Extreme Weather Risks to International Oil and Natural Gas Shipping

International Energy Agency



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Abstract

Maritime shipping is a central pillar of global oil and natural gas trade. Linked via ports and trade routes that connect suppliers with consumers, around 40% of crude oil, 30% of petroleum products, and 15% of natural gas produced make at least part of their journey from well to market via a ship. Yet these journeys face disruption from natural hazards, including extreme and severe weather events, with consequences for energy security. At the request of the French government during its 2026 G7 presidency, this report examines how extreme weather disrupts the international shipping of oil and natural gas, and how associated risks could evolve.

Extreme weather risks arise from both individual severe events and slower-onset climate pressures. Storms, flooding, drought and fog are among the risks that can affect parts of the shipping system. They impact in different ways. Ports and terminals may face asset damage, unsafe operating conditions or disruption of hinterland connections. Shipping routes, especially those via narrow bodies of water, can be affected by low water levels or storms. Impacts are shaped not only by the severity of hazards, but also by the characteristics of infrastructure, especially where ports and routes are geographically concentrated which limits the availability of alternative options.

By focusing on international oil and natural gas shipping, this report highlights a specific but important dimension of energy system resilience that has implications for energy security. The report also explores how stakeholders can strengthen resilience as the nature of extreme weather hazards evolves.

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Acknowledgements

This study was prepared by the Energy Modelling Office, Energy Demand Outlook (EMO-EDO) Division of the International Energy Agency's (IEA) Directorate of Sustainability, Technology and Outlooks. The study was directed by Hugh Hopewell under the guidance of Laura Cozzi.

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Valuable comments were provided by IEA colleagues including: Giovanni Andrean, Christine Brandstätt, Hannes Gauch, Ronan Graham, Jeanne-Marie Hays, Jérôme Hilaire, Akos Losz, Apostolos Petropoulos, Silvia Saddi, Rebecca Schulz, Zoe Soo and Daniel Wetzel.

Sylvia Beyer and Curtis Jenken provided valuable multilateral support.

The authors would also like to thank Jeremy Bowden for editing and copyediting the manuscript, and the IEA Communication and Digital Office, in particular Liv Gaunt, Astrid Dumond, Poeli Bojorquez, Isabelle Nonain-Semelin and Clara Vallois.

Many experts from outside of the IEA reviewed the report and provided valuable comments. They include: Pierre-Alexandre Bigel (Directorate-General for Energy and Climate, France), Marthe Fruytier (Port of Rotterdam), Audrey Huang (MPA Singapore), Aleksandr Kondratenko (Chalmers University of Technology), Norbert Kriedel (Central Commission for the Navigation of the Rhine), Laurent Kueny (Directorate-General for Energy and Climate, France), Emiko Nakamura (Mitsui OSK Lines), Laure Roux (Central Commission for the Navigation of the Rhine), Elie Samakh Lesec (Directorate-General for Energy and Climate, France), Elena Talalasova (Global Maritime Forum), Bryan Tremblais (Directorate-General for Energy and Climate, France), Jasper Verschuur (TU Delft), Andrew Wilson (BRS Brokers) and Nicolas Ziv (CDRI). David Gernaat (independent consultant) provided valuable inputs to the analysis of Rhine level projections.

This report was developed at the request of the French G7 Presidency, and the IEA would like to thank Pierre-Alexandre Bigel and his team for their support. This work reflects the views of the IEA Secretariat but does not necessarily reflect those of the G7 or the IEA's individual Member countries or of any particular funder or collaborator.

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Executive summary

International shipping is indispensable to oil and natural gas trade: in 2024, around 40% of crude oil, 30% of petroleum products, and 15% of natural gas supply made part of its journey to consumers by water. Yet this transport mode is exposed to risks from natural hazards, and specifically extreme weather events, that can disrupt flows and undermine energy security. This report assesses how extreme weather risks affect international oil and natural gas shipping and how they could evolve in coming decades.

Extreme weather can damage port infrastructure, interrupt operations, and restrict or close routes, forcing costly delays or diversions. Unlike other parts of the energy system, such as power outages where interruptions have an immediate impact, international fuel shipping is a relatively slow means of energy delivery. Interruptions take time to affect supply and markets, while consumers can draw on stocks if available should fuel deliveries be delayed. Nevertheless, depending on the location, severity and length of disruption, impacts have the potential to be severe and far-reaching.

Maritime crude oil trade volumes have risen by around 15% since 2000 as refinery capacity and crude oil import demand shifts from the Atlantic Basin towards Asia. liquefied natural gas (LNG) volumes have quadrupled over the same period as new export capacity in Australia, the United States and elsewhere feeds growing Asian demand. Reliance on shipping is set to increase. In the IEA's Stated Policies Scenario, international oil and natural gas shipping activity rises by over 15% by 2035, with LNG growing faster than oil. Growth is stronger in the Current Policies Scenario, underpinned by slower progress in efficiency and clean energy deployment. In either scenario, the resilience of ports, their terminals and shipping routes become more important as greater fuel volumes are channelled through shipping's network of physical nodes and trading corridors.

Port infrastructure is exposed to extreme weather hazards including flooding, high winds and extreme heat, depending on location. Virtually all ports with regular tanker activity in Japan, Korea and China are exposed to a tropical cyclone at least once in 500 years on average. The US Gulf Coast, where nearly half of the country's refining capacity is located, is also exposed to tropical cyclones and the flooding they can cause.

Tanker-handling ports experience an average downtime of 1.5 days per year due to disruption from extreme weather, with around 60% of assessed ports losing less than one day annually. Yet individual high-impact events can cause substantially longer disruptions, with ports shut for weeks or even months, before operations

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are. Physical damage is also material. Research estimates current annual weather-related physical damage to tanker-handling ports at around USD 5 billion, with Europe and North America accounting for nearly half of this due to the number and value of assets exposed. By 2050, annual damage could nearly double in the Intergovernmental Panel on Climate Change (IPCC) scenario associated with around 3 °C warming by the end of the century. River flooding accounts for around half of current estimated damage, while coastal flooding becomes a larger driver in the future as sea-level rise compounds with the risk of storm surge that tropical cyclones can cause.

Maritime trade routes are more vulnerable when they are concentrated through chokepoints that limit alternative options. Extreme weather disruption risk depends on location. For example, tropical cyclones can disrupt the Luzon Strait between the South China and Philippine seas; fog can temporarily close the Turkish Straits connecting the Mediterranean and Black seas; and drought can constrain Panama Canal transits for months. Where rerouting is possible, disruption raises voyage times, fuel use, freight costs and emissions; where practical alternatives are limited, disruption can stop flows altogether.

Some inland shipping routes face disruption from drought, which lowers water levels and limits navigability. Ships may need to reduce their draught by shedding load, reducing capacity and increasing costs. In more severe cases shippers may need to find alternative routes overland by road or rail. At Kaub on the River Rhine, between 2015 and 2026 navigation was economically unviable for around one month per year on average. In the IPCC scenario associated with global warming of above 3 °C, this could double to nearly two months by the end of the century.

Geography shapes the distribution of shipping infrastructure and routes, sometimes resulting in concentrations of ports that can be vulnerable to single weather events. Port clusters can provide regional flexibility to manage disruption, but also vulnerability should a region-wide event knock multiple ports offline.

The influence of geography applies at a small scale too. Many small island economies depend heavily on imported fuels via one or two import terminals, and face acute disruption if flows are interrupted. IEA analysis of selected fuel-importing small island economies finds that over 85% rely on imported fossil fuels for at least three-quarters of power generation. Yet fuel stocks may be limited: more than 15% of small islands in the dataset hold less than 90 days of fuel supply, while six hold as little as three weeks.

Strengthening the resilience of international fuel shipping requires action across governance, monitoring, operations, port construction and system design. Measures include disaster management frameworks, flood defences and the stockpiling of critical spares. Cooperation across stakeholders can further bolster the resilience of international oil and natural gas shipping.

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Key actions

- **Incorporate extreme weather resilience into energy security planning.** Countries should consider the impacts of disruption on their shipped energy trade flows as part of national energy strategies and emergency plans, and with consideration for projected changes in operating conditions.
- **Diversify energy sources and supply chains.** Broadening the mix of energy sources reduces the risk of serious impact should flow from any single source be disrupted. This action brings wider energy security benefits beyond addressing risk from extreme weather, as disruption risk from other causes such as conflict, malicious attacks or geopolitics can also be mitigated.
- **Enhance operations across energy shipping infrastructure.** Through operational systems and processes, strengthen the ability to maintain energy flows when infrastructure assets or supply routes are disrupted.
- **Take measures to increase infrastructure robustness.** Prioritise cost-effective measures by considering actions that could be taken to mitigate risk such as flood protection, resilient electricity and communications systems, elevated critical equipment, and protection against wind and waves.
- **Strengthen early warning and operational preparedness.** Leverage meteorological and oceanographic data and modelling for better anticipation of extreme weather conditions.
- **Address the acute vulnerability of small island economies.** Support adequate fuel reserves, resilient import infrastructure, emergency recovery plans and regional assistance arrangements; develop domestic energy sources such as renewables to reduce dependence on imported fuels.
- **Deepen international cooperation and information sharing.** Share data for better risk assessment across industry and countries; develop regionally coordinated management and responses to disruptions such as stockpiling of spare parts.
- **Foster international recognition and cooperation to limit trade route disruption.** Build consensus to support better management of trade routes, especially chokepoints and inland waterways where disruption can have far-reaching consequences.

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1. International oil and natural gas shipping – setting the scene

Maritime transport is one of the principal modes for moving fuels from supplier to buyer. This report presents a study of the risks and impacts of extreme and severe weather to the international component of oil and natural gas shipping. It considers both crude oil and its refined products, along with natural gas in the form of LNG. Only established, year-round trading routes are within the scope of the study.

This section presents key aspects of international oil and natural gas shipping, drawing on some of the characteristics of shipping in general, and implications for resilience to extreme weather events.

Historic trends and outlook

Historic trends

Global seaborne trade has expanded considerably over the last four decades, a reflection of the growing global economy and shipping's continued role as the most efficient, lowest emission, and most cost-effective option for moving large volumes of heavy goods – moving one tonne of cargo 1 000 kilometres by sea costs roughly USD 4, compared to USD 80 by rail, USD 300 by road, and USD 2 000 by air. Tanker trade as a proportion of global shipping has fallen over this period. It accounted for well over half of total traded tonnage in 1980, but by 2024 its share had decreased to 25% due to a faster increase in bulk commodities, containerised freight, and other dry cargo. Yet in absolute terms tanker trade has expanded.

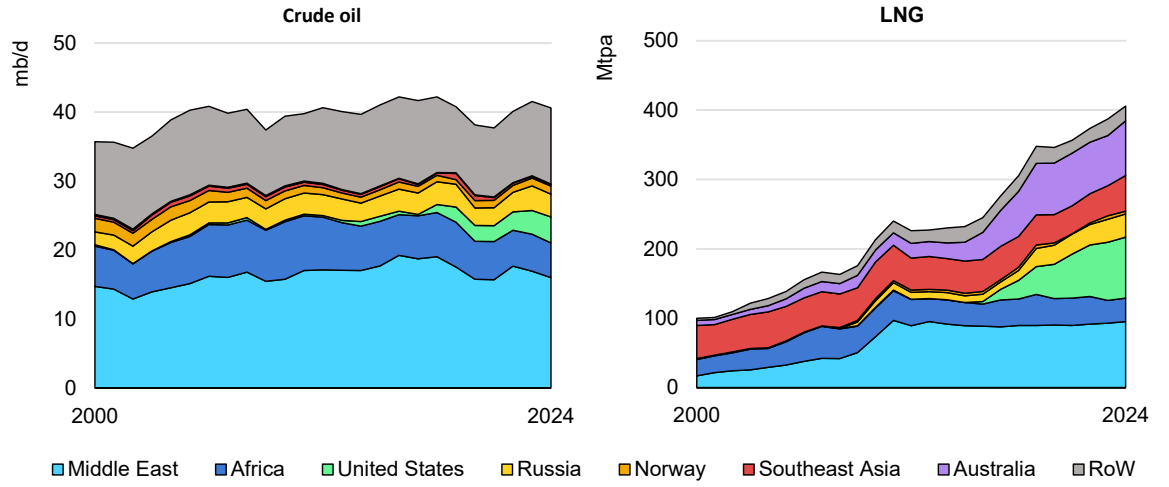
In 2024, global oil supply was around 100 million barrels per day, while about 40% of crude oil production was transported by sea. Although seaborne crude oil trade has only increased by around 15% since 2000, oil tanker transport activity, measured in tonne-kilometres, has increased by roughly 40% (Figure 1.1). This is because refinery capacity and crude oil import demand have shifted away from the Atlantic Basin toward Asia, particularly the People's Republic of China (hereafter, "China") and India, creating longer trade routes.

LNG has been a strong driver in fossil fuel shipping growth, with volumes quadrupling since 2000 due to growing demand from China, Japan, and Korea, and new suppliers in Australia, the Russian Federation (hereafter, "Russia"), West Africa (e.g., Nigeria, Angola), and the United States. LNG exports from the United States rose from around 3 Mt in 2016 to nearly 90 Mt in 2024, overtaking

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Qatar as the leading LNG exporter in 2023. The growth in United States LNG was supported by a rapid expansion in export terminals, from two in 2016 to nine by mid-2026; more than 90% of US LNG exports are shipped from Gulf Coast terminals in Louisiana and Texas. Starting February 2026, conflict in the Middle East restricted traffic through the Strait of Hormuz. It disrupted roughly one-fifth of oil and LNG supply, reduced effective tanker capacity and drove up tanker freight rates, leading to changes in the patterns of international oil and natural gas trade; this topic is explored further in Box 1.1.

Figure 1.1 Volume of maritime crude oil and LNG shipped internationally by origin



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Note: RoW = Rest of World; mb/d = million barrels of oil per day; Mtpa = megatonnes per annum.

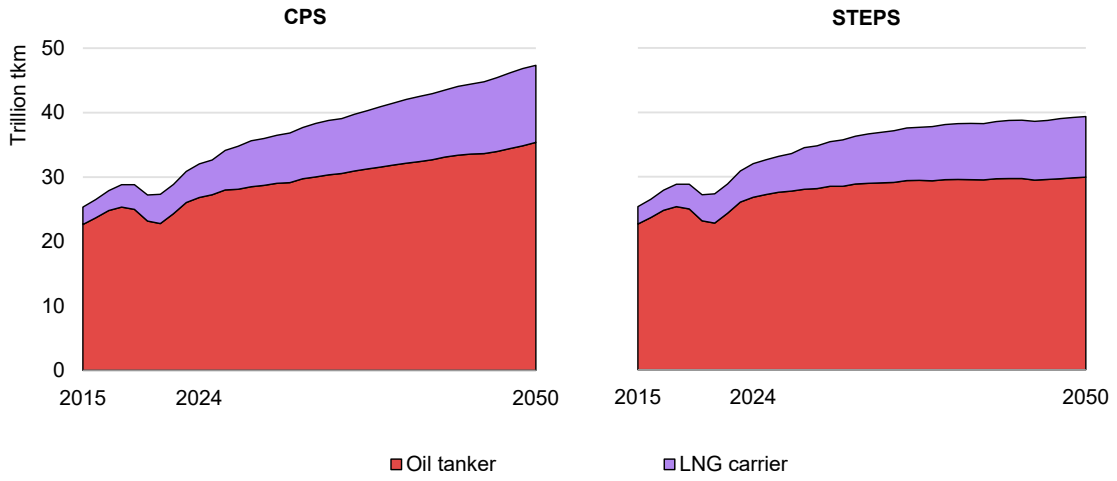
Outlook for international oil and natural gas shipping

The IEA utilises scenario analysis to explore how different policy and technology pathways could shape the future energy system and, in turn, demand for oil and liquefied natural gas shipping. The scenarios presented here are based on the World Energy Outlook 2025. The Current Policies Scenario (CPS) builds on a narrow reading of today's policies, including only those that are adopted in legislation and regulation. It offers a generally cautious perspective on the speed at which new energy technologies are deployed and integrated into the energy system. The CPS tends to project a larger continuing role for traditional fuels than the Stated Policies Scenario (STEPS), which includes a broader reading of the policy landscape – taking account of policies that have been formally tabled but not yet adopted, as well as other official strategy documents. The STEPS does not, however, assume that aspirational targets are met. It offers a more dynamic perspective on energy technology and market trends, and it projects a slightly more rapid introduction of new energy technologies than the CPS.

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Oil and natural gas shipping activity is around 32 trillion tonne-kilometres (tkm) today. In the CPS, oil and gas shipping activity increases to roughly 47 trillion tkm by 2050 (Figure 1.2). This is around 20% higher than in the STEPS, which sees faster improvements in energy efficiency and clean energy technology deployment and less reliance on fossil fuels. Under the STEPS shipping activity reaches nearly 40 trillion tkm by 2050.

Figure 1.2 International oil and gas shipping activity by scenario



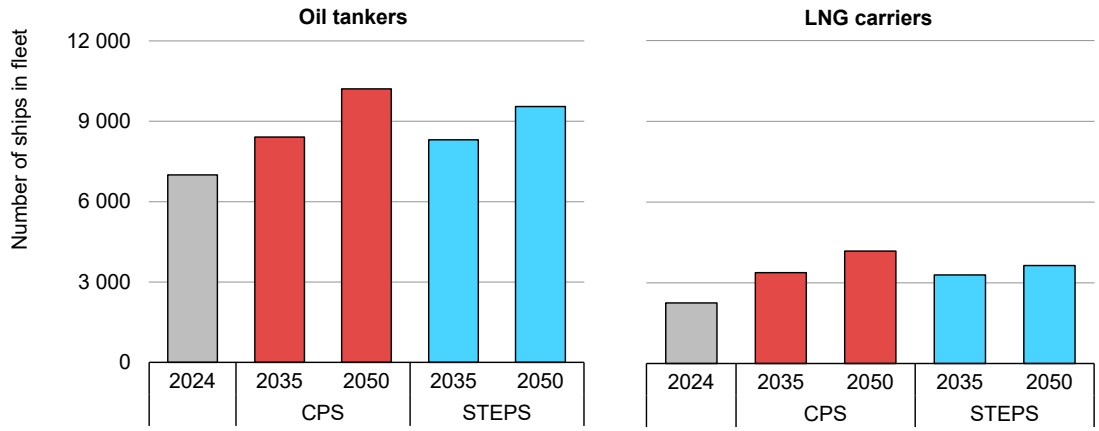
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Note: tkm = tonne-kilometres; CPS = Current Policies Scenario; STEPS = Stated Policies Scenario.

The growth in oil and natural gas shipping activity in both scenarios implies a need for additional tanker capacity, while new vessels will also be required to replace ageing ships. In the CPS, the fleet of oil tankers increases 45% by 2050 relative to today, and the fleet of LNG carriers grows by 80% (Figure 1.3). Growth is more moderate in the STEPS, with the fleet of oil tankers increasing by 35% up to 2050 and LNG carriers by 60%.

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Figure 1.3 International oil and gas tanker fleet size by scenario



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Note: CPS = Current Policies Scenario; STEPS = Stated Policies Scenario.

Characteristics of international fuel shipping and implications for resilience

Oil and natural gas shipping essentially comprises several core elements: the start and end points of shipments – i.e. ports and terminals; and the routes which connect them. This section examines the features of these components, including characteristics that could present vulnerabilities to extreme weather hazards.

Port infrastructure

Export terminals are the first key infrastructure element encountered by shipped fuels on their seaborne journey. Oil export infrastructure is generally simpler than LNG terminals and relies mainly on storage tanks, jetties, and pipeline connections, rather than complex processing and liquefaction equipment. For LNG, export terminals also include liquefaction facilities that cool natural gas to around -162 °C, as well as gas treatment systems, storage tanks, and loading infrastructure, making them far more capital intensive.

Receiving ports and import terminals sit at the destination end of the shipping chain. For crude oil, these are typically specialised tanker terminals, often at deepwater ports or offshore moorings for larger crude carriers, connected to refineries or crude storage facilities. For refined oil products, receiving infrastructure usually consists of liquid bulk terminals connected to storage tanks and onward distribution networks. Port costs vary enormously, from USD 10 000 to over USD 350 000 per call depending on vessel class and location. For LNG, the import terminal at the end of its journey is a regasification facility that converts LNG back to pipeline-quality gas by reheating it, before feeding it into gas

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transmission networks. Oil and LNG cargoes both incur port call fees for pilots, tugboats, mooring and berthing, as well as terminal fees for unloading and storage. LNG import costs also include regasification charges, which is typically a throughput fee based on the volume of gas delivered.

Oil and LNG can be loaded, received or stored at onshore terminals or handled through various types of floating and offshore infrastructure. For oil, this can include offshore loading buoys, floating storage units and ship-to-ship transfers, which allow crude or refined products to be loaded, unloaded or stored at sea rather than at a port. For LNG, regasification terminals can be built onshore or deployed as floating units, which are typically converted LNG carriers fitted with onboard regasification equipment, although some are purpose-built. Floating storage regasification units are generally favoured when speed to market and flexibility are priorities, but they tend to have higher operating costs and more limited throughput. Onshore terminals are typically better suited to large, stable import requirements because they can offer higher throughput, easier expansion, and lower unit throughput costs over long operating lifetimes.

In addition, every oil and LNG voyage requires marine insurance, which typically covers three elements: hull and machinery (i.e. physical damage to the vessel), protection and indemnity (third-party liabilities including pollution and crew injury), and cargo. On low-risk routes, baseline insurance is a relatively modest cost. However, vessels entering designated conflict zones must purchase additional war risk cover, priced as a percentage of the vessel's hull value and charged per voyage. War risk premiums can escalate quickly during periods of heightened tension, rising from roughly 0.2-0.4% of hull value to around 10% in acute high-risk situations.

Ports and trading hubs

International seaborne transport of oil and LNG is concentrated around a limited number of major exporting regions and import hubs, accounting for a large share of global volumes. Although oil and gas are produced and consumed in many countries, internationally traded seaborne volumes are normally routed through a smaller set of coastal nodes.

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Table 1.1 Selected major oil ports

Port name	Throughput volume	Description	Regional cluster
Corpus Christi, United States	130 Mt crude oil; 60 Mt oil products	Oil export hub for international markets, with very large outbound volumes linked to US shale production.	US Gulf Coast
Rotterdam, Netherlands	98 Mt crude oil; 56 Mt oil products	Major oil import, storage and redistribution hub, serving as Europe's main gateway for crude and refined products and a key trading node.	Rhine-Scheldt
Sikka, India	73 Mt crude oil; 43 Mt of oil products	Major crude import and oil products export hub serving the Jamnagar refining complex, with large crude intake and major oil-product exports to international markets.	Arabian Sea
Singapore, Singapore	184 Mt crude oil and product	World's largest bunkering hub, with substantial refining, petrochemical capacity, and major refinery-export centre.	Singapore-Johor hub
Zhoushan, China	143 Mt crude oil and product	Major crude import and refining hub, anchored by one of the world's largest integrated refining and petrochemical complexes.	Yangtze River Delta

Note: Throughput volumes relate to the most recent year for which data are available.

Sources: Port of Corpus Christi Authority (2024), Monthly Cargo Tonnage by Commodity Summary Report; Port of Rotterdam (2025), Throughput Port of Rotterdam; Ulsan Port Authority (2025), Operation by vessel and Cargo type; JM Baxi (2025), Oil & Petroleum Update; Singapore Open Data Portal (2026), Cargo Throughput Breakdown, Annual Data; TJN Data, Statistical Bulletin on National Economic and Social Development of Zhoushan City in 2024 (2026).

Asia is the largest import market for crude oil and LNG – China, Japan, and Korea are the world's top three LNG importers accounting for over 45% of global imports, and are also home to large coastal refinery and petrochemical complexes that import crude oil from the Middle East, the United States, and elsewhere. Europe imports crude oil and petroleum products mainly from Norway, the United States and the Middle East, along with occasional cargoes from South America and Africa. For gas, Europe brings in LNG sourced largely from the United States, with imports concentrated in major regasification countries including France, the Netherlands, Spain, Italy, and Belgium. These trade patterns have shifted notably since 2022, with Russian oil exports increasingly redirected away from Europe towards markets in Asia, while lower Russian pipeline gas deliveries led Europe to increase seaborne LNG imports from alternative suppliers, particularly the United States. On the supply side, the Persian Gulf remains one of the most important export basins for seaborne crude, products, and LNG. The region's position reflects the scale of resource endowments, production and export infrastructure, including large loading terminals, extensive storage, and proximity to high-growth Asian demand – although recent disruption to shipping through the Strait of Hormuz has constrained these flows.

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Table 1.2 Selected major LNG ports

Port name	Throughput volume	Description	Regional cluster
Ras Laffan, Qatar	77 Mt LNG exported	Hub that handles nearly all of Qatar's LNG shipments.	Persian Gulf
Corpus Christi, United States	19 Mt LNG exported	Large-scale LNG export hub, shipping growing volumes of US LNG from the Gulf Coast to global markets.	US Gulf Coast
Chiba, Japan	14 Mt LNG imported	LNG import hub for Japan's domestic consumption.	Tokyo Bay
Rotterdam, Netherlands	11 Mt LNG imported	Major European import, storage and redistribution hub.	North Sea
Singapore	7 Mt LNG imported	Imported gas powers over 90% of Singapore's electricity demand.	Singapore-Johor hub
Zhoushan, China	10 Mt LNG imported	Key LNG import hub, with rapidly expanding receiving and storage capacity.	Yangtze River Delta

Note: Throughput volumes relate to the most recent year for which data are available.

Sources: Kpler (2026), Ras Laffan thermal activity eases from July 7 peak, six LNG trains show thermal signatures; Port Corpus Christi (2025), Port of Corpus Christi Announces Fourth Quarter 2025 Volumes and Annual Tonnage; Chiba Prefecture (2024), Port of Chiba 2024-2025; Port of Rotterdam (2025), Throughput Port of Rotterdam; World Integrated Trade Solution (2026), Singapore Natural gas, liquefied imports by country in 2024; ANGEA (2026), Singapore; GIIGNL (2026), GIIGNL Annual Report.

Port distribution, isolated ports, and implications for resilience

Ports are not evenly distributed across global coastlines: some are geographically clustered within concentrated coastal corridors; others are regionally isolated, serving relatively small populations or areas with no alternative transport link. Port clusters can provide regional redundancy but also bring a risk of region-wide vulnerability. They tend to occur where there are combinations of resources and/or manufacturing, alongside large coastal demand centres, deepwater access, refining and processing facilities, pipeline and hinterland connections.

Table 1.3 Selected major port clusters

Port cluster	Major ports	Drivers of clustering	Energy trade significance
US Gulf Coast	Houston, Corpus Christi, New Orleans	Dense refining, petrochemical and export infrastructure along the coast.	Exports roughly 9.5 mb/d of crude and products and 80 Mt of LNG.
Persian Gulf	Ras Laffan, Jubail, Ras Tanura	Shared proximity to massive hydrocarbon reserves.	Around 20% of global oil and gas supply.
Rhine-Scheldt	Amsterdam, Rotterdam, Antwerp	Deepwater ports with North Sea access, dense refining/storage infrastructure, and inland links to the Rhine-Scheldt industrial hinterland.	Rotterdam imports roughly 2.5 mb/d and 11 Mt of LNG.

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Port cluster	Major ports	Drivers of clustering	Energy trade significance
Russian Baltic	Saint Petersburg, Ust-Luga, Primorsk	Export hub linked to Urals crude pipeline and refined product flows.	Nearly 50% of Russian seaborne oil exports.
Tokyo Bay	Chiba, Yokohama, Kawasaki	Links multiple oil and LNG receiving ports to the Tokyo metropolitan and industrial hinterland.	Imports roughly 1 mb/d and 16 Mt of LNG.
Seoul hinterland	Incheon, Daesan	Energy import cluster serving Seoul capital region, and central-west industrial hinterlands.	Incheon has the world's largest LNG import capacity; 55 Mt.

Sources: EIA (2026), Natural Gas; EIA (2026), World Oil Transit Chokepoints; EIA (2026), Petroleum & Other Liquids; Port of Rotterdam (2025), Throughput Port of Rotterdam; Reuters (2025), Marine fuel sales at Singapore bunker hub hit record highs in 2024; Energy and Clean Air (2026), March 2026 – Monthly analysis of Russian fossil fuel exports and sanctions; GIIGNL (2026), GIIGNL Annual Report; Japan Customs (2025), Kawasaki Port Trade Overview; Kawasaki City (2025), Port Survey of Kawasaki Port; Chiba Prefecture (2024), Port of Chiba 2024-2025; Chiba Prefecture (2025), Year-on-Year Comparison Table of Major Types of Cargo In and Out at Sea.

For fuel shipping, geographic concentration can strengthen system flexibility through redundancy: if one port experiences disruption, nearby ports may be able to absorb diverted cargoes, reducing regional risk. For example, a vessel collision during a typhoon in 2019 damaged and temporarily suspended operations at PetroChina's Rudong LNG import terminal. Rather than triggering a broader supply shock, cargoes were diverted to PetroChina's alternative regional LNG terminals at Tangshan and Dalian. However, clustering also creates regional exposure. Nearby ports often depend on the same coastal geography, energy infrastructure, power supply, labour pools, and hinterland connections. As a result, a single regional event with broad impact can affect multiple trade nodes. For instance, a tropical cyclone which tracks along the US gulf coastline could disrupt a significant share of global crude oil, oil product, and LNG exports, as well as refinery operations and vessel movements across several nearby ports. Such events have the potential for not just a regional but a global impact as a result of supply-chain disruption that delays shipments, raises transport costs, and forces cargoes to be rerouted or sourced from alternative hubs – putting upward pressure on shipping costs and fuel prices.

Isolated import terminals and concentrated infrastructure present a different set of energy security and economic risks for importers. For example, Costa Rica's seaborne petroleum-product imports are concentrated at the Moin terminal, while in Uruguay all seaborne crude oil is received through the Terminal del Este, before being transported by pipeline to the country's sole refinery. Neither country has a cross-border oil pipeline that could provide an alternative import route. This lack of alternative infrastructure means these countries are heavily dependent on a single port for all their oil and gas imports. If terminal operations are disrupted, the importer may lose its only source of fuel supply, with potentially significant energy security or economic consequences. For instance, a leak at Uruguay's only

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offshore crude oil import buoy in August 2025 cut crude supply to the country's sole refinery. Crude inventories lasted just two weeks before the refinery shut down, and repairs took six weeks to complete, forcing Uruguay to buy refined fuels instead at an estimated cost of USD 500 000 per day. Small island economies are particularly exposed to the risks associated with isolated import infrastructure, and section 2.2 explores these challenges in more detail.

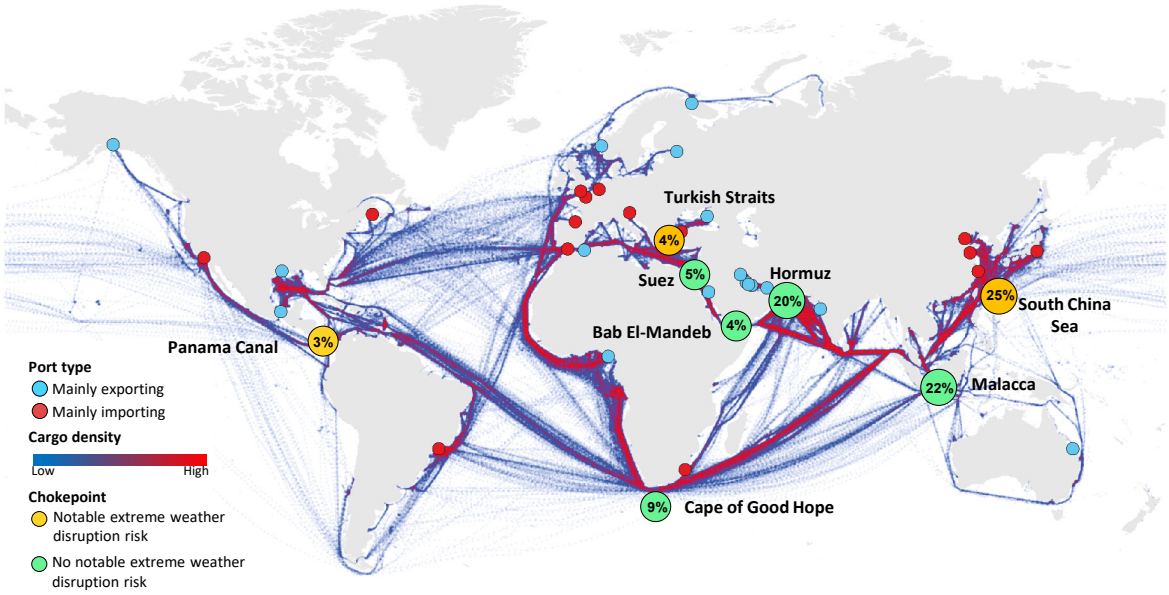
Trading routes and maritime chokepoints

Several trading route corridors dominate the international shipment of oil and natural gas. The greatest volumes run along the Middle East-Asia corridor, reflecting the scale of Gulf oil exports and the pull of Asian demand. A second major trade route connects the Middle East to Europe, while a third set of routes connects the Atlantic Basin to Europe and Asia, with oil and gas primarily coming from the US Gulf Coast, West Africa, and more recently South America. Finally, the Panama Canal is an important route for some Atlantic Basin cargoes to Asia, particularly US Gulf Coast LNG exports.

The most vulnerable sections of these routes are the narrow or strategically important maritime passages, known as maritime chokepoints, where high volumes of trade are concentrated and where disruption can force vessels to queue, reroute, or stop moving altogether. As global trade volumes of oil and gas continue to expand, the risk of severe congestion or disruption at key chokepoints could increase. Such disruption can stem from geopolitical tensions, conflict, piracy, accidents, or extreme weather events. For oil and gas trade, the most heavily congested maritime passages are the Strait of Hormuz, the Strait of Malacca, and the South China Sea. In 2024 around one-fifth of global oil and LNG supply passed through each of the Hormuz and Malacca straits, while the South China Sea carried around one-quarter of oil supply and one-third of LNG supply (Figure 1.4). Extreme weather is not a primary source of disruption at most major chokepoints, although some are exposed to specific weather-related risks, including tropical cyclones around the Luzon Strait and South China Sea, fog in the Turkish Straits, and drought at the Panama Canal.

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Figure 1.4 Global chokepoints and their corresponding shares of global oil supply, 2024



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Notes: Percentages refer to the share of oil transit in global oil production, in 2024. Cargo density is estimated based on deadweight tonnage and load factor of ships as per Automatic Identification System data. This document, as well as any data and map included herein, are without prejudice to the status of sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

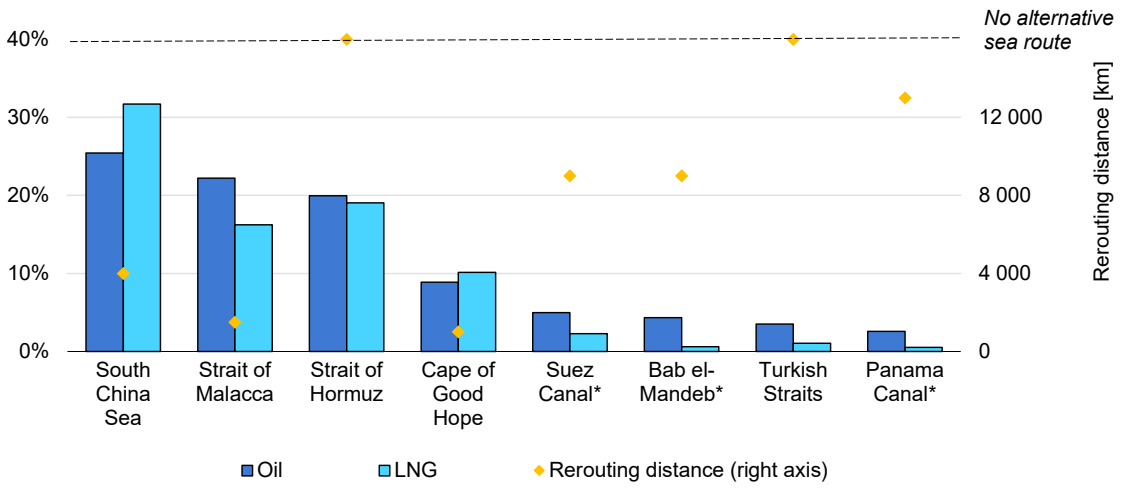
Sources: IEA analysis based on United Nations Global Platform (2024), AIS Data; Verschuur (2022), Ports' criticality in international trade and global supply-chains; EIA (2026), Global Energy Security Data.

The South China Sea is a major corridor for oil and LNG trade, carrying around 25% of global oil supply and 32% of global LNG trade (Figure 1.5). The Luzon Strait, which connects the South China Sea with the western Pacific, is particularly exposed to extreme weather, including typhoons that frequently pass through the area. Severe storms can temporarily disrupt vessel movements through the Strait and surrounding waters, creating delays and disruption for energy shipments.

The Turkish Straits, comprising the Bosporus and Dardanelles, carry a relatively small share of global energy trade – around 4% of seaborne oil trade and 1% of LNG trade – but form the only maritime connection between the Black Sea and the Mediterranean. Unlike many other chokepoints, vessels transiting between the Black Sea and global markets have no alternative maritime route if the straits are closed. Navigation is also periodically disrupted by poor visibility, with fog frequently causing temporary suspensions of vessel traffic.

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Figure 1.5 Selected oil and LNG chokepoints by share of global supply and rerouting distance



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*Assumed to reroute around Cape of Good Hope.

Note: Cape of Good Hope rerouting distance assumes a longer route around South Africa at distance from the coast.

Sources: IEA analysis based on EIA (2026), Global Energy Security Data; EIA (2025), World Oil Transit Chokepoints; Reuters (2024), Panama Canal seeks LNG comeback after 65% decline in traffic; Panama Canal (2024), Principal Market Segments Through the Neopanamax Locks; IEA (2024), Suez Canal – Factsheet; Verschuur (2025), Maritime chokepoint dependencies and systemic risks.

For oil and gas exports from the US Gulf Coast to Asia, the shortest path runs through the Panama Canal. Nevertheless, high canal fees and low water levels during periods of congestion or drought can act as a barrier and restrict transits, as occurred in 2023 and 2024. Canal fees typically range from USD 100 000 to USD 500 000 per transit depending on vessel size and whether the ship is laden or empty, although fees paid through priority transit auctions can spike well beyond this range during periods of severe congestion. For instance, an LPG tanker paid USD 5 300 000 for a single Panama Canal transit during September 2026. Ships bound for Asia can reroute around the Cape of Good Hope instead of transiting the Panama or Suez canals when significant disruptions make either route impractical. However, this often comes at a substantial cost premium, as longer routes increase fuel consumption and voyage time – fuel costs can represent more than 50% of operational shipping costs. For example, a tanker travelling from the US Gulf Coast to Japan via the Cape of Good Hope rather than the Panama or Suez canals would sail an additional 13 000 km, increasing transit time by 26 days and total fuel consumption by 75% assuming no change in speed[1]. If the disruption is prolonged, such rerouting can raise freight rates globally.

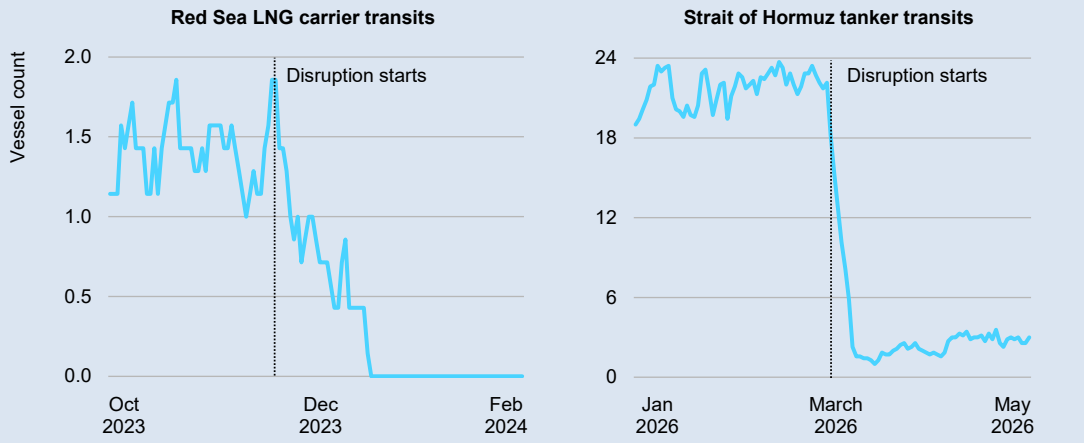
[1] Additional energy requirements could be compounded by some operators increasing shipping speeds to meet delivery deadlines. Conversely some operators may choose to reduce speed to compensate for higher fuel costs from the longer journey.

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Box 1.1 Chokepoints and geopolitical disruption

Risks to international oil and natural gas shipping come from several sources. Alongside extreme weather, geopolitical tensions and conflict can also disrupt trade flows, especially at narrow chokepoints. The nature of these risks differ – geopolitical situations tend to be longer-lived than extreme weather events, and while this can illustrate the extent of potential disruption, it tends to result in a different response – including the development of alternative routes to market. Recent disruption to shipping through the Red Sea in 2023 and the Strait of Hormuz in 2026 clearly illustrate how heightened security risks can cause sharp falls in commercial shipping activity. However, the consequences for fuel markets differed substantially, largely depending on whether alternate routes were available. Following attacks on commercial vessels in the Red Sea beginning in November 2023, many operators stopped transiting the Bab el-Mandeb Strait and Suez Canal, instead rerouting vessels around the Cape of Good Hope. LNG shipping was particularly affected, with LNG trade through the Red Sea nearly halting in January 2024.). Yet, with an alternative route available, global LNG supply ultimately did not decline overall.

Vessel transits through the Red Sea and the Strait of Hormuz during periods of geopolitical disruption to commercial shipping, 2023-2026



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Notes: This chart presents daily transits based on a seven-day rolling average. The Strait of Hormuz tanker transit count includes ships carrying crude oil, refined oil products, LPG, and LNG.

Sources: IEA analysis based on Kpler (2026) and Bloomberg Terminal (2026) (accessed 15 September 2026).

Conversely, the ongoing disruption to the Strait of Hormuz following the escalation of conflict in the Middle East at the end of February 2026 has had more direct implications. Vessel activity through the Strait fell sharply in the weeks following conflict escalation, as operators cancelled or delayed voyages, vessels anchored on either side of the Strait, and routine commercial transits became increasingly limited. Oil flows through Hormuz fell from around 20 mb/d to around 5 mb/d in the second quarter of 2026, while LNG movements through the Strait declined by more

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than 90% according to EIA estimates. With no alternative shipping route and only limited pipeline capacity to export terminals outside the Gulf, the scale of disruption prompted IEA Member countries to make 400 million barrels of emergency oil stocks available to the market, the largest collective action in the Agency's history.

Disruption risks

As global fuel shipping continues to expand, the risk of disruption to energy infrastructure and trade routes becomes more prominent. These risks are material for energy security, as a substantial share of oil and gas trade depends on flows passing through vulnerable regions, transport corridors, and bottlenecks. Disruption can reduce the effective fleet capacity, as longer or delayed voyages keep vessels occupied for more time and reduce the number of trips they can complete over a given period. This tightens vessel availability, raising freight rates and, in turn, the delivered cost of oil and gas.

Impacts from disruptions are not necessarily felt immediately across supply chains and markets – shipping is a relatively slow transfer of goods, and consumers can draw on stocks where available should fuel deliveries be delayed. Even so, disruption can have severe and far-reaching impacts, depending on where it occurs, how severe it is and how long it lasts.

Table 1.4 Major disruption risks

Disruption	Risk	Impact	Example
Geopolitics and security	Political instability, conflict, or sanctions in key oil and gas producing regions.	Potential to interrupt production, constrain exports, or reroute trade flows.	The 2026 conflict in the Middle East sharply reduced traffic through the Strait of Hormuz, disrupting energy flows through a chokepoint that normally carries 20% of oil and LNG supply.
Cyberattack	Cyberattacks targeting upstream production, refineries, terminals, and distribution systems.	Can shut down operations, interrupt production, and delay the timely movement of oil and gas shipments.	The 2022 cyberattack on Oiltanking and Mabanaft disrupted terminal operations in northwest Europe, delaying tanker and barge shipments in and out of the Rhine-Scheldt cluster by up to a week.
Operational incidents	Maritime accidents in narrow or congested waters.	Can obstruct shipping routes or damage vessels, delaying the transport of large volumes of oil and gas.	The 2021 grounding of the Ever Given in the Suez Canal disrupted shipments of 26 million barrels of oil products and 0.5 Mt of LNG over a six-day period.

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Disruption	Risk	Impact	Example
Natural hazards	Natural hazards stemming from extreme weather, tsunamis, or earthquakes.	Can damage import and export terminals, causing lost production or delays in oil and gas deliveries.	Hurricane Harvey in 2017 led to a 45% decline in US oil exports in the two weeks following the hurricane.

Sources: IEA (2026), Strait of Hormuz Factsheet; Reuters (2022), Oil shipments in European oil hub delayed after cyber attacks; Reuters (2021), The Ever Given's stranding in the Suez Canal; S&P Global (2021), Suez Canal logjam has more than 320 ships waiting, further clogging up trade; Energy Products (2021), Impact of the Suez blockade on LNG sector; EIA (2026), Petroleum & Other Liquids.

Geopolitical tensions remain one of the most significant sources of disruption risk. Political instability, conflict and war, public unrest, labour disputes, or sanctions in key oil and gas producing regions can interrupt production or constrain fuel shipping. Cyber risk is also becoming more material across oil and gas supply chains. Attacks targeting upstream production, pipelines, refineries, terminals, and distribution systems can shut down operations, interrupt production, delay the loading of oil and gas tankers, or disrupt the unloading and onward movement of cargoes at destination markets. As oil and gas logistics rely increasingly on digital control systems, cyber incidents can create operational disruption even where physical infrastructure remains intact.

Operational incidents can include physical accidents and infrastructure failures and can be similarly disruptive. In narrow or congested chokepoints, shipping incidents can obstruct transit and delay large volumes of oil and gas trade. The 2021 grounding of the Ever Given in the Suez Canal illustrated how a single accident can block a major shipping artery, disrupting 26 million barrels of oil products and 0.5 Mt of LNG flow through the Suez Canal over a six-day period.

These disruption risks interact with a broader range of risks from natural hazards, comprising geophysical events (e.g. earthquakes and tsunamis), as well as extreme weather events (e.g. storms, floods, droughts, extreme temperatures). These can damage port infrastructure, disrupt operations, and constrain or block shipping routes. The risks will change as weather patterns shift under an evolving climate, potentially increasing the frequency and intensity of extreme events. The remainder of this report will focus on the risks of extreme weather to international oil and natural gas shipping.

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2. Extreme weather risks to shipping infrastructure

Ports and the terminal complexes in which they are located are the start and end points of shipped oil and natural gas. Like other energy infrastructure, they face disruption risks from weather and climate hazards, including periods of extreme and severe conditions. This section outlines the key risks and characteristics of oil and natural gas shipping infrastructure and its vulnerability to these hazards. It also assesses the extent of damages and downtime and presents measures that can be taken to enhance resilience.

Shipping infrastructure exposure to weather-related disruption

Oil and gas shipping infrastructure is exposed to a range of weather-related hazards that can damage buildings and equipment, restrict vessel movements and interrupt loading and unloading operations. Seaports are particularly exposed because of their location along coasts and estuaries, where extreme winds and waves, heavy precipitation, and river and coastal flooding can affect both port access and fuel-handling infrastructure. At oil and gas terminals, vulnerable assets include jetties and mooring systems, loading equipment and pipelines, storage tanks, pumping systems and electrical and control equipment. LNG terminals also rely on specialised cryogenic infrastructure, while floating facilities such as Floating LNG (FLNG) and Floating Storage and Offloading (FSO) units are directly exposed to winds, waves and currents. Such facilities may need to suspend operations or disconnect to move to safer waters during severe storms. As weather regimes evolve, changes in temperature, precipitation, sea levels, winds, waves and extreme events could alter both the frequency and severity of disruption to port and maritime transport infrastructure.

Asian and US Gulf Coast seaports face high tropical cyclone exposure

Tropical cyclones are among the most damaging weather-related hazards for ports, causing costly physical damage and operational disruptions. These rapidly rotating storms, also referred to as hurricanes or typhoons, form over tropical oceans and can combine extreme winds with heavy rainfall, storm surges, high waves and flooding – compounding impacts on coastal infrastructure. Tropical cyclone intensity is commonly measured using the Saffir-Simpson Hurricane Wind

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Scale, ranging from Category 1 to 5. Category 3 and above, with sustained winds of at least 178 km/h, are classified as major cyclones. Seaports hit by a moderate Category 1 cyclone typically require one to two days to resume full operations. While the Saffir-Simpson scale reflects wind intensity, high winds account for only part of the damage associated with tropical cyclones.

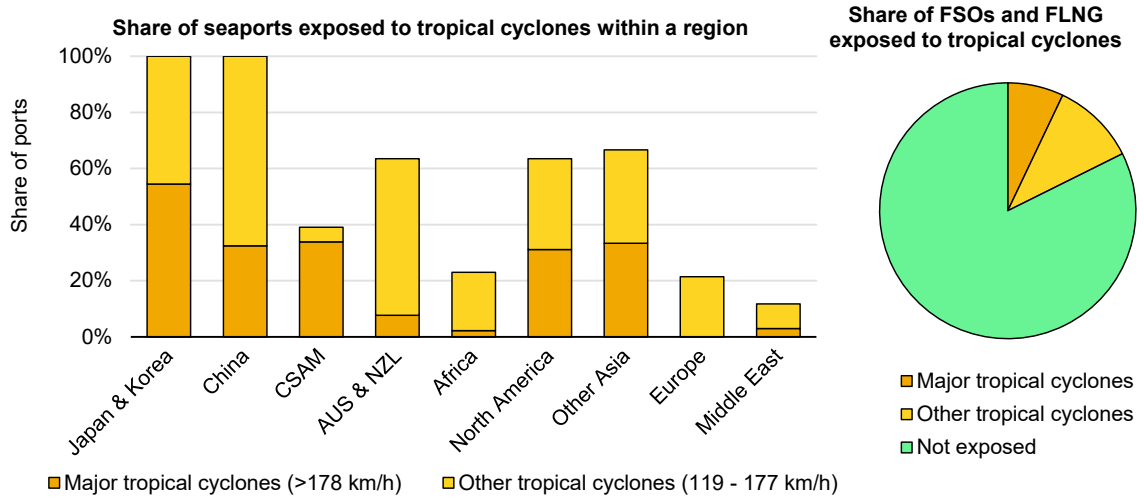
Port exposure is particularly high in East Asia (Figure 2.1). IEA analysis estimates that virtually all ports with regular tanker activity in Japan, Korea and China are exposed to a tropical cyclone on average at least once in 500 years; in Japan and Korea more than half of ports face exposure to a major tropical cyclone. In recent years, Japan's Kobe and Osaka ports were severely damaged by Typhoon Jebi in 2018, and Korea's Port of Busan has repeatedly suspended vessel movements and cargo handling during cyclones (for instance following Typhoon Nanmadol in 2022). Approaching cyclones regularly lead to temporary closures of major Chinese ports, disrupting vessel schedules and cargo flows – as happened to the Shanghai and Ningbo hubs during Cyclone Bavi in July 2026.

IEA estimates indicate that among the assessed regions, North America, Central and South America, and parts of Asia including Bangladesh and Oceania each show exposure of around one-third of ports with regular tanker activity to major tropical cyclones. In North America, the US Gulf Coast is particularly exposed, with major regional ports such as Corpus Christi, Houston and New Orleans, facing recurrent risks of severe operational disruption and infrastructure damage.

While less than 10% of Australia and New Zealand's tanker-handling ports are exposed to major tropical cyclones, more than half face exposure to Category 1 and 2 storms, including all of Australia's LNG liquefaction terminals. In March 2026, Tropical Cyclone Narelle disrupted LNG production at the Wheatstone, Gorgon facilities and Northwest Shelf projects in Western Australia. At the Wheatstone facility, extreme winds damaged several hundred air-cooled heat exchangers, requiring the shutdown of both LNG trains at the 8.9 Mt facility, with full production restored around four weeks later. IEA analysis shows that less than 5% of Africa's ports with regular tanker activity are exposed to major tropical cyclones. However, exposure is concentrated along the eastern coasts and in island economies, including Comoros and Mauritius. In Mozambique Cyclone Idai damaged parts of the Port of Beira in 2019, including warehouses and grain and coal terminals.

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Figure 2.1 Seaport, FSO and FLNG exposure to tropical cyclones by region and cyclone category



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Notes: CSAM = Central & South America, AUS & NZL = Australia & New Zealand, FSO = Floating Storage and Offloading (crude oil). FLNG = Floating Liquefied Natural Gas. Assessment of 1 606 seaports that see at least one tanker landing per year on average, 162 FSO and 8 FLNG vessels. Cyclone exposure is assessed for a 1-in-500-year return period. Storm categories refer to the Saffir-Simpson Hurricane Wind Scale; major tropical cyclones are defined as events of Category 3 (≥178 km/h) or higher. Exposure assesses the presence of assets in areas that can be adversely affected by a hazard but does not enable conclusions to be drawn regarding the assets' vulnerability.

Source: IEA analysis based on Bloemendaal et al. (2023), STORM tropical cyclone wind speed return periods and IMF PortWatch (2026), Ports (accessed 15 June 2026).

The locations of 7% of FSO and FLNG facilities are exposed to major tropical cyclones. But floating offshore hydrocarbon projects can invest in cyclone-resilient technology to offset this risk. For instance, the Coral South FLNG project at the coast of Mozambique installed a permanently moored vessel with a large-diameter internal turret. Other floating facilities use detachable mooring systems that allow vessels to leave the area when a cyclone approaches. For example, the planned Delfin FLNG vessels in the US Gulf are designed to disconnect and sail to calmer waters, while Australia's Stybarrow Venture FPSO relocated when Tropical Cyclone Nicholas approached in 2008.

In the Middle East and Europe, major tropical cyclone exposure among the ports and LNG terminals assessed is relatively low, although individual events and other types of storms can cause severe disruption. In a rare event, Cyclone Mekunu struck southern Oman in 2018 and the Port of Salalah suspended operations and subsequently reported extensive damage requiring recovery and salvage operations. Europe, meanwhile, is affected by extratropical cyclones. For instance, during Storm Helios in Malta in 2023, strong winds and high waves damaged pipelines, loading arms and other infrastructure at the Marsaxlokk oil and gas terminal, suspending bunkering operations.

Projections of tropical cyclone activity remain highly uncertain. These uncertainties are particularly significant at regional and local level – including

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port-level risk assessments, where relatively small shifts in storm tracks can strongly affect local exposure. At a global level, research tends to conclude that the average tropical cyclone intensity is on the increase, while there is less consensus regarding changes in frequency. This means that cyclone-prone regions may experience more intense storms, exposing areas historically affected by Category 1-2 cyclones to stronger events.

Flooding is the most common disruption to ports

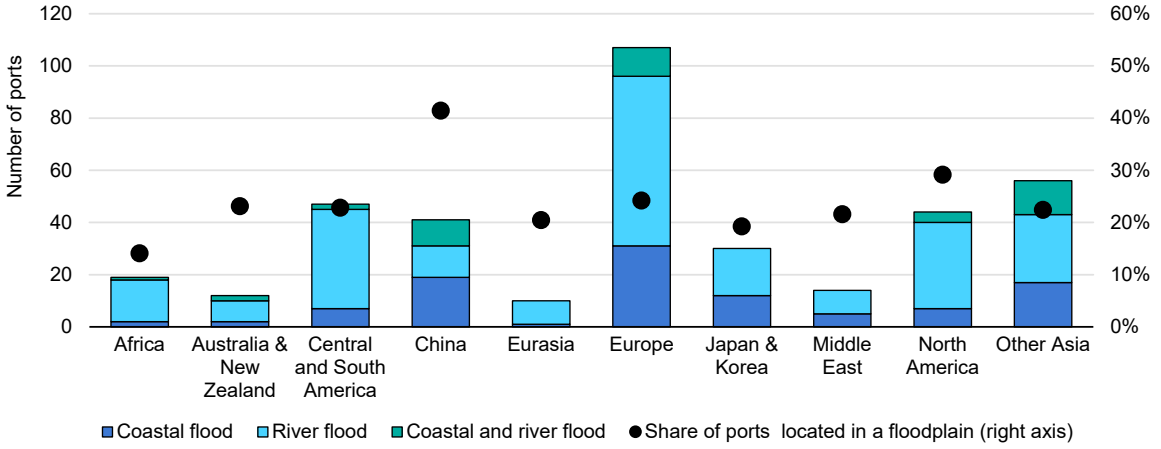
As ports require direct access to navigable waters and are often located in low-lying coastal areas, estuaries and river deltas, they can be affected by both river and coastal flooding. Flooding can inundate terminals, storage areas and equipment and, just as importantly, disrupt the roads, railways and pipelines connecting ports with their hinterlands. These wider impacts can make flood-related disruptions particularly persistent: evidence indicates that floods affect port operations for nearly 11 days on average, compared with 4.25 days for cyclones, with longer disruption often linked to damage to hinterland infrastructure. River flooding occurs when high river flows exceed the capacity of the river channel and inundate surrounding areas, often following prolonged or intense rainfall. Coastal flooding results from unusually high sea levels and can be driven by storm surges, high tides and waves. Ports located at a river mouth can face compound risks where high river discharge coincides with elevated coastal water levels, amplifying flood severity.

IEA analysis estimates that around one-quarter of ports with tanker activity are exposed to river or coastal flooding (Figure 2.2). Exposure is highest in China, where more than 40% of the assessed ports are affected, followed by North America at nearly 30% (concentrated along the US Gulf Coast). Europe has the largest number of exposed ports, at more than 100. Globally, river flooding affects more ports than coastal flooding, except for in China where exposure to coastal flooding is greater than to river flooding. In the case of LNG terminals, one-third of operating LNG liquefaction capacity[2] is exposed to river flooding. In the United States and Africa, exposed terminals account for nearly 80% and 70% of operating capacity, respectively. Of the LNG capacity exposed to river flooding, about a quarter also face coastal flood risk.

[2] This excludes Floating Liquefied Natural Gas (FLNG).

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Figure 2.2 Seaport exposure to river and coastal flooding by region



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Notes: Assessment of 1 606 seaports that see at least one tanker landing per year on average. River flood and coastal flood exposure are assessed for a 1-in-500-year return period. Exposure assesses the presence of assets in areas that can be adversely affected by a hazard but does not enable conclusions to be drawn regarding the assets' vulnerability.

Sources: IEA analysis based on JRC (2024), Global River Flood Hazard Maps; WRI (2020), Aqueduct Floods and IMF PortWatch (2026), Ports (accessed 15 June 2026).

Evolving weather patterns are expected to exacerbate flood risks to port infrastructure. Potentially deeper cyclonic depressions and rising mean sea levels can increase the severity and frequency of unusually high sea levels and storm surges, intensifying coastal flooding. IEA analysis estimates that two-thirds of all assessed ports with tanker landings are located in areas projected to experience at least 20 centimetres(cm) of sea-level rise by mid-century compared to the 1995-2014 average, under the scenario of the Intergovernmental Panel on Climate Change associated with around 3 °C of global warming by the end of the century (IPCC's Around 3 °C scenario)[3]. By mid-century, more than 70% of ports already situated in coastal floodplains are projected to experience a sea-level rise and more than 30 additional ports become exposed to coastal flooding. More intense heavy rainfall could expand areas currently classified as river floodplains and increase water levels for a given return period, thereby increasing river flood risks. By the end of the century in the Around 3 °C scenario, more than 90% of assessed ports are projected to experience an increase in heavy rainfall. Among ports already located in river floodplains, more than 15% could experience increases in heavy rainfall of more than 20%, potentially increasing inundation depths. Similarly, assessing LNG liquefaction capacity already located in river floodplains shows that nearly a quarter is projected to face increases in heavy rainfall of more than 20%.

Drought can also constrain maritime access where seaports depend on freshwater-fed channels or estuaries. For instance, low water levels have led to a

[3] IPCC's Around 3 °C scenario refers to the Shared Socioeconomic Pathway 2-4.5 (SSP2-4.5).

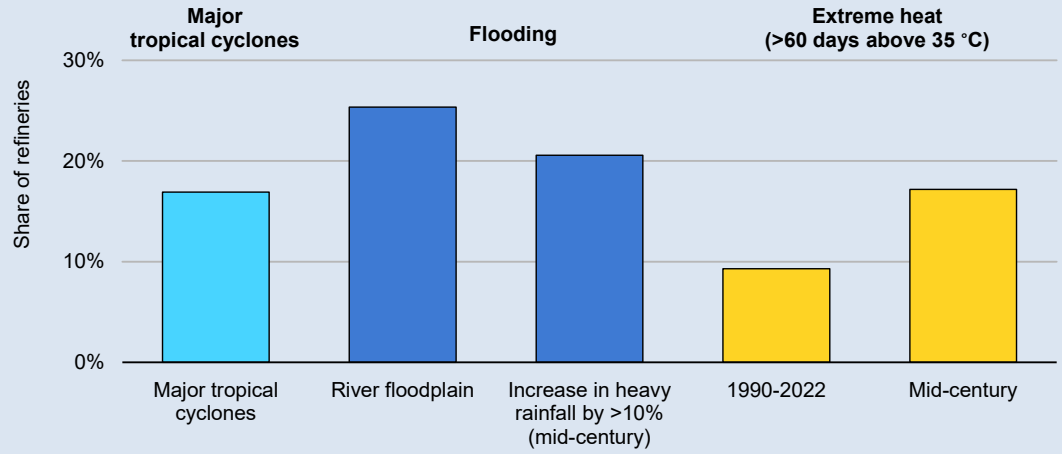
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reduction in the permissible vessel draught in the Paraná-Río de la Plata port system, including at Argentina's Port of Rosario. By the end of the century in the Around 3 °C scenario, 30% of ports in Central and South America are projected to experience a substantial decline in overall rainfall, potentially aggravating drought-related constraints.

Box 2.1 Extreme weather risks to coastal refineries

With around 40% of crude oil transported by sea, refineries are often built in close proximity to ports, optimising logistics for access to both imported crude oil and exported refined products. The IEA estimates that nearly 60% of global refining capacity is located within 20 kilometres of a coastline, and a third are situated close to the sea level. Coastal refineries often rely on marine terminals, where crude oil is unloaded from tankers into storage tanks or pipelines supplying the refinery, while refined products are also stored or loaded onto vessels. Ship-to-shore transfers are particularly sensitive to extreme weather: high winds, waves and storm conditions make berthing and mooring unsafe, leading to the suspension of cargo transfers, with vessels waiting offshore until conditions allow operations to resume.

Exposure of coastal refineries to weather-related hazards, present and mid-century (IPCC's Around 3 °C scenario)



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Notes: Assessment of refineries located within 20 km of a coastline. River flood and tropical cyclone exposure is assessed for a 1-in-500-year return period. Storm categories refer to the Saffir-Simpson Hurricane Wind Scale; major tropical cyclones are defined as events of Category 3, 4 or 5. Exposure assesses the presence of assets in areas that can be adversely affected by a hazard but does not enable conclusions to be drawn regarding the assets' vulnerability.

Sources: IEA analysis based on JRC (2024), Global River Flood Hazard Maps, Bloemendaal et al. (2023), STORM tropical cyclone wind speed return periods, and IPCC (2021), WGI Interactive Atlas.

Risk increases where refineries are geographically concentrated, because several refineries could be affected by a single extreme weather event. Such clustering of refineries, or a regional dependency on relatively few facilities, increases regional

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disruption risk. Nearly half of the United States' refining capacity is located on the Gulf Coast, and throughput is regularly affected when storms hit during the annual tropical cyclone season or the winter months. Refining flows were reduced by as much as a third in 2005 after several storms hit, with weeks needed to return to pre-event levels. Bangladesh's sole refinery on the coast at Chattogram experienced disruptions due cyclone-related port shutdowns in 2007 and 2020.

The IEA estimates that more than 15% of coastal refineries are exposed to a risk of major tropical cyclones and one-quarter to river or coastal flooding. Virtually all refineries in Japan, Korea, India and Mexico are exposed to tropical cyclones. While cyclone and flood risks are lower in the Middle East, half of coastal refineries have experienced more than 100 days of extreme heat per year since 1990. These risks may increase in the future. By the end of the century in the IPCC's Around 3 °C scenario, nearly 90% of refineries located in river floodplains could experience at least a 10% increase in heavy rainfall. By 2050, the share of refineries exposed to coastal flooding could rise from 8% to 14%, while coastal refineries in the Middle East could face up to 30 additional days of extreme heat per year.

Refineries have adopted measures to increase resilience to extreme weather events. Shutdown protocols, preparedness plans, and redundant power supply and generators are key measures to mitigate shocks. Elevating control rooms and electrical equipment also helps mitigate flood risk. Refiners can install cooling on tanks storing volatile liquids to reduce the activation of pressure relief systems, and redesign vacuum and cooling systems to cope with higher temperatures. Refiners may also strategically diversify new refining locations to reduce concentration risk.

Extreme heat is an increasing risk to port operations

Extreme heat can affect both port infrastructure and operations. High temperatures can soften pavements, which may then be damaged by heavy yard equipment. They can also cause thermal expansion of piers and steel components and deform railway tracks. Heat can restrict construction and maintenance activities and increase cooling requirements for buildings, machinery and electrical equipment, placing additional demand on supporting power systems. Mooring, loading and unloading facilities, handling equipment, warehouses and port hinterland infrastructure can also become increasingly vulnerable at high temperatures.

Fuel terminals face additional heat-related risks. Higher temperatures can increase evaporation from stored petroleum products and affect fuel transfer by raising the risk of pump cavitation. For LNG terminals, heat ingress into cryogenic storage tanks generates boil-off gas. At LNG liquefaction plants high ambient

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temperatures can reduce the efficiency of refrigeration and cooling systems and, at liquefaction plants, potentially constraining LNG production.

Historically, exposure to extreme heat has been concentrated in a relatively small number of ports and LNG terminals. IEA analysis shows that more than 90% of ports with tanker landings and more than 75% of operating LNG liquefaction capacity[4] experienced fewer than 10 days per year with temperatures of 35 °C or above on average between 1990 and 2022, while only around 50 ports and 15% of LNG liquefaction capacity experienced 60 days or more. Three-quarters of these ports and all of the LNG capacity are in the Middle East, where more than 40% of ports with tanker landings experienced over 100 days of extreme heat per year. As a result, facilities in this region are often designed to operate under high temperatures, using measures such as heat-resistant pavement materials and additional cooling or power capacity. Exposure to heat is projected to become considerably more widespread: by mid-century in the IPCC's Around 3 °C scenario, the number of ports experiencing temperatures of 35 °C or above for more than 60 days per year could nearly triple, extending into regions with historically limited exposure. Nearly a quarter of currently operating LNG liquefaction capacity is also projected to experience these conditions.

In addition to infrastructure resilience, protecting workers is important, as port activities frequently involve prolonged outdoor work and exposure to heat from machinery and paved surfaces. Ports already operating under very high temperatures provide examples of such measures: Dubai Ports Authority regulations explicitly recognise that wharf operations regularly take place above 40 °C and require measures such as limiting exposure time, job rotation, readily available drinking water, rest areas and medical facilities.

Economic impacts of weather-related disruption

Severe weather events frequently disrupt port operations. While most disruption is short-lived and has limited impact, major hazard events can cause extensive damage to port infrastructure, leading to prolonged operational interruptions, significant economic trade-related losses and substantial reconstruction and investment needs.

Port operations can experience substantial trade losses

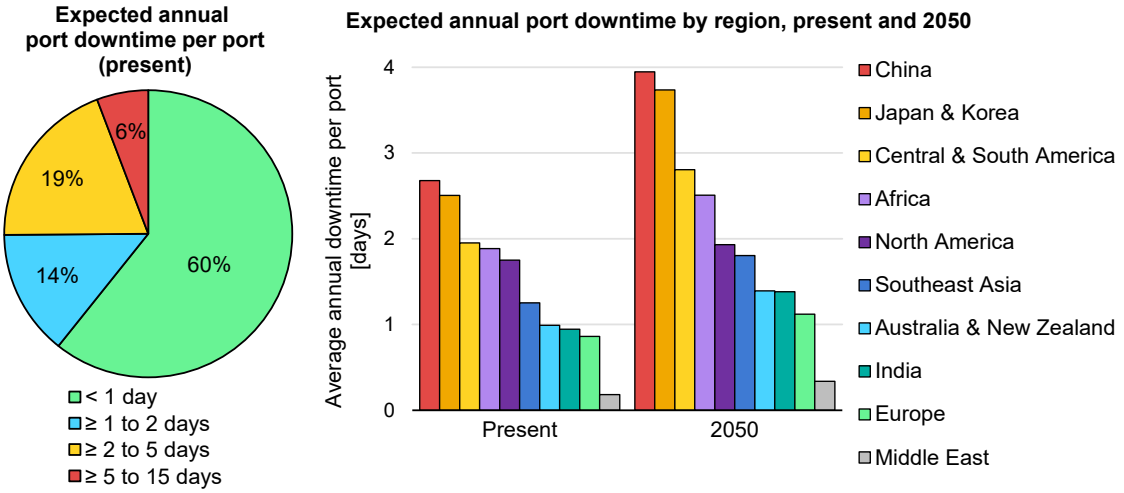
A study by Verschuur et al. assessed in 2023 the exposure of major ports worldwide to natural hazards and estimated the associated average annual

[4] This excludes Floating Liquefied Natural Gas (FLNG).

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weather-related downtime. IEA analysis shows that across the roughly 1 200 ports with at least one tanker landing per year, weather-related disruption amounts to around 1.5 days per port per year on average under present climate conditions (Figure 2.3). Overall, around 60% of assessed ports experience less than one day of weather-related downtime per year on average, while 25% are estimated to face between two and 15 days annually. Ports in China, Japan and Korea experience the highest levels of disruption, with average weather-related downtime exceeding 2.5 days per year due to their exposure to tropical cyclones, followed by ports in Central and South America at nearly two days per year. In Africa and Europe, disruption is more frequently driven by the exceedance of operational thresholds rather than physical damage to infrastructure.

Figure 2.3 Estimated average annual port downtime, by region, present and 2050



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Notes: Assessment of 1 204 ports that see at least one tanker landing per year on average. Estimates for 2050 are based on the IPCC's Around 3 °C scenario, projecting a global warming of around 3 °C by the end of the century.

Sources: IEA analysis based on Verschuur et al. (2023), Multi-Hazard Risk to Global Port Infrastructure and Resulting Trade and Logistics Losses and IMF PortWatch (2026), Ports (accessed 15 June 2026).

While the analysis suggests relatively short expected average downtimes, low-probability high-impact individual hazard events, such as tropical cyclones of categories 4 or 5, can have considerable impact, especially when reconstruction capacity is constrained. In 2003, Korea's Port of Busan was left inoperable for 91 days after Typhoon Maemi, and in 2019 China's Port of Wenzhou closed for 45 days due to flooding and landslides triggered by Typhoon Lekima. In 2017, Hurricane Harvey led to a full shutdown of the Port of Corpus Christi for 7 days. Such operational disruptions come with significant trade losses. For example, China's Port of Dalian lost about USD 13 million per day during its 5-day disruption in 2019 after Typhoon Lekima, and Australia's Port of Brisbane experienced a USD 52 million loss due to Cyclone Yasi in 2011. However, temporary disruption without substantial damage does not necessarily translate into annual port

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throughput losses. IEA analysis shows that between 2019 and 2026, commercial vessel landings at the Port of Houston and Port of Gwangyang were around 15% to 20% higher in the seven days following a weather-related disruption than during the seven days preceding it. Vessel traffic rebounded to clear backlogs once operations resumed, offsetting activity losses after short-term disruption.

Climate-related disruption to port operations is projected to increase through an intensification of extreme weather events in the future, if no additional resilience measures are taken. Analysis shows that an additional metre in storm surge height or 10 metres per second in wind speed is associated with a 2-day average increase in the duration of disruption. By 2050, estimated global downtime at affected ports could rise by around 35% in the Around 3 °C scenario. Ports in China, Japan and Korea are expected to continue experiencing the highest levels of downtime per port. Ports in Southeast Asia and India see a stronger increase in downtime than ports in North America or Europe.

Tropical cyclones are among the most damaging hazards

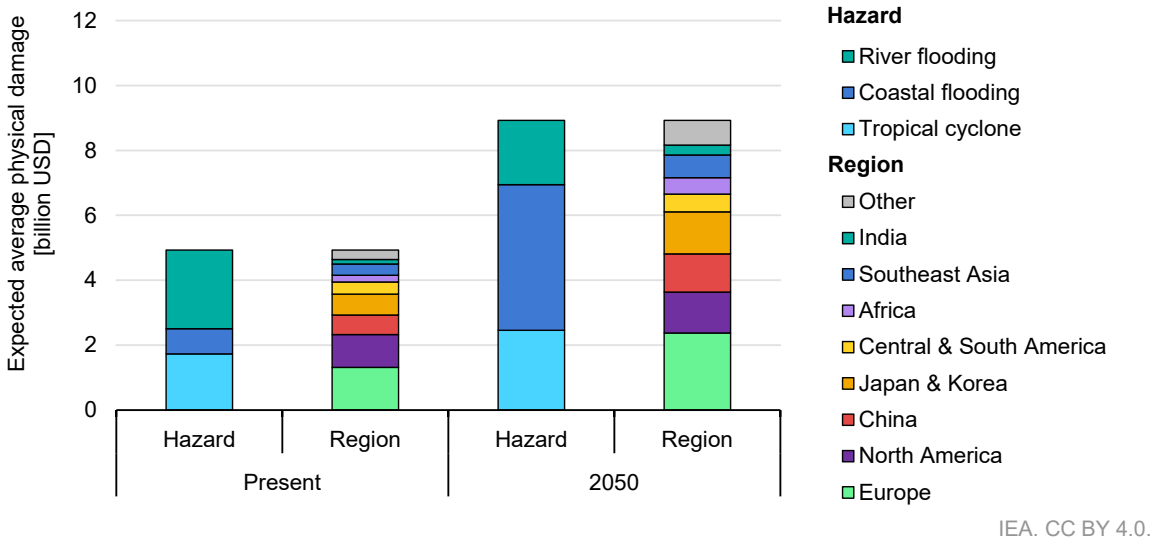
Major natural hazard events can cause extensive physical damage to port infrastructure, entailing substantial losses and reconstruction costs. Between 2015 and 2025, reported direct damage and reconstruction costs across 20 ports totalled USD 1.2 billion. Category-5 Hurricane Katrina in 2005 caused damage of USD 820 million to seven US Gulf Coast ports, making it one of the costliest hazard events reported in the past decades. Damage caused by the storm also resulted in a loss of around 1.5 mb/d of oil production and 2 mb/d of refining capacity, triggering an IEA emergency oil stock release of 60 million barrels over 30 days to the market.

Verschuur et al. estimated in 2023 expected annual costs due to weather-related physical damage. The research showed that across the roughly 1 200 ports with at least one tanker landing per year, weather-related annual physical damage would amount to about USD 5 billion in present climate conditions. Europe and North America account for nearly half of the expected average damage due to their large number of ports and high infrastructure value.

In line with operational disruptions, a warming climate is projected to increase hazard-related physical damage to ports if no additional resilience measures are taken (Figure 2.4). By 2050, physical damage-related average costs are expected to nearly double in the IPCC's Around 3 °C scenario. While river flooding accounts for half of today's estimated physical damage, under this scenario future sea-level rises and storm intensification would mean the impact of coastal flooding would become increasingly severe; by 2050, coastal flooding accounts for about half of the physical damage.

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Figure 2.4 Estimated average annual physical damage, by hazard and region, present and 2050



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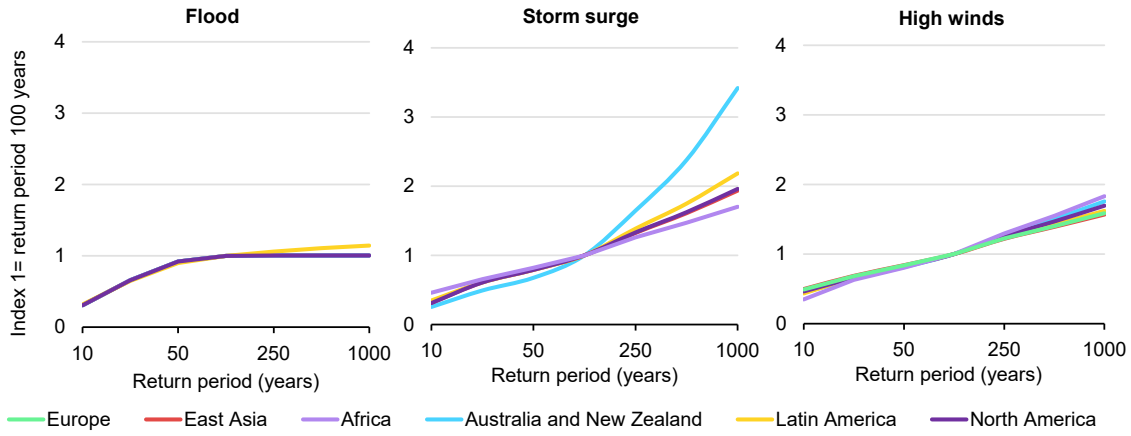
Notes: Assessment of 1 204 ports that see at least one tanker landing per year on average. Estimates for 2050 are based on the IPCC's Around 3 °C scenario, projecting a global warming of around 3 °C by the end of the century.

Sources: IEA analysis based on Verschuur et al. (2023), Multi-Hazard Risk to Global Port Infrastructure and Resulting Trade and Logistics Losses and IMF PortWatch (2026), Ports (accessed 15 June 2026).

While average annual damage estimates capture the expected long-run cost burden of weather-related hazards, they can mask the scale of losses from rare, high-impact events. Probable maximum loss (PML) estimates provide a complementary insight by indicating the level of loss associated with an extreme event that is only expected to occur once in a given return period, for example a 100-year event, which has a 1% annual probability of being exceeded. CDRI's GIRI estimates for port infrastructure show that the regional PMLs for floods rise rapidly at lower return periods but tend to level off beyond around 100 years, with the highest average losses in Latin and North America (Figure 2.5). By contrast, tropical cyclone (storm surge and high wind) losses continue to increase markedly at longer return periods, particularly in Australia and New Zealand, pointing to substantially greater tail risk from severe cyclone events.

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Figure 2.5 Probable maximum loss from flood, storm surge and wind for port infrastructure by region



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Notes: Probable Maximum Loss (PML) indicates the expected loss associated with a given return period. Regional values are the median of country-level PML estimates and do not necessarily correspond to regional PMLs.

Source: IEA analysis based on CDRI (2026), GIRI.

The impact of extreme weather on small islands can be severe

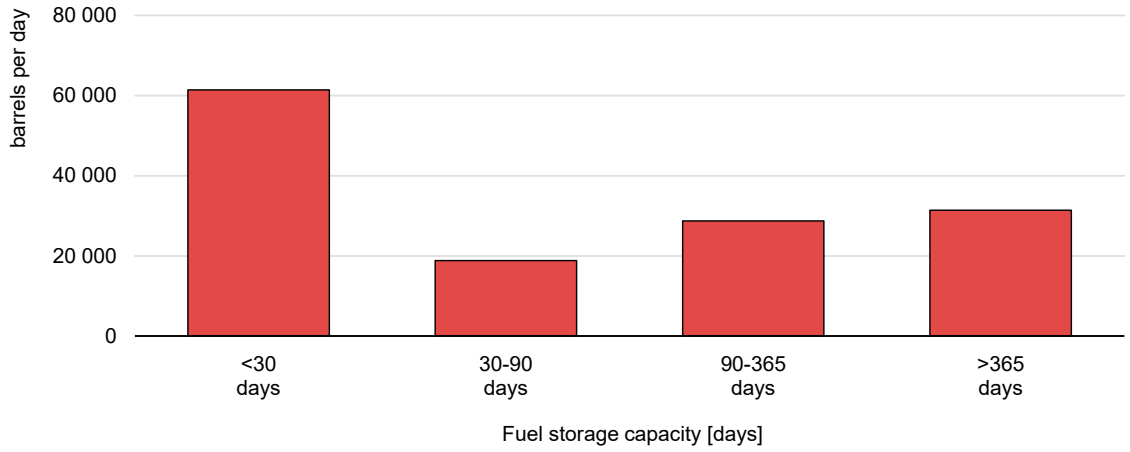
Fuel import-dependent islands that rely on only one or two isolated import terminals face substantial energy security risks because they often have no or limited developed local energy sources, instead relying on seaborne fuel imports to meet most or all of their energy needs. Due to these distinct characteristics, physical damage or operational disruption from natural hazards can quickly lead to severe fuel shortages with consequential impacts on island economies and populations. In addition, over 85% of small island economies assessed are developing economies, and they tend to have less established recovery processes, fiscal resources, and technical expertise available for disaster response and reconstruction.

The IEA assessed 76 fuel-importing small island economies that rely on one or two terminals and lack a mainland interconnection. Results indicate a strong reliance on diesel for power generation which, combined with limited fuel storage, emerges as a key issue – over 85% of the small island economies rely on imported fossil fuels for at least three-quarters of power generation, mostly diesel. At least thirteen of the 76 island economies studied hold less than 90 days fuel supply – below the IEA's oil stockholding benchmark for Member countries – while six hold as little as three weeks. These constraints can exacerbate the vulnerability of small islands, as port disruption caused by a natural hazard often creates additional logistical challenges for disaster response and recovery, including securing fuel for backup generation and delivering materials and equipment for infrastructure repair. During the 2010 Haiti earthquake, damage to unloading facilities at Haiti's

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main fuel terminal constrained tanker landings at a time when the country's fuel stocks stood at around two weeks of supply. The resulting shortage affected hospital generators, relief logistics, and broader emergency response.

Figure 2.6 Total oil consumption for small island economies, by fuel storage capacity groupings



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Note: Based on IEA dataset for 76 fuel-importing small island economies; some small island economies excluded due to data limitations.

Assessment of exposure to extreme weather events for ports of 76 small island economies indicates a notable risk from tropical cyclones. About 60% of the ports in small island economies are exposed to major tropical cyclones (Category 3 or higher) and nearly 40% face a risk of tropical cyclone conditions of Category 4. Most of the severely affected island ports are in the Asia-Pacific and the Caribbean, including the Northern Marina Islands, the Bahamas and Haiti. In addition, the assessment found that the ports in Fiji and the Solomon Islands are at risk of disruption by coastal flooding. Sea-level rise is projected to exacerbate this risk. The sea level around all small island economies is projected to rise by 17 to 29 cm by mid-century in the IPCC's Around 3 °C scenario compared to the 1995-2014 average.

Diversifying energy supplies and reducing reliance on seaborne fuel imports is central to mitigating the impact of extreme weather on energy security in small island economies. Accelerating the clean energy transition is one of the clearest pathways to achieving this. In recent decades, renewable deployment has accelerated across many island economies, helping to strengthen energy security. Many of these small islands have substantial solar potential, which can help displace imported oil products in power generation and support electrification. For instance, Palau's electricity generation was 97.5% diesel-based in 2019, with fuel imports accounting for 9.6% of GDP. Since then, Palau has commissioned a

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15.3-MW solar PV and 13.2-MWh battery project for USD 30 million and actively promoted rooftop solar installations. By 2024, solar PV accounted for 30% of Palau's electricity generation and the island has announced its ambition to entirely switch to renewables by 2050, eliminating reliance on imported fuels. In addition to investing in renewable energy sources to enhance energy security, small island economies also need to invest in port resilience measures to better absorb shocks from extreme weather events.

Strengthening seaport resilience to weather-related hazards

Building the capacity to anticipate, withstand, respond to and recover from weather-related disruptions is essential for the management of weather-related risks to ports. Port owners and public authorities are increasingly integrating climate resilience into their strategies. Terminal operators have an interest in minimising disruption to their infrastructure. Investment in risk management, resilient infrastructure and emergency preparedness is a key part of future-proofing ports and the wider maritime supply chain against rising extreme weather risk.

Framework for strengthening resilience

Port infrastructure resilience refers to a port's capacity to maintain an acceptable level of service for ships, cargo and customers. Resilience can be defined along four inherent capacities, presented here in the context of risks from weather-related hazards:

- **Anticipate:** The ability of relevant stakeholders to anticipate potential risks and impacts of disruption. Improved access to weather data and forecasts can support this, especially when port authorities are able to respond to the forecasts by taking action to mitigate asset exposure. Consideration of climate projections can support long-term readiness planning.
- **Withstand:** The physical ability of assets to withstand impacts from extreme weather events. This may be through asset hardening such as flood defences, or operational changes.
- **Respond:** The ability to maintain operations at a similar level of service during and after disruption, such as through disaster response plans. This includes flexibility and agility to adjust operations and contain failures which may in turn limit cascading effects.
- **Recover:** The ability to rapidly restore normal operations after a disruption.

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Over recent years, multiple international initiatives have developed comprehensive frameworks to guide port operators and policy makers in strengthening the resilience of their infrastructure, including a guidebook and best practice case studies by the United Nations Resilient Maritime Logistics. The World Association of Waterborne Transport Infrastructure and the initiative Resilience4Ports from the International Coalition for Sustainable Infrastructure publish industry guidance on climate resilience and adaptation.

Measures to strengthen port resilience

In many countries, public authorities have started incorporating resilience requirements into regulations, and port operators are implementing targeted measures to protect their assets and operations against extreme weather events and the evolving climate. Table 2.1 summarises some examples of the different types of resilience measures that port operators can develop and invest in.

Overview of seaport resilience measures

Type	Examples of port resilience measures
Governance Implementing policies, regulations and standards to support resilience	• Comprehensive port-level resilience framework • Disaster and emergency plans • Natural hazard risk and climate resilience assessments • Asset insurance coverage • Mutual aid agreements with neighbouring ports and emergency services
Monitoring Anticipating threats and understanding the strain on assets	• Publicly available, real-time weather data • Early-warning systems • Environmental sensors • Digital asset twins • Structural-health sensors • AI-based predictive maintenance systems
Operational Putting in place procedures for management of a system or asset	• On-site power generation; island grid system • Standardised, interchangeable equipment components • Stockpile critical spare parts • Oil-spill preparedness and response • Safe shutdown procedures • Workforce cross-training
Hardening Increasing the robustness of structures and systems	• Breakwaters and wave-attenuation structures • Underground power and communication lines • Upgrade drainage and pumping capacity • Weather-proof equipment enclosures and structures • Mandated asset design standards

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Type	Examples of port resilience measures
	• Floodplain widening (nature-based solution) • Restoration or building of coastal buffers (nature-based solution) • Islands/wetlands creation from dredged sediment (nature-based solution)
System design Improving the system's configuration and architecture	• Alternative transport corridors / rerouting options • Spare berth and terminal capacity • Setback and managed-retreat zones • Redundant communication and navigation systems

Building resilience capabilities requires developing and regularly updating comprehensive port-level resilience frameworks. This includes priority areas and timeframes as well as disaster and emergency management plans with clearly defined responsibilities. For instance, Japan's Port of Yokohama, Port of Kobe and Port of Nagoya have developed disaster and emergency action plans, which were enacted following damage and disruption from tropical cyclones and flooding. The US Port of Long Beach published a Climate Adaptation and Coastal Resiliency Plan, evaluating impacts that evolving weather regimes may have on coastal infrastructure, transportation networks and critical facilities, including utilities. It identifies five priority strategies and distinguishes near- and medium-term actions, including new port policies and design guidance, sea-level rise assessments, and flood studies for development permits. To anticipate and prepare for shocks, improved hazard monitoring capabilities using publicly available, real-time weather data and the adoption of early-warning systems are key. Automated monitoring of assets improves damage detection and helps the recovery process. For example, the Netherlands' Port of Rotterdam operates a public Weather & Tide dashboard with current and forecast water levels, currents, wind, visibility and water depths, in combination with an automated asset monitoring system that uses sensors and satellite information. Regional resilience can be strengthened through regional cooperation across ports, with some plans in place, such as for southern California and Hawaii.

Operational resilience can be strengthened by adding redundancy, modularity and failure containment for critical systems, equipment and the workforce. This includes measures such as stockpiling critical spare parts, standardising interchangeable equipment components and cross-training staff across different roles. Fail-safe operations can be achieved through compartmentalising systems, on-site power generation and island grid systems, oil-spill preparedness and shutdown protocols. For example, the US Port of Houston's Hurricane Preparedness Procedures, implemented in the aftermath of lessons learnt from Hurricane Harvey, contain clear requirements for inventories of emergency supplies and establishes staged shutdown thresholds.

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Physical hardening of assets can help withstand exposure to greater levels of extreme weather. Asset robustness can be enhanced through mandated design standards and investments in the hardening of port structures and electricity supply. The Netherlands' Port of Rotterdam is protected through a movable storm-surge barrier and has incorporated flood resilience in recent major port expansion through land elevation, water-robust layouts and enhanced protection requirements for terminals and critical assets. The US' Port Authority of New York and New Jersey implemented a flood protection programme in the wake of lessons learnt from the impact of Hurricane Sandy in 2013. Australia's Port of Townsville and the US Port of Tampa Bay built protection walls and buildings, designed to withstand tropical cyclones and storm surges. In addition, nature-based solutions help to mitigate a port's hazard-level exposure to river and coastal flooding, by leveraging natural processes and ecosystems. For instance, Kenya's Port of Mombasa included mangrove restoration in their Green Port Policy to reduce coastal erosion and flooding.

Finally, resilience needs to be integrated into a port operation's system design by creating redundancy through alternative communication and navigation systems, as well as additional transport corridors and rerouting options. For example, Japan's Port of Kobe has a target to restore at least one berth and transport route on each of two separate port islands (Port Island and Rokko Island) within three days.

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3. Extreme weather risks to shipping routes

The routes taken by international oil and natural gas shipping use maritime and inland waterways. Both face exposure to extreme weather hazards that could impact shipping. This section outlines the key risks and the characteristics of route vulnerabilities to these hazards. It considers established, year-round routes and presents case studies on notable weak points: the Panama Canal and River Rhine.

Route concentrations increase vulnerability

The impact of extreme weather hazards on international oil and gas shipping routes depends on location, the characteristics of the route, and the availability of alternative routes. In common with port infrastructure, there can be greater impact from adverse weather when routes are concentrated together. Vulnerability to extreme weather is magnified where there are limited or no alternative route options, such as passages through chokepoints and along inland waterways.

Storms, fog and low water levels present hazards

On the open sea, ships have the choice of the exact route taken to reach their destination port. Generally, vessel operators choose a straight-line route and optimised speed according to fuel consumption, travel time and cargo scheduling. However, under adverse weather conditions, vessels have the option to alter course or speed to manage, avoid or wait out the passage of poor conditions, even if that incurs longer journey times or disruption to the overall fleet schedule. For instance, operators assume several additional days for an Atlantic crossing in winter compared to summer months, as seasonal heavy seas slow vessels.

However, in the case of routes passing through chokepoints and inland waterways, options for alternative vectors are limited or non-existent, since vessels are channelled through narrow bodies of water. With no other choice, any disruption to navigability of the route from extreme weather events has more impact.

There are three key weather hazards that have the potential to disrupt shipping routes: storms, such as severe winter storms or tropical cyclones that bring hazardous conditions through high winds and heavy seas; droughts which can lead to low water levels on inland waterways; and fog which can disrupt due to lower visibility.

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Dense fog in particular can make channels difficult to navigate and increases the risk for vessel collisions. The Turkish Straits, providing passage from the Mediterranean to Black seas, is regularly disrupted by dense fog. Impacts are for relatively short periods of time – typically in the order of hours. Seaports on the United States Gulf Coast are similarly affected. The Port of Houston experienced disruption of 3-4 days per year between 2019 and 2025 due to dense fog forming over its access channel.

In general, the economic impact of shipping disruption due to weather events relates to shipping delays rather than physical damage. Vessel losses are relatively rare but do occur – between 2015 and 2024, 19 crude oil, LNG and LPG tankers were reported as lost. Severe weather conditions such as storms and fog can heighten the risk of collisions and elevate the consequences of equipment malfunctions and human negligence to become greater security threats for crew, cargo and vessel. Recent examples include the Tresta Star's grounding during a tropical cyclone near La Réunion in 2022 and the foundering of the MT Terra Nova during strong winds and high waves in Manila Bay in 2024 – which caused an oil spill of 1 500 metric tonnes.

Tropical cyclones are a key disruption risk

Storms, of which tropical cyclones can be a potent variety, may bring adverse shipping conditions as winds challenge vessel operations and manoeuvrability, and whip up waves leading to rough seas. These conditions can impact all shipping activities, whether maritime or inland. However tropical cyclones tend to be most powerful when offshore, typically losing their energy once they make landfall. To avoid tropical cyclones ships may divert or delay passage, but options to do this are limited if the voyage includes a region with few route options, such as a strait.

The Luzon Strait is a strategic maritime chokepoint between northern Luzon (Philippines) and Chinese Taipei that is regularly disrupted by tropical cyclones. Approximately 250 kilometres wide, it connects the Philippine Sea in the western Pacific to the South China Sea, forming part of the main trans-Pacific corridor used by ships travelling between the Americas and major East Asian ports. The strait supports access to major ports including Hong Kong, Shanghai (China), Busan (Korea), and Yokohama (Japan). In 2023, 19% of global maritime trade passed through it, and on average, 70 vessels totalling 4.3 million metric tons transit the Luzon Strait per day. Tankers account for 35% of transits, making mineral products the strait's top traded commodity.

Due to the Luzon Strait's location, transiting vessels face a high exposure risk to tropical cyclones. Since November 2020, the strait experienced 25 days with vessel transits at least 80% below the average. Tropical storms or cyclones were

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the main cause of all transit disruption. Their impact varies from year to year according to storm numbers, intensity and tracks. In 2019 and 2022 no significant disruption was recorded; yet the strait was heavily disrupted between August and November 2024, experiencing nine days of sharply reduced vessel transits. In some instances, transits are halted for whole days, such as during tropical cyclones Ragasa in September 2025, and Maring in October 2021. Vessel transit typically rebounds two days after a cyclone has exited the region, with the strait seeing two to three times typical traffic as a backlog clears.

Table 3.1 Disruption on the Luzon Strait due to tropical cyclones

Tropical cyclone	Time period	Days of disruptions	Transit disruption
Siony	Nov 2020	1	87%
Chanthu (Kiko)	Sep 2021	1	87%
Kompasu (Maring)	Oct 2021	1	100%
Betty	May 2023	3	91%
Doksuri (Egay)	Jul 2023	2	96%
Saola (Goring)	Aug 2023	2	82%
Jenny	Oct 2023	1	83%
Dindo	Aug 2024	1	83%
Krathon (Julian)	Sep 2024	3	90%
Kong-Rey (Leon)	Oct 2024	2	93%
Yinxing (Marce)	Nov 2024	2	84%
Man-Yi	Nov 2024	1	90%
Whipa (Crising)	Jul 2025	1	83%
Ragasa	Sep 2025	1	100%
Fung-Wong	Nov 2025	3	92%

Note: Days of disruption are defined as days with vessel transits being ≤ 20% of the average vessel transit per day.
Source: IEA analysis based on IMF PortWatch (2026), Luzon Strait (accessed 15 March 2026).

Drought risk to the Panama Canal

Linking the Atlantic and Pacific oceans, the Panama Canal has served since 1914 as an important shortcut for maritime routes between East Asia and the US East Coast, as well as the west coasts of North and South America and Europe – around 3% of global oil supply transited through this chokepoint in 2025. The canal crosses the Isthmus of Panama using a series of locks that lift vessels over the continental divide. A major expansion was completed in June 2016, opening a third set of locks and creating a new lane for larger vessels, known as

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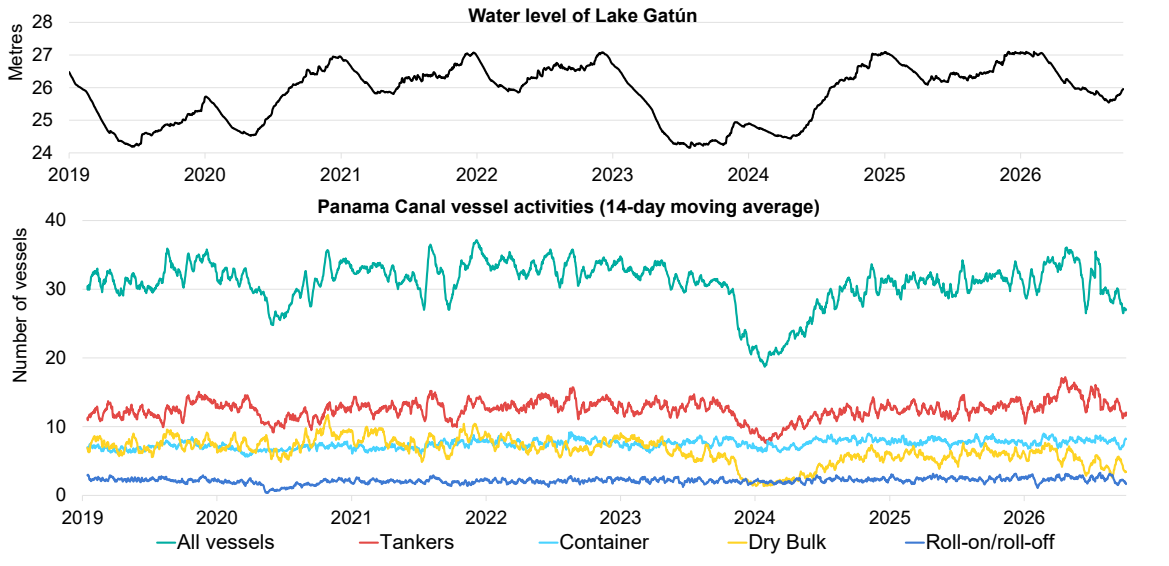
Neo-Panamax ships. The expansion opened up options for tanker routes and led to the rerouting of most eligible LPG carriers sailing from North America to Asia through the Panama Canal, instead of around the Cape of Good Hope (Africa).

Droughts limit the Panama Canal's throughput

Navigability of the Panama Canal depends on availability of water from two reservoirs to operate its locks: Lake Gatún (5.2 km^3), which is part of the waterway, and nearby Lake Alajuela (0.6 km^3). Canal transits comprise the dominant water demand on these reservoirs. Most water used during lock operation is subsequently discharged to the ocean, amounting to about 250 million litres per vessel transit. When droughts cause reservoir levels to drop, the Panama Canal Authority (ACP) reduces the number of ship transits per day. Furthermore, toll surcharges are applied when Gatún Lake water levels lie outside defined thresholds.

During El Niño events, the region tends to experience lower rainfall. A severe drought in 2023 coincided with an El Niño event and reduced transits in 2024 by around a third. In contrast to container ships, tankers and dry bulk carriers reduced transits significantly during this period, indicating greater sensitivity to paying sharp increases in canal tolls (Figure 3.1). A strong El Niño event was forecast for 2026-2027 and in September 2026, the ACP reduced transit capacity from 36 per day to 32 in response to drought conditions. Restricted capacity has economic implications for all traffic seeking transit – an LPG tanker bid a record USD 5.3 million for priority passage in September 2026.

Figure 3.1 Panama Canal vessel transits and Lake Gatún water levels, 2019-2026



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Sources: IEA analysis based on IMF PortWatch (2026), Panama Canal; ACP (2026), Gatun Water Level Indicators, (accessed 10 October 2026).

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Changing weather patterns are likely to intensify droughts

Recent drought-induced transit reductions have raised concerns regarding water levels under projected rainfall and temperature regimes. Recent research finds that under fixed transits, minimum annual lake levels may decline substantially until the end of the century under pathways projecting a global temperature rise of 3 °C or more by the end of the century. In these scenarios, declines in Gatún Lake water levels could amount to 0.3 to 0.4 metres (m) (1.2 to 1.5%), with end-century annual minima around 25.3 m, driven mainly by large deficits of wet-season rainfall and secondarily by higher evaporation in a warmer climate.

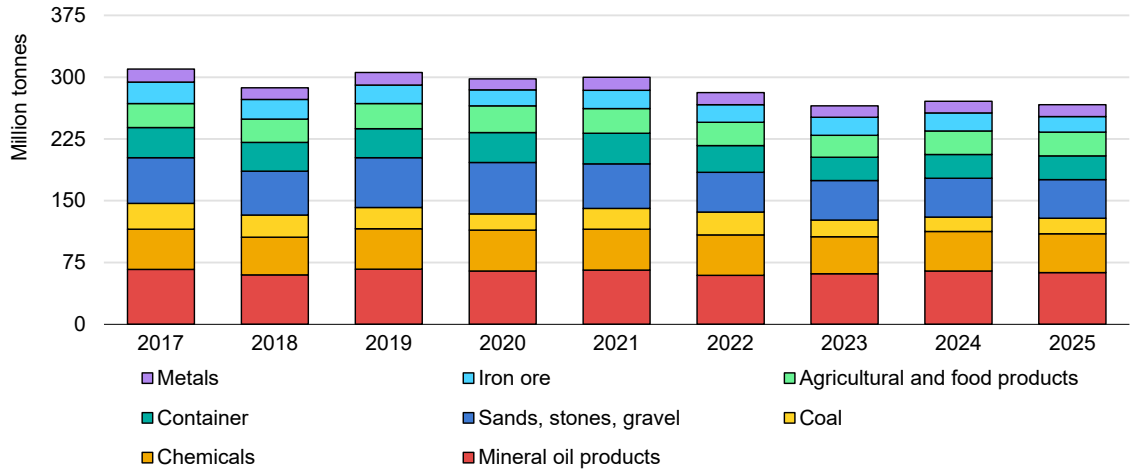
In light of recent droughts and climate projections, the ACP and governments of neighbouring countries are advancing major infrastructure projects to provide alternatives to transport cargo and fuels across the isthmus. The ACP is planning the construction of a new reservoir in western Panama known as the Río Indio project. It will provide an additional water source for canal operations at an estimated USD 1.6 billion. In 2025, ACP launched the construction of a 2.5-million-barrel-per-day LPG pipeline. This new project is expected to cost USD 4-8 billion and has a projected completion date of 2031. Elsewhere, Mexico is investing in the 309-kilometre Trans-Isthmus Railroad, intended to provide an alternative route to the Panama Canal by connecting Pacific and Gulf ports.

Drought risk to the River Rhine

In addition to maritime routes, inland waterways provide important transportation routes for fuel shipping. For instance, the River Rhine is a backbone of European industry and one of the continent's most important freight corridors. Stretching around 1 230 kilometres from the Swiss Alps to the North Sea, the river crosses or borders six countries and connects major industrial centres along the Basel-Rotterdam axis with the ports of Rotterdam and Antwerp, and global markets. In particular, the German Rhine corridor hosts major steel, chemical and petroleum-refining clusters, whose supply chains depend heavily on inland waterway transport for both raw materials and finished products. Around 285 million tonnes of goods were transported on the Rhine in 2024 with mineral oil products accounting for 23%, chemicals for 17% and coal for 6% (Figure 3.2). Between 2020 and 2024, nearly 30% of Germany's refined oil product imports were shipped on the Rhine.

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Figure 3.2 Transport volume on the Rhine: main cargo segments, 2017-2025



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Note: Container is defined as weight of cargo in container.
Sources: IEA analysis based on CCNR (2025), Statistical Annex.

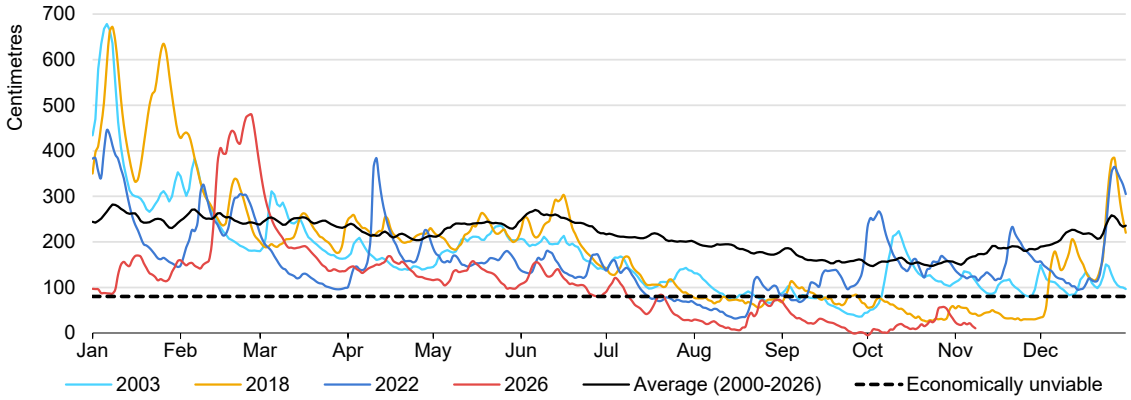
Droughts affecting the Rhine have economic impacts

In recent years, recurrent droughts and periods of low water have increasingly constrained commodity transport on the Rhine. The Kaub river gauge, located in the central section of Germany's Middle Rhine, lies close to one of the river's most important hydrological chokepoints and is widely used as an indicator of navigability conditions along this section of the Rhine. Between 2015 and 2025, more than 10 million tonnes of oil products and gas passed Kaub each year on average, accounting for close to 40% of total freight transported along the Middle Rhine.

Lower waters reduce navigable channel depth, which can in turn substantially reduce the carrying capacity of vessels well before navigation becomes physically impossible. In six individual years since 2000, the water level measured at Kaub has remained below 80 cm for more than 30 days. At this level, in order to comply with shipowners 'under keel clearance' policies, standard shipping contracts may no longer oblige carriers to transport cargo. At around this level, a typical Rhine tanker barge may be able to carry only 20-30% of its maximum load, sharply increasing transport costs. In particularly severe drought years – 2003, 2018, 2022 and 2026 – measured water levels at the Kaub gauge fell below 40 cm. This is equivalent to a fairway depth of about 1.5 m, a level at which navigation becomes extremely constrained such that conventional barges may no longer be able to operate. Extremely low water levels generally occur during and following summer droughts, from July to November (Figure 3.3).

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Figure 3.3 Measured water level at Kaub in years of severe drought compared to the average, 2000-2026



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Notes: "Economically unviable" is defined as a measured water level of below 80 cm at Kaub, a level at which an average tanker barge can only carry 20-30% of its maximum load and standard shipping contracts may no longer oblige carriers to transport cargo.

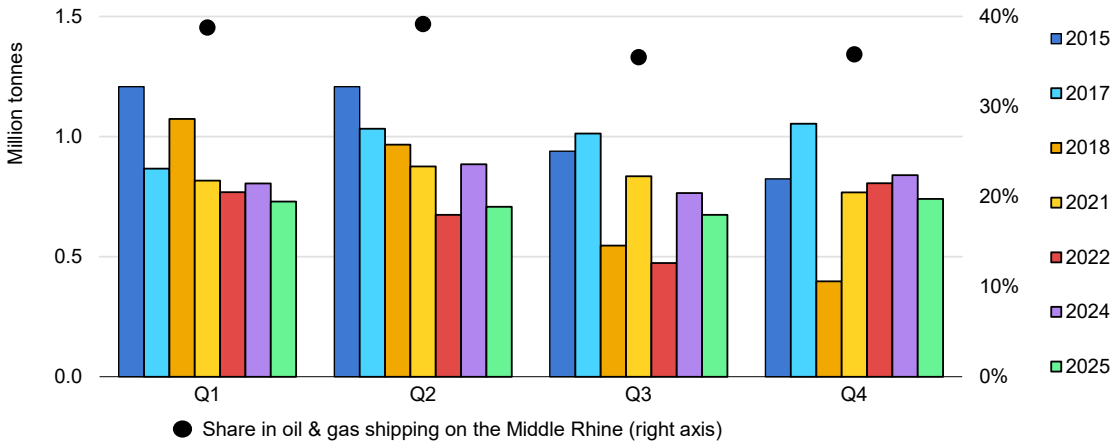
Sources: IEA analysis based on WSV (2026), PegelOnline: Stammdaten Kaub (accessed 09 November 2026).

The drought of 2018 illustrates the scale of this type of disruption. Water levels at Kaub remained so low that cargo transport was economically challenging for almost four months, including around one month during which navigation by conventional barges was severely restricted. The resulting disruption was visible in freight volumes: total commodity transport on the Rhine declined by around 8% compared with 2017, while shipments of oil and gas products passing Kaub fell by about 24% (Figure 3.4).

The most recent drought affecting the Middle Rhine began in July 2026 and was still ongoing in mid-November. The drought has caused water levels to fall to record lows, although full economic consequences will only become clear later in the year. From mid-July to mid-November 2026, water levels at Kaub remained below economically viable thresholds. For three months, the river depth fell to levels that were effectively impassable for conventional tanker barges. Estimates suggest that already 30 days of low-water conditions can reduce German industrial production by around 1%. At the peak of the 2018 low-water episode (in November) industrial production was estimated to have been reduced by around 1.5%, corresponding to a decline in German GDP of close to 0.4%.

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Figure 3.4 Volumes of oil products and gas passing through Kaub by quarter, 2015-2025



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Sources: IEA analysis based on Destatis (2026), Datensätze zum Güterverkehr in der Schifffahrt (accessed 20 August 2026).

Limited rerouting capacity contributes to cascading economic impacts

Limited rerouting capacity can amplify the economic impact of Rhine droughts. As falling water levels reduce vessel loading capacity to limit ship draught, industries initially seek to maintain river transport by using more vessels or specialised low-draught barges, but the limited availability of such vessels can eventually force cargo onto road and rail. In late-July 2026, for example, Rhine cargo vessels were operating at around 20% of normal capacity, requiring four to five vessels to transport volumes normally carried by one fully loaded barge.

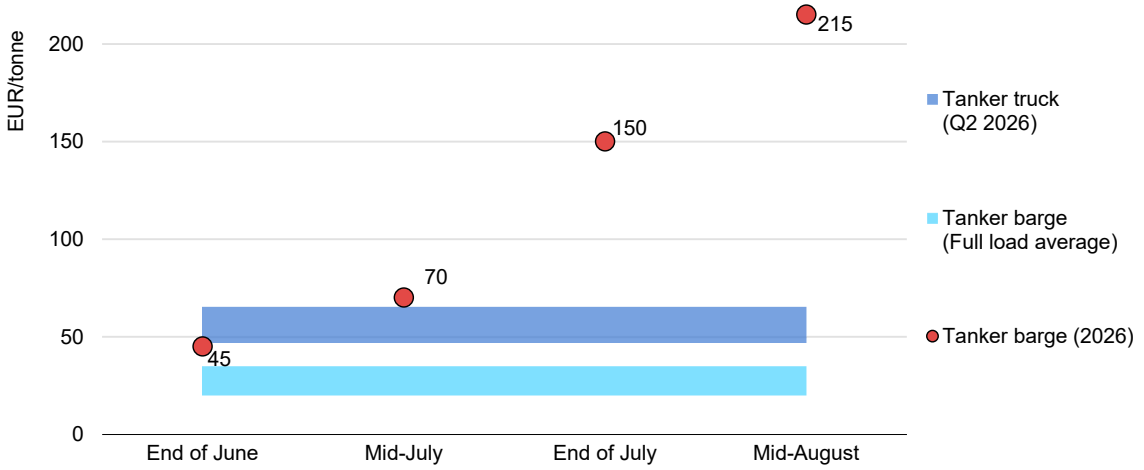
This scarcity was reflected in tanker-barge freight rates between Rotterdam and Karlsruhe, which increased from around EUR 45 per tonne at the end of June to EUR 150-160 per tonne at the end of July and reportedly reached around EUR 215 per tonne in mid-August (Figure 3.5). By late-July, these rates were already exceeding estimated freight rates for road-tanker transport, strengthening the economic incentive to divert suitable cargo to alternative modes where capacity was available.

In practice, however, road and rail can replace only a fraction of disrupted Rhine volumes at short notice. For instance, it requires about 100 tanker trucks to replace an average fully loaded tanker barge of around 2 550 tonnes. Constraints include the limited availability of specialised vehicles and rail capacity, as well as the large number of individual movements and additional loading and unloading operations required to replace high-volume barge transport. To facilitate rerouting and ease capacity constraints, in August 2026 France and several German states along the

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Rhine temporarily suspended Sunday and public-holiday restrictions for tanker truck movements associated with Rhine low water.

Figure 3.5 Tanker barge and tanker truck freight rates for Rotterdam to Karlsruhe



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Note: Freight rates presented do not reflect additional costs such as loading/unloading charges, terminal fees, waiting times or cargo insurance.

Sources: IEA analysis based on DataPorturia (2026), Rhine River in Germany Reaches Critical Navigability Levels; Reuters (2026), Low water hampers Rhine river shipping in Germany; OilPrice (2026), Europe Dodges a Rhine Crisis; PressePortal (2026), Transportbarometer.

Where additional road and rail capacity is insufficient, low Rhine water levels can spread from a transport disruption into shortages of industrial inputs and, ultimately, curtailed production. Refineries and chemical plants are particularly exposed as they continuously handle large volumes of bulk liquids that are difficult to reroute at short notice. For refineries, the main vulnerability is not necessarily crude supply, which in Germany is largely pipeline-based, but the movement of intermediate feedstocks, blending components and finished products. For instance, at MiRO Karlsruhe (310 000 b/d capacity), crude oil arrives via the Transalpine Pipeline, while around one-quarter of refinery products leave the site by waterway. The ongoing 2026 drought illustrates these constraints. Restricted Rhine movements limited MiRO's ability to ship surplus gasoline, diesel and heating oil towards the Netherlands and Switzerland, leading suppliers to lower truck-loading prices around Karlsruhe – upstream of the Kaub chokepoint – while fuel markets farther downstream tightened. These logistical bottlenecks were reflected in retail prices: in mid-August 2026, diesel and gasoline prices in several Rhine states were more than EUR 0.08 per litre higher than in other regions. At the same time, eastern France temporarily faced fuel supply shortages. Around 14% of filling stations in the Grand Est experienced supply difficulties for gasoline and diesel, with particularly strong pressures in Alsace and the Vosges.

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Similar effects were observed in the region during the severe 2018 drought, leading Switzerland and Germany to release oil stocks in November 2018, as rail and pipeline deliveries could not fully compensate for reduced Rhine imports. Germany released 70 000 tonnes of gasoline, 150 000 tonnes of diesel and 56 000 tonnes of kerosene from strategic stocks; Switzerland released compulsory stocks, including a further 63 000 tonnes of diesel and 26 000 tonnes of gasoline.

Changing weather patterns are projected to reduce the Rhine's navigability

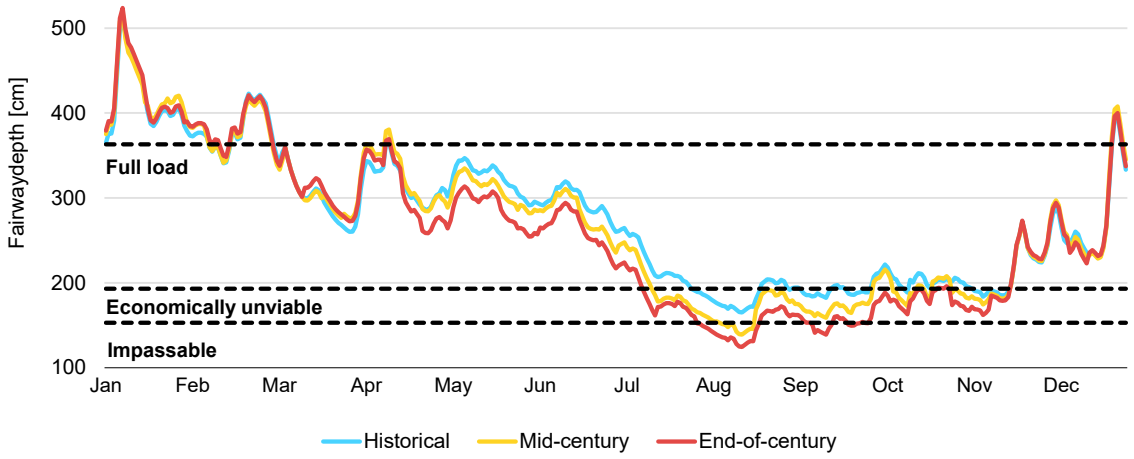
Changing precipitation and temperature patterns are likely to heighten the risk of low water levels on the Rhine and could further reduce the river's navigability in the next decades. Research finds that the Rhine shifts towards a regime less influenced by snow and glacial melt and more dominated by variations in rainfall by the end of the century, leading to higher winter and lower summer flows. As a result, seasonal extreme water levels on the Rhine are likely to intensify.

IEA analysis shows how these trends could translate into reduced navigability. During a drought year[5] mid-century, economically unviable conditions for tanker traffic around Kaub on the Middle Rhine could persist for nearly three months, while the number of days with impassable conditions could increase by 50% to more than a month per year. Conditions during a drought year could deteriorate further towards the end of the century, with economically difficult navigation exceeding 110 days and severe navigability restrictions occurring for around 60 days per year. Declines in water levels relative to recent drought years are projected to be most pronounced between July and September – historically months with the lowest water levels – reaching more than 10% by mid-century and nearly 20% by the end of the century (Figure 3.6).

[5] In this analysis, a drought year is defined as a year during which measured water levels at Kaub fell below 80 cm for more than 30 days.

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Figure 3.6 Navigability conditions around Kaub, Middle Rhine during a drought year, historical average and in the IPCC's Above 3 °C scenario



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Notes: The fairway depth is defined as the water level measured at Kaub plus 113 cm. "Impassable" is defined as a measured water level of below 40 cm at Kaub, a level at which conventional barges can no longer operate, and commercial shipping is severely restricted. "Economically unviable" is defined as a measured water level of below 80 cm at Kaub, a level at which an average tanker barge can only carry 20-30% of its maximum load and standard shipping contracts may no longer oblige carriers to transport cargo. A drought year is defined as a year during which measured water levels at Kaub fell below 80 cm for more than 30 days; the historical average comprises 2015, 2018, 2022 and 2026 (until 14 October).

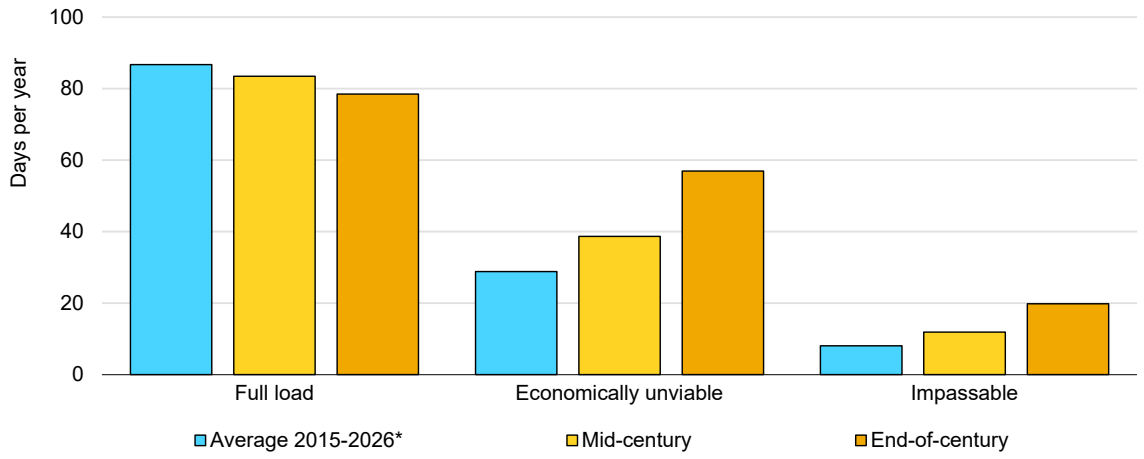
Sources: IEA analysis based on WSV (2026), PegelOnline: Stammdaten Kaub (accessed 14 October 2026).

The evolving climate could increase the frequency of drought years. Between 2015 and 2026, Kaub experienced on average around three months during which tankers were able to pass fully loaded and one month of economically difficult conditions. By the end of the century in the IPCC scenario associated with a global warming of above 3 °C[6], the number of days with water levels of below the economically viable threshold could double to nearly two months (Figure 3.7).

[6] IPCC's Above 3 °C scenario refers to the Shared Socioeconomic Pathway 3 – 7.0 (SSP3-7.0).

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Figure 3.7 Navigability conditions around Kaub, Middle Rhine, historical average and in the IPCC's Above 3 °C scenario



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* 2026 includes data until 14 October.

Notes: "Impassable" is defined as a measured water level of below 40 cm at Kaub, a level at which conventional barges can no longer operate and commercial shipping is severely restricted. "Economically unviable" is defined as a measured water level of below 80 cm at Kaub, a level at which an average tanker barge can only carry 20-30% of its maximum load and standard shipping contracts may no longer oblige carriers to transport cargo.

Sources: IEA analysis based on PegelOnline (2026), Stammdaten Kaub (accessed 14 October 2026).

These risks can be partly mitigated through a combination of vessel, infrastructure and logistics measures. Ship operators can deploy shallow-draught vessels or retrofit existing barges to retain more carrying capacity during low water, while shippers can increase inventories, secure low-water vessel capacity and prepare rail and road alternatives for critical cargoes. Public authorities can support these efforts through improved water-level forecasts and real-time navigation information, alongside targeted measures to increase available water depth at critical bottlenecks. For instance, the Middle Rhine Fairway Optimisation Project, launched in November 2025, aims at increasing fairway depth at constrained sections from 1.90 m to 2.10 m, with completion of the wider project targeted for 2033. At the same time, industrial electrification and Europe's transition to low-emission energy sources is expected to reduce demand for fuel transport on the Rhine. The German 2040 transport forecast in 2025 estimates overall cargo crossing the Lower Rhine to decline by 21%. Mineral oil products and gas are projected to decline from around 21 Mt in 2019 to 9 Mt in 2040, a reduction of nearly 60%, although these products would still account for around 9% of total freight. Lower fuel transport demand can offset the reduction in annual navigation capacity. However, this does not remove the risk of temporary bottlenecks as low water restrictions are projected to be concentrated in summer months and could sharply reduce vessel loads for several consecutive weeks.

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Annex

Abbreviations and acronyms

ACP	Panama Canal Authority
AI	artificial intelligence
ANGEA	Asia Natural Gas & Energy Association
AUS & NZL	Australia and New Zealand,
CSAM	Central and South America
CCNR	Central Commission for the Navigation of the Rhine
CDRI	Coalition for Disaster Resilient Infrastructure
CPS	Current Policies Scenario
EIA	Energy Information Administration (United States)
EUR	euro
FLNG	floating liquefied natural gas
FPSO	floating production, storage and offloading
FSO	floating storage and offloading
G7	Group of seven
GDP	gross domestic product
GIIGNL	Groupe International des Importateurs de Gaz Naturel Liquéfié (International Group of Liquefied Natural Gas Importers)
GIRI	Global Infrastructure Risk Model and Resilience Index
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
LNG	liquefied natural gas
LPG	liquefied petroleum gas
PML	probable maximum loss
PV	photovoltaic
RoW	rest of world
STEPS	Stated Policies Scenario
USD	United States dollar
UNDRR	United Nations Office for Disaster Risk Reduction
WSV	Wasserstraßen- und Schifffahrtsverwaltung des Bundes (German Federal Waterways and Shipping Administration)
WRI	World Resources Institute

Glossary

bcm	billion cubic metres
°C	degree Celsius
b/d	barrels per day

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cm	centimetre
km	kilometre
km^3	cubic kilometre
km/h	kilometre/hour
m	metres
mb/d	million barrels of oil per day
Mt	megatonne
Mtpa	megatonne per annum
MW	megawatt
MWh	megawatt hour
tkm	tonne-kilometres

See the IEA glossary for a further explanation of many of the terms used in this report.

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