg (%)

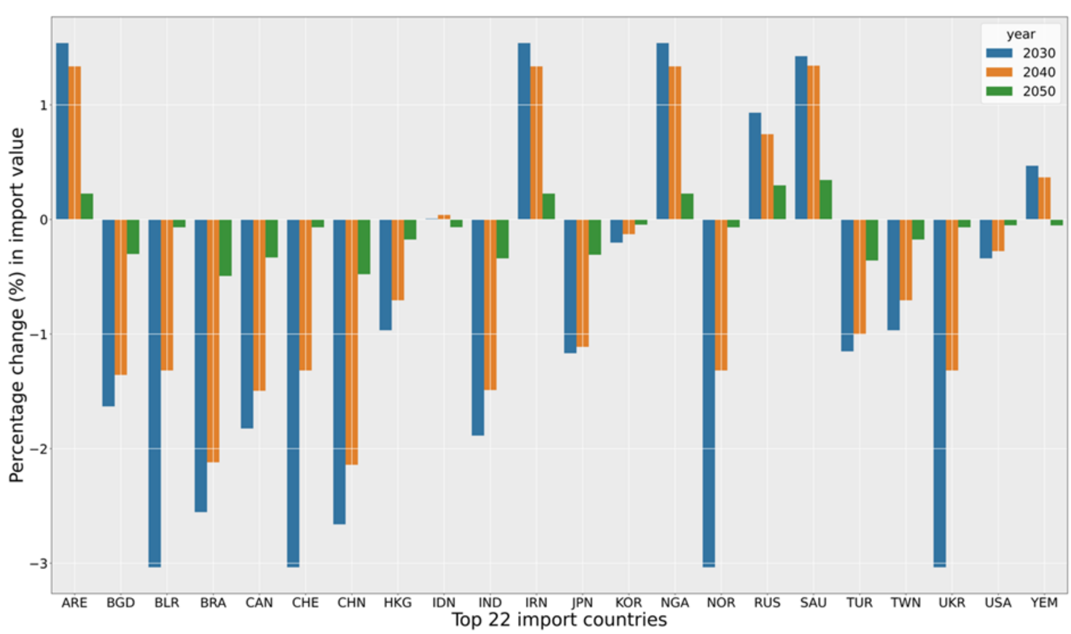
Percent change (%) in export unit transport costs (USD/ton-km), relative to business-as-usual scenario



Source: (Equitable Maritime Consulting, 2023[7])

Annex Figure 3.A.3. Projected change in import values from top 22 countries to Hamburg (%)

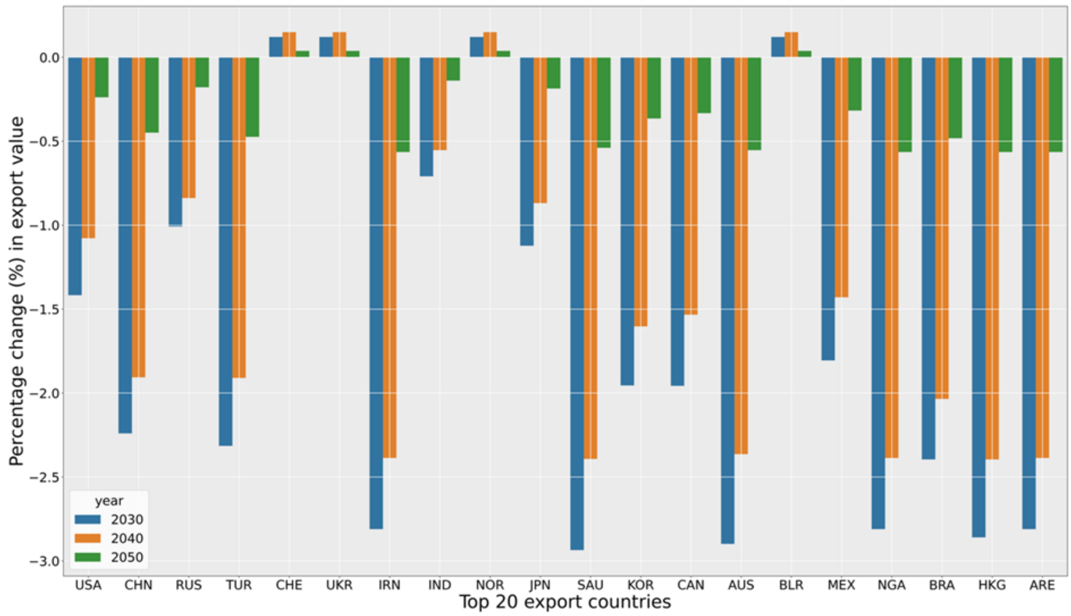
Percent change (%) in import value (Billion USD), relative to business-as-usual scenario



Source: (Equitable Maritime Consulting, 2023[7])

Annex Figure 3.A.4. Projected change in export values from Hamburg to the top 20 countries

Percent change (%) in export value (Billion USD), relative to business-as-usual scenario

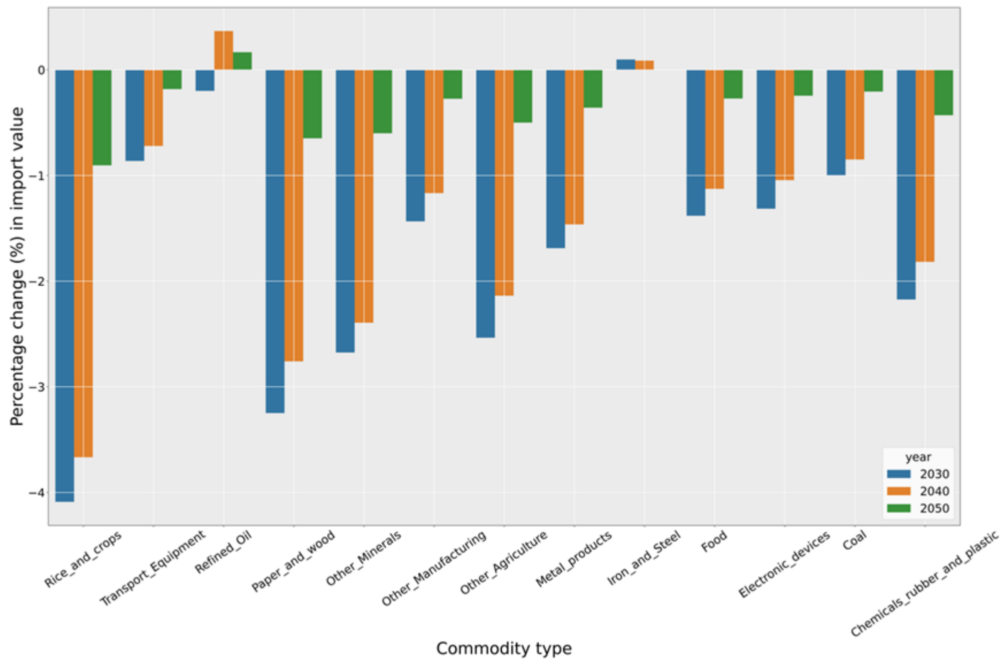


Source: (Equitable Maritime Consulting, 2023[7])

The comparison of different years reveals similarities to the absolute change findings. However, the commodity most significantly affected in terms of percentage is no longer food. Instead, rice and crops experience the most substantial percentage decline in imports, amounting to 4.1% in 2030. Additionally, the export value of refined oil sees a reduction of approximately 8%.

Annex Figure 3.A.5. Projected change in import value of each commodity type to Hamburg (%)

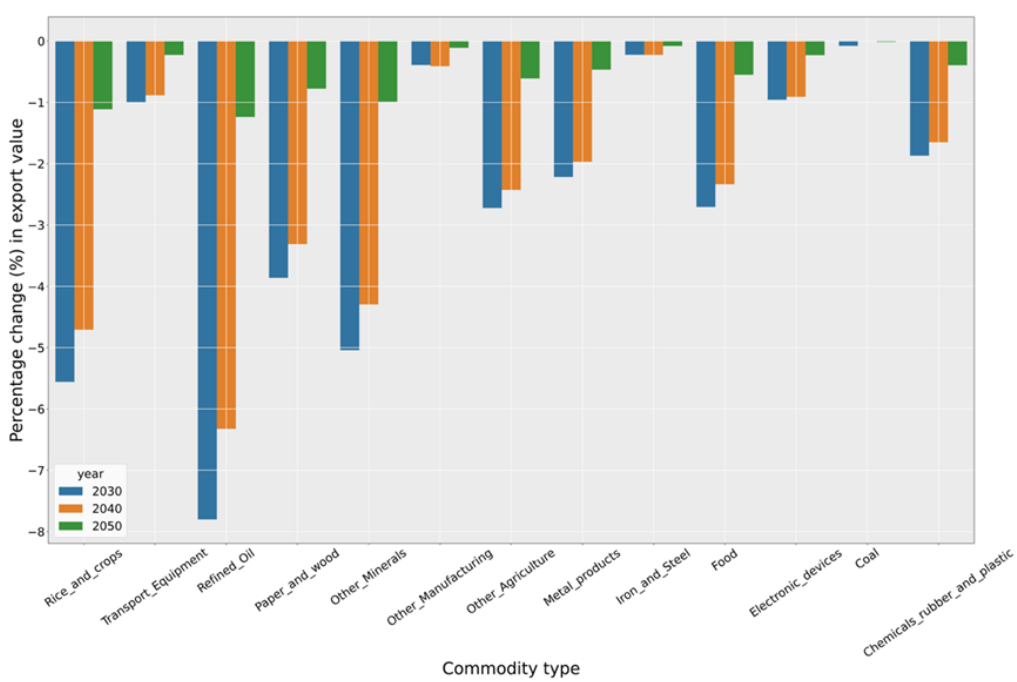
Percent change (%) in import value (Billion USD), relative to business-as-usual scenario



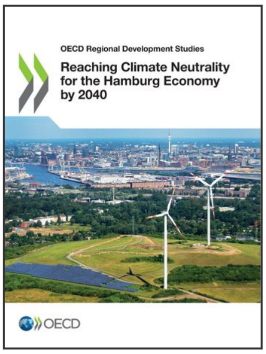
Source: (Equitable Maritime Consulting, 2023[7])

Annex Figure 3.A.6. Projected change in the export value of each commodity type from Hamburg (%)

Percent change (%) in export value (Billion USD), relative to business-as-usual scenario



Source: (Equitable Maritime Consulting, 2023[7])



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