Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Navigating sustainability transitions: Implications of Green Growth and Post-growth pathways for the maritime transport industry

Jakob Lass-Ovens
Institut für Seeverkehrswirtschaft und Logistik
Johannes Schmidt
schmidt@isl.org
Institut für Seeverkehrswirtschaft und Logistik
Patrick Specht
Institut für Seeverkehrswirtschaft und Logistik
Marija Jović Mihanović
Institut für Seeverkehrswirtschaft und Logistik

Research Article

Keywords: Sustainability, Post-growth, Green Growth, Scenario Analysis, Maritime Logistics, Port Development

Posted Date: September 4th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10627601/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Additional Declarations: No competing interests reported.

Abstract

The maritime industry operates in an increasingly uncertain environment shaped by climate change, geopolitical developments and technological innovation. This paper examines how Green Growth and Post-growth could reshape global trade and consequently the maritime transport industry. The topic is important because current maritime business models remain strongly linked to growth in cargo volumes and throughput. Using scenario analysis, this paper evaluates two sustainability transition pathways in terms of their implications for cargo structures, trade patterns, port activities, and strategic development priorities. A comparison with a conventional growth scenario shows that both pathways imply a gradual shift away from fossil fuels, transforming cargo structures while creating new opportunities in renewable energy, alternative fuels, critical raw materials, and circular economy logistics. Under a Post-growth pathway, these developments are expected to be more pronounced, driven by lower material consumption, shorter supply chains, and greater regionalisation. Future competitiveness under sustainability transition pathways is likely to depend increasingly on specialised services, industrial integration, and support for the energy transition rather than cargo volume growth alone. Given the sector's long investment cycles and capital intensity, policy and industry strategies should embrace scenario thinking to reduce risks, identify opportunities, and strengthen long-term resilience.

1. Introduction

In recent decades, the world has been facing a growing number of interconnected challenges, including climate change, geopolitical instability, resource constraints, technological transformation, demographic change, and increasing social inequalities (OECD 2025b). Together, these developments are reshaping economies, production systems, global trade, and the way societies envision future development. As governments, businesses, and international organisations seek responses to these challenges, an important debate has emerged over how environmental sustainability, economic prosperity, and social well-being can be achieved simultaneously (OECD 2024). This debate is particularly relevant to maritime transport because the sector is fundamentally linked to global trade, production, and consumption patterns, making it highly exposed to changes in future economic development.

Historically, economic development has largely been based on a conventional growth paradigm, reflected in the pursuit of economic expansion and thus rising GDP as a key indicator of prosperity and societal progress (Callen 2017). While this model has delivered significant economic benefits, it has also contributed to increasing resource use, greenhouse gas emissions, and environmental pressures (Steffen et al. 2015). In response to these environmental challenges, alternative development pathways have gained increasing attention. Among these, Green Growth is the dominant policy framework, relying on technological innovation, renewable energy deployment, resource efficiency, and supportive policies to reconcile continued economic growth with environmental sustainability through "decoupling" (OECD 2025a). This approach is reflected in current maritime decarbonisation strategies, including the IMO's ambition to achieve net-zero GHG emissions by around 2050 (IMO 2023), which rely on a combination of technical, operational and market-based elements. However, the feasibility of achieving sufficient decoupling remains contested (Psaraftis and Kontovas 2020; Laskar et al. 2025). In contrast to Green Growth, Post-growth perspectives argue that technological progress alone is unlikely to achieve environmental objectives at the required scale and speed. Instead, they advocate lower material and energy consumption while placing greater emphasis on equity, societal well-being, and operating within planetary boundaries (Engler et al. 2024). Within the maritime economics literature, Haralambides and Gujar (2023) acknowledge the possibility of such a transition, while Monios and Wilmsmeier (2022) explicitly discuss "degrowth" as a potential paradigm shift for achieving shipping decarbonisation. Despite this growing debate, little research has systematically examined how alternative macroeconomic pathways may reshape global trade, cargo structures, port activities, and maritime business models.

To address this gap, the paper compares Green Growth and Post-growth scenarios with a Conventional Growth baseline to assess their implications for maritime transport. Drawing on academic and policy literature as well as expert insights, the paper applies scenario analysis to examine how these pathways may influence cargo structures, trade patterns, port

activities, and strategic development priorities. Rather than advocating a particular economic model, it adopts a neutral and exploratory perspective to identify potential risks, opportunities, and strategic implications for maritime policy makers and industry actors.

2 Background

2.1 Sustainability transition pathways

Modern economic development is dominated by a conventional growth paradigm centered on increasing production, consumption, trade, and, ultimately, Gross Domestic Product (GDP) as the primary drivers of prosperity and societal progress (Steffen et al. 2015). Since the mid-twentieth century, sustained GDP growth has become a central objective of governments, businesses, and international institutions, based on the assumption that economic expansion generates higher employment, rising incomes, greater fiscal capacity for public services, and improved living standards (Callen 2017; UN 2023, 2015). While this growth paradigm has delivered substantial economic and social benefits, it has also been accompanied by increasing resource use, greenhouse gas emissions, biodiversity loss, and mounting pressure on planetary boundaries, including climate change and biosphere integrity (Rockström et al. 2009). In response to these challenges, alternative development paradigms have emerged. Among them, Green Growth and Post-growth have become the two most influential perspectives in contemporary academic and policy debates.

Today, Green Growth represents the dominant policy framework for addressing climate change while maintaining continued economic growth. The concept gained prominence following the global financial crisis of 2008 and has since been adopted by international organisations such as the OECD, the World Bank, and the United Nations as a pathway to reconcile environmental sustainability with continued economic growth (Lenaerts et al. 2022). Green Growth is commonly defined as fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which human well-being depends (OECD 2011). The central premise of Green Growth is that economic activity can be decoupled from environmental degradation through technological innovation, improved resource efficiency, renewable energy deployment, and supportive policy frameworks. In this perspective, economic growth is not viewed as the root cause of environmental challenges but rather as a potential enabler of the investments and innovations required to address them. Consequently, Green Growth strategies emphasise carbon pricing, environmental regulation, clean technology development, energy efficiency improvements, infrastructure investments, and circular economy initiatives to reduce greenhouse gas emissions while maintaining economic prosperity (OECD 2025a). A key concept within the Green Growth literature is decoupling. Relative decoupling occurs when environmental pressures continue to increase but at a slower rate than economic output, whereas absolute decoupling refers to a situation in which economic output continues to grow while environmental impacts decline (Vogel and Hickel 2023). Green Growth assumes that sufficiently rapid and sustained absolute decoupling can be achieved through technological progress, structural economic change, renewable energy deployment, and resource efficiency improvements (Gbadeyan et al. 2024). Whether such large-scale and sustained absolute decoupling can be achieved, remains the subject of considerable academic debate. Despite this uncertainty, Green Growth remains the dominant framework underpinning climate and industrial policy in many countries (Infante-Amate et al. 2025; World Bank 2012). It forms the basis of numerous national decarbonisation strategies and international initiatives aimed at achieving climate neutrality while sustaining economic growth and development.

In recent years, however, the continued pursuit of economic growth has come under increasing scrutiny. A key driver of this debate is the growing concern over whether sustained economic expansion is compatible with global climate, sustainability and social objectives. Despite significant technological progress and improvements in resource efficiency and carbon intensity, greenhouse gas emissions continue to rise globally, raising doubts that absolute decoupling can be achieved at the scale and pace required to meet climate targets. While some countries have managed to decouple emissions from economic growth, this has not yet occurred on a global scale (Figure 1) (Vogel and Hickel 2023; Freire-

González et al. 2024). While proponents of Green Growth highlight the potential of accelerated climate action to stimulate innovation, productivity growth, investment, and economic development, critics question whether technological progress alone can reduce emissions at a sufficient pace to remain within planetary boundaries (Vogel and Hickel 2023).

The limitations of absolute decoupling are further compounded by growing evidence of resource depletion, biodiversity loss, and ecosystem degradation (Richardson et al. 2023). At the same time, GDP has been criticised as an incomplete measure of societal progress, as it fails to adequately account for environmental degradation, social well-being, and the distribution of economic benefits. Consequently, questions have been raised the desirability and feasibility of continuous economic growth on a finite planet (Engler et al. 2024). Against this background, Post-growth has gained increasing prominence as an alternative framework for organising economic activity within ecological limits. Rather than viewing GDP growth as an objective in itself, Post-growth seeks to decouple societal well-being from the imperative of continuous economic expansion. The concept emphasises ecological sustainability, social equity, economic justice, and human flourishing within planetary boundaries (Jackson 2017). While Post-growth encompasses a diverse range of perspectives, these generally share the view that environmental sustainability cannot be achieved solely through technological innovation and efficiency improvements. Instead, Post-growth argues that high-income economies must reduce material and energy throughput while prioritising human well-being, social equity, and ecological resilience over continued GDP growth (Sandberg et al. 2019). Post-growth should not be confused with economic decline or recession, and generally recognises that lower-income economies may still require economic growth to improve living standards (Engler et al. 2024). Although the practical implementation of Post-growth pathways remains uncertain, their potential implications for society, industry, and economic systems are significant and increasingly discussed in both academic and policy circles.

2.2 Structural growth dependence and transition drivers in the maritime industry

The maritime industry is deeply intertwined with global production systems, consumption patterns, energy markets, and international trade. Consequently, the sector has evolved in an environment characterised by expanding global trade, increasing transport volumes, and growing economic integration. This has created a structural dependence on expanding trade and cargo throughput, making the sector particularly exposed to both Green Growth and Post-growth pathways. To understand why sustainability transitions may have profound implications for the maritime industry, it is first necessary to examine the structural characteristics of its prevailing business models, particularly the sector's existing dependence on continued growth.

This growth dependence is embedded in three interrelated characteristics of the sector: (1) revenue models that depend on transport volumes, (2) capital-intensive asset and cost structures that require high utilisation rates, and (3) competitive dynamics that reward economies of scale and network expansion. Together, these characteristics help explain why sustainability transitions may have far-reaching implications for the maritime industry.

2.2.1 Structural growth dependence

The revenues of shipping companies, ports, and terminal operators are directly linked to the movement, handling, and storage of cargo. Since maritime transport constitutes a form of derived demand, the sector ultimately depends on industrial production, consumer spending, and international trade. Historically, the maritime industry has benefited substantially from the expansion of global trade since the post-World War II period, with increasing cargo volumes translating into higher revenues across the sector (Stopford 2009). This dependence is also evident in the dominant cargo and network structures of maritime transport. Major bulk commodities, containerised goods, and specialised cargoes are predominantly transported over long distances through increasingly integrated global supply chains. As a result,

developments that alter trade patterns, transport distances, or cargo volumes can have significant implications for maritime business performance. The industry's growth orientation is further reflected in commonly used performance indicators such as cargo throughput, vessel traffic, and market share. Although commercial performance is ultimately measured in terms of profitability and shareholder value, these outcomes remain closely linked to transport volumes and network utilisation (Cheon et al., 2018). Consequently, sustained changes in trade volumes, cargo composition, or transport distances have direct implications for the revenue base of shipping companies, ports, and terminal operators.

A second source of growth dependence lies in the industry's cost structure. Maritime transport is highly capital intensive and characterised by substantial fixed costs, long asset lifecycles, and significant upfront investments. Shipping companies, terminal operators, and port authorities therefore depend on maintaining high asset utilisation rates in order to recover investments and achieve acceptable returns. Over recent decades, this dynamic has encouraged the pursuit of economies of scale throughout the maritime sector. In shipping, this is reflected in the emergence of increasingly larger vessels, particularly in the container segment, where ultra-large container vessels have been introduced to reduce transport costs per unit (Haralambides 2019). Vessel ordering and shipbuilding frequently follow pro-cyclical patterns, with strong freight markets encouraging additional capacity investments (Ferrari et al. 2018). Both shipping and port investments are often characterised by long lead times and significant uncertainty, resulting in capacity expansions that frequently precede actual demand. Once these large-scale assets are in place, their commercial viability depends on sustained utilisation to realise economies of scale and achieve profitability. Business performance in the maritime sector is therefore closely linked to the ability to attract or handle sufficient cargo volumes to utilise increasingly capital-intensive infrastructure and vessels. Ports have followed similar expansion trajectories. Accommodating larger vessels and maintaining competitiveness requires continuous investments in port infrastructure, terminal capacity, dredging, and hinterland connections. These projects involve long planning horizons, substantial capital expenditures, and are typically justified by expectations of continued growth in cargo volumes and transport demand (Bhurtyal et al. 2024). As with shipping, the profitability of these investments depends on maintaining high utilisation rates over long lifecycles. Accordingly, prolonged periods of slower trade growth or structural declines in throughput may increase the risk of underutilised infrastructure and stranded assets.

Finally, the maritime sector's competitive environment further reinforces growth-oriented behaviour. Maritime transport has become a highly commoditised industry in which transport services are often difficult to differentiate. Combined with price-sensitive customers, cyclical overcapacity, and relatively thin margins, this creates strong incentives to compete through cost reduction, scale expansion, and network growth. These competitive pressures have contributed to significant horizontal and vertical integration across the maritime sector. Examples include carrier alliances and consolidation within container shipping, the rise of global terminal operators, and the expansion of maritime firms into hinterland logistics and integrated supply chain services (Brooks and Pallis 2012). Liberalisation, privatisation, and deregulation since the 1980s have further accelerated these developments by facilitating cross-border investment, corporate consolidation, and the entry of financial investors (Ghorbani et al. 2022). As a result, many maritime markets are increasingly characterised by oligopolistic structures in which competitive advantage derives from economies of scale, network control, and market power. Larger firms are often better positioned to optimise network utilisation, negotiate favourable conditions with customers and suppliers, spread risks across markets, and mobilise capital for large-scale investments. Consequently, growth is not merely a desirable outcome but a strategic imperative for maintaining competitiveness (Franc and Van Der Horst 2010; Ghorbani et al. 2022). Although firms may occasionally restrict capacity to stabilise freight rates and improve profitability (Ezinna et al. 2022), the sector's prevailing business models remain fundamentally dependent on sufficiently high trade volumes to utilise accumulated assets, realise network effects, and achieve expected returns on investment. This does not imply that maritime firms cannot adapt to alternative development pathways. Rather, it suggests that sustainability transitions characterised by slower economic growth, lower material throughput, shorter supply chains, or declining transport demand challenge several of the structural assumptions underpinning the industry's prevailing business models

2.2.2 Transition drivers affecting maritime transport

The maritime industry's structural growth dependence makes it particularly sensitive to external developments that reshape production systems, trade patterns, and transport demand. While maritime business models have historically benefited from expanding trade and increasing transport volumes, sustainability transitions may alter both the volume and composition of maritime trade, as well as the technological and regulatory environment in which shipping and ports operate. Transition drivers that are particularly relevant include changing consumption and production patterns, regionalisation of supply chains, and maritime decarbonisation.

Changes in consumption and production patterns

Sustainability transitions may significantly alter patterns of energy use, production, and consumption, with important implications for maritime transport demand. While both Green Growth and Post-growth aim to reduce the environmental footprint of economic activity, they differ in their assumptions regarding future material and energy demand (Infante-Amate et al. 2025). A key source of the maritime sector's exposure to these transitions is its dependence on fossil fuel trade. Crude oil and oil products alone accounted for 23.5% of global seaborne trade volumes in 2025 and continue to play a central role in tanker shipping and global energy supply chains (Clarkson Research Services Limited 2026). As energy systems become increasingly electrified and renewable energy deployment accelerates, demand for fossil fuel transport is expected to decline. Although new cargoes such as hydrogen, ammonia, methanol, and critical raw materials will generate additional maritime transport demand, they are unlikely to fully replace existing fossil fuel trades in terms of transported volumes or shipping patterns.These developments are expected to be more pronounced under Post-growth pathways, which additionally assume lower material consumption, longer product lifecycles, improved reparability, and more sufficiency-oriented consumption patterns. Circular economy practices may reduce primary resource demand, but recycling alone is unlikely to satisfy future material requirements (IEA 2024b). As discussed in detail in Section 4, not all cargo segments are equally exposed. Overall, the magnitude of these changes remains uncertain and will depend on technological progress, policy choices, consumer behaviour, and the transition pathway ultimately pursued.

Regionalisation and supply chain reconfiguration

Geopolitical tensions, trade disputes, supply chain disruptions, and growing concerns over economic security have renewed interest in nearshoring, reshoring, and regional production networks. These developments, commonly associated with strategic autonomy, economic resilience, and supply chain security (World Bank 2025), may shorten transport distances as production moves closer to end markets. Since maritime revenues depend not only on cargo volumes but also on transport distances, such developments could reduce overall transport activity even if trade volumes remain relatively stable. Under Green Growth, regionalisation is primarily viewed as a strategy to strengthen resilience and supply chain security. In contrast, Post-growth considers more localised production and shorter supply chains as structural features of a lower-throughput economic system. The impacts are likely to differ across cargo segments. Manufactured goods and intermediate products are generally more exposed than essential bulk commodities such as grain, whose transport demand is expected to remain comparatively resilient despite potentially shorter trade routes and smaller shipment sizes (Nelson and Edwards 2020).

Climate policy and maritime decarbonisation

Alongside changes in transport demand, the maritime industry faces increasing pressure to reduce its own greenhouse gas emissions. Decarbonisation has become a central objective of international, regional, and national climate policy, affecting shipping, ports, and port-based industries irrespective of whether economies follow Green Growth or Post-growth pathways. Achieving substantial emission reductions will require a combination of operational improvements, technological innovation, and the deployment of low-carbon fuels. Although alternative fuels such as green methanol, ammonia, hydrogen, and advanced biofuels are widely regarded as key enablers of maritime decarbonisation, their large-

scale availability remains uncertain and their costs are expected to remain above those of conventional marine fuels for the foreseeable future (Hübscher and Lemper 2024; Costa 2026). Ports face a dual challenge. They must both decarbonise their own operations and provide the infrastructure required for alternative fuels, renewable energy supply chains, carbon capture and storage, and new industrial activities. This is likely to strengthen their role as energy and industrial hubs while requiring substantial new investments.

3 Methodology

3.1 Research design and scenario approach

The following analysis explores how alternative sustainability pathways may shape the maritime industry, including shipping, ports, and port-based industries. Given the uncertainty surrounding future economic, technological, and societal developments, the study adopts a qualitative scenario approach grounded in strategic foresight (Van der Heijden 2005; Monteiro and Dal Borgo 2023; Ramírez and Wilkinson 2016) to explore how Green Growth and Post-growth pathways may influence trade patterns and maritime transport demand.

Rather than predicting the future, the scenarios provide plausible representations of how different sustainability pathways may influence trade patterns, commodity demand, and maritime activities up to 2050. The analysis builds on the foundations from the previous chapter and combines insights from the literature with a structured expert inquiry conducted at the Institute of Shipping Economics and Logistics (ISL). The participating experts brought complementary in international trade and markets, port and maritime economics, environmental issues, and supply chain management. Drawing on global scenario assumptions and existing research, the experts developed a shared assessment of the most plausible implications for trade flows, cargo demand, shipping, ports, and port-based industries under alternative future conditions.

Three contrasting global scenarios are considered: (1) Conventional Growth, characterised by continued economic expansion and rising resource consumption; (2) Green Growth; and (3) Post-growth (see Section 2.1 for 2 and 3 for definitions of the latter two).

3.2 Scenario assumptions

Scenario 1: Conventional Growth

Economic growth remains the dominant policy objective, and global production, consumption, and trade continue to expand. While technological progress and efficiency improvements occur, they are insufficient to offset increasing resource use and environmental pressures. As a result, greenhouse gas emissions, resource depletion, and climate-related risks remain significant challenges for the global economy and the maritime sector. Although many governments and institutions pursue Green Growth ambitions, actual developments continue to resemble a Conventional Growth pathway, with resource consumption, trade volumes, and economic activity continuing to increase.

Scenario 2: Green Growth

Economic growth continues, but environmental sustainability becomes a central objective of economic development. Technological innovation, decarbonisation, renewable energy deployment, and resource efficiency enable a substantial reduction in environmental impacts while maintaining economic expansion (OECD 2025a; Infante-Amate et al. 2025). As a result, a large share of technological innovation, public funding, and industrial policy is directed towards low-carbon technologies, renewable energy systems, electrification, and circular economy solutions. International trade remains

robust, although cargo structures, supply chains, and industrial activities evolve in response to the energy transition and climate policies.

Scenario 3: Post-growth

Ecological sustainability and social well-being become the primary objectives of economic development. In addition to decarbonisation efforts, material and energy throughput are deliberately reduced (see Section 2.1). As a result, demand for some traditional cargoes and long-distance transport declines, while regional value chains, circular economy activities, and new service-oriented functions gain importance. For the maritime sector, this implies a more fundamental restructuring of trade patterns, transport demand, business models, and value creation than under the Green Growth scenario.

Table 1 summarises the key characteristics of the three scenarios considered in this study. The scenarios differ in their assumptions regarding policy objectives, measures of economic success, resource and energy consumption, climate strategies, and the role of technology, resulting in distinct developments in international trade. Building on these assumptions, the following section examines their implications for individual cargo segments, shipping markets, ports, and port-based industries.

Table 1: Key characteristics of the three future scenarios applied in this study

Criteria	Scenario 1: Conventional Growth	Scenario 2: Green Growth	Scenario 3: Post-growth
Primary policy objective	Economic growth	Economic growth with sustainability	Well-being within ecological limits
Economic success measured by	GDP growth	GDP growth and sustainability performance	Social & environmental outcomes
Resource & energy consumption	Continues to increase	Greater efficiency and circularity	Reduced throughput and circularity
Climate strategy	Incremental action and adaptation	Strong decarbonisation through technology	Decarbonisation and sufficiency
Role of technology	Efficiency improvements supporting growth	Key enabler of decarbonisation and resource efficiency	Supports sufficiency, resilience, and localisation
International trade	Continued expansion	Stable to growing, changing composition	Lower growth and increased regionalisation

4 Results

Building on the scenario assumptions presented in the previous section, this chapter examines the implications of the three alternative development pathways for maritime transport and port activity. Given the limited empirical evidence on how Green Growth and particularly Post-growth trajectories may affect international trade, the results should be interpreted as an exploratory scenario assessment rather than a forecast. The objective is not to predict future developments but to identify plausible changes in trade patterns, cargo demand, shipping activity, and port functions under different sustainability paradigms. Table 2 provides an overview of the expected developments across the principal cargo segments and port activities under the three scenarios. The subsequent sections discuss these developments in

greater detail and highlight their strategic implications for shipping companies, ports, terminal operators, and port-based industries.

Table 2: Indicative developments within maritime transport and port activity in the three growth scenarios

	Scenario 1: Conventional Growth	**Scenario 2: Green Growth**	**Scenario 3: Post-growth**
Container	**Increase** – driven by growing trade and consumption	**Moderate increase** – growth partly offset by circular economy and resource efficiency	**Decrease** – lower consumption, longer product lifetimes, regionalisation
Liquid bulk	**Stable** – declining oil partly offset by LNG and chemicals	**Decline** – lower fossil fuel demand, growth in alternative energy carriers	**Strong decline** – substantially lower fossil fuel consumption
Dry bulk	**Stable to slight increase** – continued demand for raw materials	**Stable to slight decline** – critical minerals partly offset lower coal and iron ore demand	**Decline** – reduced material throughput and higher circularity
Break bulk	**Increase** – industrial expansion and infrastructure investment	**Increase** – renewable energy and decarbonisation projects	**Mixed** – lower trade volumes but continued port infrastructure investments
Cruise	**Increase** – rising incomes, growing tourism demand, & expanding leisure consumption	**Limited increase** – constrained by environmental regulation and decarbonisation costs	**Decline** – lower discretionary consumption and environmental regulation
Port-based industrial activities	**Stable to moderate increase** – continued importance of refining, petrochemicals, LNG, and export-oriented manufacturing	**Transformation with moderate growth** – expansion of hydrogen, renewable fuels, CCS or critical raw material processing	**Transformation with stable to lower output** – increasing focus on remanufacturing, recycling, circular economy activities, and regional production networks
Overall	**Increase** – continued growth in trade and transport demand	**Moderate increase** – changing cargo composition and supply chains	**Decline** – lower throughput, increased regionalisation

4.1 Container shipping and handling

Container shipping is closely linked to global consumption patterns and international trade in manufactured goods. Under the Conventional Growth scenario, container volumes continue to increase as economic growth, consumer demand, and global supply chains expand. Ports face ongoing pressure to invest in container handling capacity, logistics facilities, and hinterland connections.

Under Green Growth, container shipping continues to grow, albeit at a slower pace. Resource efficiency, circular economy practices, and longer product lifecycles moderate demand growth, while new cargoes related to renewable energy technologies and sustainable consumer products emerge. Ports increasingly compete through low-carbon logistics solutions and supply chain integration.

The strongest impacts occur under the Post-growth scenario. Lower material consumption, increased repair and reuse, longer product lifetimes, and greater regionalisation reduce demand for the transport of manufactured goods. As a result, container volumes decline, particularly for fast-moving consumer goods and imported consumer products. Ports may therefore face lower throughput and increasing pressure to repurpose logistics and terminal areas.

4.2 Liquid bulk cargo shipping and handling

Liquid bulk is among the most exposed cargo segments due to its strong dependence on fossil fuel trade. Under Conventional Growth, declining crude oil demand – driven by gradual decarbonisation, improvements in energy efficiency, and efforts to reduce resource depletion – is partly offset by continued growth in LNG, chemicals, biofuels, and other energy products, resulting in relatively stable overall volumes. Ports and shipping companies remain closely linked to fossil fuel value chains. Given that oil and petroleum products constitute the largest cargo segment in global seaborne trade, replacing these volumes through alternative fuels and emerging energy carriers is likely to be challenging, even under ambitious energy-transition scenarios.

Under Green Growth, the transition away from fossil fuels accelerates. Declining crude oil, petroleum product, and LNG volumes are partly compensated by growing trade in hydrogen derivatives, ammonia, methanol, biofuels, and CO_2 transport. This requires significant investments in new energy infrastructure and the transformation of traditional liquid bulk terminals into multi-energy hubs.

Post-growth leads to the strongest decline in liquid bulk volumes. Lower overall energy demand and deep decarbonisation significantly reduce fossil fuel trade. While alternative fuels continue to grow, they are unlikely to replicate the scale of today's oil markets. Many ports therefore face substantial reductions in liquid bulk throughput and the need for structural adjustment.

4.3 Dry bulk cargo shipping and handling

Dry bulk markets are expected to experience substantial structural changes under all scenarios. Under Conventional Growth, demand for many raw materials remains strong, although declining coal volumes are only partly offset by growing trade in minerals required for the energy transition. Bulk ports continue to play a central role in industrial supply chains and resource imports, but overall cargo growth becomes increasingly dependent on non-fossil bulk commodities.

Under Green Growth, demand shifts further towards critical minerals such as lithium, copper, bauxite, and other materials required for renewable energy systems, batteries, and electrification. At the same time, coal and some traditional bulk commodities (e.g., fertiliser or alumina) experience long-term decline. Ports increasingly specialise in strategic raw materials and circular material flows. Given that coal remains one of the largest cargo segments in global seaborne trade, replacing these volumes through growing trade in critical minerals is likely to be challenging, as such commodities are typically transported in significantly lower quantities.

Under Post-growth, lower material throughput, higher resource efficiency, and circular economy practices reduce demand for many primary raw materials. Commodities such as coal, iron ore, alumina, cement, and fertilisers are particularly affected. While some demand remains for essential industries and hard-to-abate sectors such as steel, cement, and maritime transport, bulk terminals face declining utilisation rates and increasing pressure to diversify their activities.

4.4 Break bulk and project cargo shipping and handling

Break bulk and project cargo are strongly linked to industrial activity and infrastructure development. Under Conventional Growth, volumes continue to expand alongside industrial production, vehicle trade, and infrastructure investment. Ports therefore continue investing in multipurpose terminals and handling equipment.

Under Green Growth, this segment benefits from the energy transition. Demand increases for wind turbine components, transformers, electrical equipment, batteries, copper products, and other cargoes associated with renewable energy and

industrial decarbonisation. Project cargo becomes increasingly important for ports involved in energy-transition supply chains.

Under Post-growth, lower material consumption and reduced trade intensity place downward pressure on traditional break bulk cargoes such as vehicles, machinery, and steel products. However, part of this decline may be offset by project cargo linked to renewable energy systems, infrastructure renewal, and regional industrial development. Consequently, the outlook for this segment remains more mixed than for fossil fuel-related trades.

4.5 Cruise shipping

Cruise shipping is highly sensitive to consumer spending and tourism demand. Under Conventional Growth, rising incomes and growing international tourism support strong expansion of the cruise sector. Cruise ports continue to invest in passenger terminals and destination infrastructure.

Under Green Growth, economic expansion continues but becomes more constrained by environmental regulation, carbon pricing, and the challenges associated with cruise decarbonisation. Demand increasingly shifts towards higher-value and lower-emission cruise offerings. Ports respond by investing in shore power, alternative fuel bunkering, and low-emission passenger facilities.

Post-growth presents the most challenging environment for cruise shipping. Lower discretionary consumption, a greater emphasis on local tourism, and stronger environmental constraints reduce demand for cruise travel. As a result, the sector may contract substantially, requiring some ports to repurpose passenger terminals or scale back cruise-related infrastructure.

4.6 Port-based industrial activities

Port-based industries are likely to undergo significant transformation under all scenarios. Under Conventional Growth, refineries, petrochemical activities, fossil fuel logistics, LNG infrastructure, and conventional manufacturing remain important components of many port-industrial clusters.

Under Green Growth, industrial activity increasingly shifts towards low-carbon sectors. Growth areas include hydrogen production, renewable fuel manufacturing, carbon capture and storage, battery production, critical raw material processing, and renewable energy supply chains. Ports evolve into integrated energy and industrial transition hubs supporting decarbonisation across multiple sectors.

Under Post-growth, industrial development focuses less on maximising production volumes and more on resource efficiency and circularity. Repair, remanufacturing, recycling, material recovery, and regional production networks become increasingly important. At the same time, refining activities and export-oriented industrial production lose significance. Ports therefore play a growing role as hubs for circular economy activities and regional value creation.

5 Discussion

Sustainability transitions reshape maritime transport and port activity

The findings presented in the previous section suggest that the maritime industry is highly exposed to future sustainability transitions, regardless of whether these are pursued through Green Growth or Post-growth pathways. As highlighted, shipping companies, ports, and port-based industries are closely linked to global systems of production, consumption, energy use, and international trade. Consequently, structural changes within these systems are likely to have profound

implications for maritime transport demand, cargo composition, infrastructure requirements, and business models. The analysis broadly supports existing literature arguing that the transition away from fossil fuels will fundamentally reshape maritime transport systems (e.g. Lu et al. 2023; Notteboom and Haralambides 2025; Song 2024).

Both Green Growth and Post-growth scenarios imply substantial reductions in the demand for fossil fuels, affecting cargo segments that currently account for a considerable share of global seaborne trade. In particular, declining trade in crude oil, petroleum products, and coal represents one of the most significant long-term challenges for the maritime industry. While new cargo streams associated with renewable energy systems, alternative fuels, critical raw materials, carbon management, and circular economy activities are expected to emerge, these are unlikely to fully compensate for the volumes currently generated by fossil fuel supply chains.

The analysis further indicates that the implications differ considerably between the two sustainability pathways. Under Green Growth, international trade and maritime transport remain comparatively robust, although cargo structures, supply chains, and industrial activities undergo significant transformation as economies decarbonise. Under Post-growth, these developments are reinforced by deliberate reductions in material and energy throughput, greater resource efficiency, and more regionalised production systems. Consequently, several transport-intensive cargo segments may experience structural decline, challenging business models that have historically depended on continuously expanding trade volumes. The scenarios demonstrate that both sustainability paradigms imply profound structural adjustments for the maritime sector. The principal difference lies not in whether the maritime sector transforms, but in the pace, magnitude, and underlying drivers of that transformation.

From throughput growth towards value creation

A key finding of the scenario analysis is that sustainability transitions should not be viewed solely as constraints on maritime transport. Instead, both Green Growth and Post-growth imply a restructuring of economic activity that creates new forms of maritime value creation and reshapes the sector's role within global production and logistics systems. New opportunities are expected to emerge from the energy transition, circular economy, and low-carbon industries. Ports may increasingly evolve into integrated energy and industrial hubs supporting renewable energy supply chains, alternative fuels, and carbon management (Mazzocchi et al. 2026; Wan et al. 2025). At the same time, expanding material recovery, recycling, and remanufacturing activities are likely to increase demand for reverse logistics and strengthen the role of ports as industrial symbiosis hubs (Kovačič Lukman et al. 2022). A further opportunity concerns emerging high-value cargo segments. The transition towards low-carbon economies is expected to increase demand for critical raw materials such as lithium, cobalt, nickel, copper, and rare earth elements, many of which will continue to rely on international maritime transport (IEA 2024a). In parallel, industries such as biotechnology, advanced manufacturing, and precision engineering are likely to generate cargoes characterised by high value density and demanding logistics requirements. These developments reward reliability, specialisation, and integrated logistics services rather than economies of scale alone.

Overall, the findings suggest that sustainability transitions may gradually shift the strategic logic of the maritime industry from maximising throughput towards creating value through specialisation, industrial integration, and service innovation. While cargo volumes will remain important, future competitiveness is likely to depend increasingly on the ability of ports and shipping companies to support emerging energy systems, industrial ecosystems, and circular value chains.

Strategic implications for maritime stakeholders

Table 3 summarises the principal risks, opportunities, and strategic responses associated with the Green Growth and Post-growth pathways.

Table 3
Risks and opportunities matrix for the maritime sector under alternative development pathways

Key risk	Green Growth	Post-growth
	♣ Declining fossil fuel trade **♣ High investment for decarbonisation** **♣ Rising transport costs due to alternative fuels & carbon pricing** **♣ Risk of stranded fossil fuel infrastructure** **♣ Uncertainty regarding future energy carriers**	**♣ Declining demand for transport-intensive cargoes** **♣ Lower utilisation of vessels, terminals, & logistics infrastructure** **♣ Stranded assets due to reduced throughput** **♣ Reduced demand for long-distance transport** **♣ Pressure on growth-oriented business models**
Key opportunities	♣ Growth in renewable energy supply chains ♣ Alternative fuel production, storage, & transport ♣ Critical raw material trade ♣ Carbon capture and storage (CCS) value chains ♣ Ports as energy & industrial transition hubs	♣ Circular economy logistics & material recovery ♣ Repair, remanufacturing, & recycling activities ♣ Regional value creation & industrial ecosystems ♣ New service-oriented & specialised business models / Ports as hubs for circular, resilient supply chains
Strategic implications	♣ Accelerate decarbonisation investments ♣ Adapt infrastructure to new energy carriers ♣ Positioning within emerging energy value chains ♣ Develop low-carbon logistics services	♣ Reduce dependence on throughput growth ♣ Diversify revenue streams beyond cargo volumes ♣ Increase flexibility and resilience of infrastructure ♣ Focus on value creation rather than volume maximisation

For ports, these developments imply a growing need to balance traditional capacity expansion strategies with investments that enhance flexibility, diversification, and resilience. Future competitiveness may increasingly depend on the ability to facilitate industrial transformation, support emerging energy systems, and generate regional economic value rather than maximising cargo throughput alone. Similarly, shipping companies may need to adapt fleet compositions, service networks, and business models to changing cargo structures, higher decarbonisation costs, and potentially lower transport demand in selected market segments. Policymakers, in turn, face the challenge of coordinating transport, industrial, energy, and climate policies while accounting for the long investment cycles that characterise maritime infrastructure.

Preparing for uncertain futures

Beyond the individual scenario outcomes, the analysis highlights a broader strategic challenge. The maritime industry already operates in an increasingly uncertain environment shaped by geopolitical tensions, climate change, technological change, and evolving trade patterns. Recent disruptions—including the COVID-19 pandemic, the grounding of the *Ever Given*, attacks on commercial shipping in the Red Sea, and tensions surrounding the Strait of Hormuz—have illustrated the vulnerability of global maritime supply chains to external shocks (Notteboom and Haralambides 2025; Uthpala and Kavirathna 2025).

While considerable attention has been devoted to strengthening operational resilience, little effort has gone into preparing for long-term structural transformations in the global economy. Yet sustainability transitions, together with broader developments such as regionalisation, nearshoring, strategic autonomy, and changing consumption patterns, have the potential to reshape global trade and maritime transport over coming decades. For an industry characterised by capital-intensive assets and investment horizons spanning several decades, these developments create significant strategic uncertainty. Investment decisions regarding vessels, terminals, and port infrastructure are frequently based on expectations of continued trade growth and may therefore become exposed to risks of underutilisation, overcapacity, or stranded assets. Consequently, the greatest strategic risk may not be the emergence of a particular future scenario, but the failure to systematically consider alternative development pathways. Maritime stakeholders that regularly reassess underlying assumptions, diversify revenue sources, and adopt flexible investment strategies are likely to be better positioned to navigate an increasingly uncertain future.

6 Conclusion

This paper explored how alternative sustainability pathways may influence maritime transport and port activity through a qualitative scenario analysis. Building on the concepts of Conventional Growth, Green Growth, and Post-growth, the study examined how different assumptions regarding economic development, resource use, and sustainability could reshape international trade, cargo demand, and the strategic role of ports and shipping. The analysis demonstrates that both Green Growth and Post-growth imply profound structural changes for the maritime industry. Although the two pathways differ in the magnitude of their impacts, both point towards declining fossil fuel transport, changing cargo compositions, and the emergence of new value chains associated with renewable energy, alternative fuels, critical raw materials, and circular economy activities. These developments suggest that future competitiveness will increasingly depend not only on transport volumes but also on specialisation, industrial integration, and the ability to create value through new logistics and energy services.

A central contribution of this paper is to show that Post-growth must not be understood simply as a scenario of decline for the maritime industry. Instead, both Green Growth and Post-growth represent distinct pathways of structural transformation that challenge established assumptions regarding the relationship between economic growth, international trade, and maritime development. While Post-growth may reduce demand for some traditional cargo segments, it simultaneously creates opportunities for new industrial activities, circular economy systems, and service-oriented business models.

Several limitations should be acknowledged. The scenarios presented are exploratory and do not constitute forecasts. Considerable uncertainty remains regarding technological innovation, policy choices, consumer behaviour, geopolitical developments, and the pace of sustainability transitions. Future research should therefore complement qualitative scenario analysis with quantitative trade and transport modelling, investigate regional differences across ports and shipping markets, and assess the resilience of alternative investment strategies under different sustainability pathways.

Ultimately, the key strategic question for the maritime industry is not whether transformation will occur, but how ports, shipping companies, and policymakers can position themselves to remain resilient and competitive under fundamentally different futures. Rather than relying on a single vision of future growth, maritime strategy should increasingly embrace scenario thinking as a means of preparing for multiple plausible development pathways.

Declarations

Author Contribution

Conceptualisation: JS, JL and PS;Formal analysis: JS, JL and PS; Investigation: JS and PS; Methodology: JS and PS; Project administration: JS; Supervision: JS; Validation: JL, MM and PS; Visualisation: JS; Writing - Original Draft: JS, JL and PS; Writing - Review & Editing: JS, MM, JL and PS

Acknowledgement

The authors would like to thank Prof. Dr. Burkhard Lemper for his valuable comments and constructive feedback. His insights helped improve the clarity and quality of the paper.

References

1. Bhurtyal, Sanjeev, Sarah Hernandez, Sandra Eksioglu, and Manzi Yves. 2024. A Two-Stage Stochastic Optimization Model for Port Infrastructure Planning. *Maritime Economics & Logistics* 26(2):185–211. https://doi.org/10.1057/s41278-023-00262-0
2. Brooks, Mary R., and Athanasios A. Pallis. 2012. 'Port Governance'. In *The Blackwell Companion to Maritime Economics*, 1st edn, edited by Wayne K. Talley. Wiley. https://doi.org/10.1002/9781444345667.ch25
3. Callen, Tim. 2017. 'Gross Domestic Product: An Economy's All'. https://www.imf.org/en/publications/fandd/issues/series/back-to-basics/gross-domestic-product-gdp
4. Clarkson Research Services Limited. 2026. *Shipping Intelligence Network*. World Totals. % Shares'.
5. Costa, Renata. 2026. Technological Bottlenecks in Fuels for Maritime Decarbonization. *Journal of Marine Science and Engineering* 14(6):570. https://doi.org/10.3390/jmse14060570
6. Engler, John-Oliver, Max-Friedemann Kretschmer, Julius Rathgens, Joe A. Ament, Thomas Huth, and Henrik Von Wehrden. 2024. 15 Years of Degrowth Research: A Systematic Review. *Ecological Economics* 218:108101. https://doi.org/10.1016/j.ecolecon.2023.108101
7. Eurostat, O. E. C. D. 2026. IMF, and World Bank 2026. 'Gross Domestic Product (GDP) – World Bank – In Constant International-$'. Version With minor processing by Our World in Data. World Development Indicators 129. https://ourworldindata.org/grapher/co2-emissions-and-gdp
8. Ezinna, Paul C., Emma Nwanmuoh, Uzochukwu I. Ozumba, and Josiah Ogbuka. 2022. Ocean Carrier Alliances and the Impact on Container Freight Rate. *Journal of International Maritime Safety Environmental Affairs and Shipping* 6(2–3):117–127. https://doi.org/10.1080/25725084.2022.2125713
9. Ferrari, Claudio, Malvina Marchese, and Alessio Tei. 2018. Shipbuilding and Economic Cycles: A Non-Linear Econometric Approach. *Maritime Business Review* 3(2):112–127. https://doi.org/10.1108/MABR-01-2018-0002
10. Franc, Pierre, Martijn Van Der Horst. 2010. Understanding Hinterland Service Integration by Shipping Lines and Terminal Operators: A Theoretical and Empirical Analysis. *Journal of Transport Geography* 18(4):557–566. https://doi.org/10.1016/j.jtrangeo.2010.03.004
11. Freire-González, Jaume, Emilio Padilla Rosa, and Josep Ll. 2024. Raymond. 'World Economies' Progress in Decoupling from CO2 Emissions'. *Scientific Reports* 14 (1): 20480. https://doi.org/10.1038/s41598-024-71101-2
12. Gbadeyan, Oluwatoyin J., Joseph Muthivhi, and Linda Z. Linganiso, Nirmala Deenadayalu. 2024. Decoupling Economic Growth from Carbon Emissions: A Transition toward Low-Carbon Energy Systems—A Critical Review. *Clean Technologies* 6(3):1076–1113. https://doi.org/10.3390/cleantechnol6030054
13. Ghorbani, Mohammad, and Michele Acciaro, Sandra Transchel, Pierre Cariou. 2022. Strategic Alliances in Container Shipping: A Review of the Literature and Future Research Agenda. *Maritime Economics & Logistics* 24(2):439–465. https://doi.org/10.1057/s41278-021-00205-7

14. Global Carbon Budget. 2025. 2025. 'CO_2 Emissions'. Version with major processing by Our World in Data. Global Carbon Project, Global Carbon Budget v15.
15. Haralambides, Hercules. 2019. Gigantism in Container Shipping, Ports and Global Logistics: A Time-Lapse into the Future. *Maritime Economics & Logistics* 21(1):1–60. https://doi.org/10.1057/s41278-018-00116-0
16. Haralambides, Hercules, Girish Gujar. 2023. The New Normal, Global Uncertainty and Key Challenges in Building Reliable and Resilient Supply Chains. *Maritime Economics & Logistics* 25(4):623–638. https://doi.org/10.1057/s41278-023-00275-9
17. Hübscher, Andreas. 2024. and Burkhard Lemper. *Klimaziele Der Seeschifffahrt Sind Kaum Zu Schaffen. Ambitionierte Ziele, Herausforderungen Und Lösungsansätze*. Working Paper. Institut für Seeverkehrswirtschaft und Logistik.
18. IEA. 2024a. *Global Critical Minerals Outlook 2024*. International Energy Agency.
19. IEA. 2024b. *Recycling of Critical Minerals: Strategies to Scale Up Recycling and Urban Mining. Strategies to Scale up Recycling and Urban Mining*. International Energy Agency.
20. IMO, and ON REDUCTION OF GHG EMISSIONS FROM SHIPS'. 2023. '2023 IMO STRATEGY. https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/annex/MEPC%2080/Annex%2015.pdf
21. Infante-Amate, Juan, and Emiliano Travieso, Eduardo Aguilera. 2025. Green Growth in the Mirror of History. *Nature Communications* 16(1):3766. https://doi.org/10.1038/s41467-025-58777-4
22. Jackson, Tim. 2017. *Prosperity without Growth: Foundations for the Economy of Tomorrow*. Second Edition. Routledge, Taylor & Francis Group.
23. Kovačič Lukman, Rebeka, Kristijan, Brglez, and Damjan Krajnc. 2022. A Conceptual Model for Measuring a Circular Economy of Seaports: A Case Study on Antwerp and Koper Ports. *Sustainability* 14(6):3467. https://doi.org/10.3390/su14063467
24. Laskar, Imranul I., and Hadi Dowlatabadi, Amanda Giang. 2025. Expert Assessments of Maritime Shipping Decarbonization Pathways by 2030 and 2050. *Earth's Future* 13(4). https://doi.org/10.1029/2024EF005255. e2024EF005255.
25. Lenaerts, Klaas, and Simone Tagliapietra, Guntram Wolff. 2022. The Global Quest for Green Growth: An Economic Policy Perspective. *Sustainability* 14(9):5555. https://doi.org/10.3390/su14095555
26. Lu, Bo, Xi Ming, Hongman Lu, Deyang Chen, and Hongbo Duan. 2023. Challenges of Decarbonizing Global Maritime Container Shipping toward Net-Zero Emissions. *Npj Ocean Sustainability* 2(1):11. https://doi.org/10.1038/s44183-023-00018-6
27. Mazzocchi, Paolo, Luigi Capoani, Fabio Carlucci, and Barbara Trincone. 2026. European Ports as Energy Hubs: A Sustainability Index to Assess Territorial Development. *Business Strategy and the Environment* 35(3):3711–3739. https://doi.org/10.1002/bse.70348
28. Monios, Jason, Gordon Wilmsmeier. 2022. Maritime Governance after COVID-19: How Responses to Market Developments and Environmental Challenges Lead towards Degrowth. *Maritime Economics & Logistics* 24(4):699–722. https://doi.org/10.1057/s41278-022-00226-w
29. Monteiro, Bruno. 2023. and Rodrigo Dal Borgo. *Supporting Decision Making with Strategic Foresight: An Emerging Framework for Proactive and Prospective Governments.* OECD Working Papers on Public Governance No. 63. Vol. 63. OECD Working Papers on Public Governance. https://doi.org/10.1787/1d78c791-en
30. Nelson, Anitra. 2020. and Ferne Edwards. *Food for Degrowth: Perspectives and Practices*. 1st edn. Edited by Anitra Nelson and Ferne Edwards. Routledge. https://doi.org/10.4324/9781003004820
31. Notteboom, Theo, Hercules Haralambides. 2025. Geopolitics on Steroids: Opportunity or Mayhem for Seaports? In *Infrastructure Grids and Networks: The Challenges Ahead, Amid Security and Efficiency*, by Carlos Secci and Alessandro Gili. Ledizioni LediPublishing.

32. *Towards Green Growth*. OECD OECD, and Publishing. 2011. https://doi.org/https://doi.org/10.1787/9789264111318-en
33. OECD. 2024. How's Life? 2024: Well-Being and Resilience in Times of Crisis. *OECD Publishing*. https://doi.org/10.1787/90ba854a-en
34. *Investing in Climate for Growth and Development*. OECD OECD, and Publishing. 2025a. https://doi.org/https://doi.org/10.1787/16b7cbc7-en
35. OECD. 2025b. *Managing Emerging Critical Risks: Case Studies and Cross-Country Synthesis Report*. OECD Publishing. https://doi.org/10.1787/1f9858ea-en
36. Psaraftis, Harilaos N., and Christos A. Kontovas. 2020. 'Decarbonization of Maritime Transport: Is There Light at the End of the Tunnel?' *Sustainability* 13 (1): 237. https://doi.org/10.3390/su13010237
37. Ramírez, Rafael. 2016. and Angela Wilkinson. *Strategic Reframing: The Oxford Scenario Planning Approach*. First edition. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780198745693.001.0001
38. Richardson, Katherine, Will Steffen, and Wolfgang Lucht et al. 2023. Earth beyond Six of Nine Planetary Boundaries. *Science Advances* 9(37):eadh2458. https://doi.org/10.1126/sciadv.adh2458
39. Rockström, Johan, Will Steffen, and Kevin Noone et al. 2009. A Safe Operating Space for Humanity. *Nature* 461(7263):472–475. https://doi.org/10.1038/461472a
40. Sandberg, Maria, Kristian Klockars, Kristoffer, and Wilén. 2019. Green Growth or Degrowth? Assessing the Normative Justifications for Environmental Sustainability and Economic Growth through Critical Social Theory. *Journal of Cleaner Production* 206(January):133–141. https://doi.org/10.1016/j.jclepro.2018.09.175
41. Song, Dong-Ping. 2024. A Literature Review of Seaport Decarbonisation: Solution Measures and Roadmap to Net Zero. *Sustainability* 16(4):1620. https://doi.org/10.3390/su16041620
42. Steffen, Will, Wendy Broadgate, Lisa Deutsch, and Owen Gaffney, Cornelia Ludwig. 2015. The Trajectory of the Anthropocene: The Great Acceleration. *The Anthropocene Review* 2(1):81–98. https://doi.org/10.1177/2053019614564785
43. Stopford, Martin. 2009. *Maritime Economics*. 3rd ed. Routledge.
44. UN. 2015. *Transforming Our World: The 2030 Agenda for Sustainable Development*. New York. https://documents.un.org/doc/undoc/gen/n15/291/89/pdf/n1529189.pdf
45. UN. 2023. *Valuing What Counts: Framework to Progress Beyond Gross Domestic Product: Our Common Agenda Policy Brief 4*. UN Executive Office of the Secretary-General (EOSG) Policy Briefs and Papers. UN Executive Office of the Secretary-General (EOSG) Policy Briefs and Papers. New York. https://doi.org/10.18356/27082245-27
46. UNCTAD. 2024. *Review of Maritime Transport 2024*. United Nations Conference on Trade and Development.
47. Uthpala, G. A. J., and C. A. Kavirathna. 2025. Geopolitical Conflicts and The Resilience of Maritime Logistics: A Critical Synthesis. *Journal of Desk Research Review and Analysis* 3(2):45–62. https://doi.org/10.4038/jdrra.v3i2.85
48. Van der Heijden, Kees. 2005. *Scenarios: The Art of Strategic Conversation*. 2nd ed. Wiley.
49. Vogel, Jefim, Jason Hickel. 2023. Is Green Growth Happening? An Empirical Analysis of Achieved versus Paris-Compliant CO2–GDP Decoupling in High-Income Countries. *The Lancet Planetary Health* 7(9):e759–e769. https://doi.org/10.1016/S2542-5196(23)00174-2
50. Wan, Zheng, Anwei Nie, Jihong Chen, Chuan Pang, Yusheng, and Zhou. 2025. Transforming Ports for a Low-Carbon Future: Innovations, Challenges, and Opportunities. *Ocean & Coastal Management* 264:107636. https://doi.org/10.1016/j.ocecoaman.2025.107636
51. World Bank. 2012. *Inclusive Green Growth: The Pathway to Sustainable Development*. The World Bank.
52. World Bank. 2025. *Port Reform Toolkit – Module 1: Trends*. The World Bank. http://documents.worldbank.org/curated/en/099073025114034506

Figures

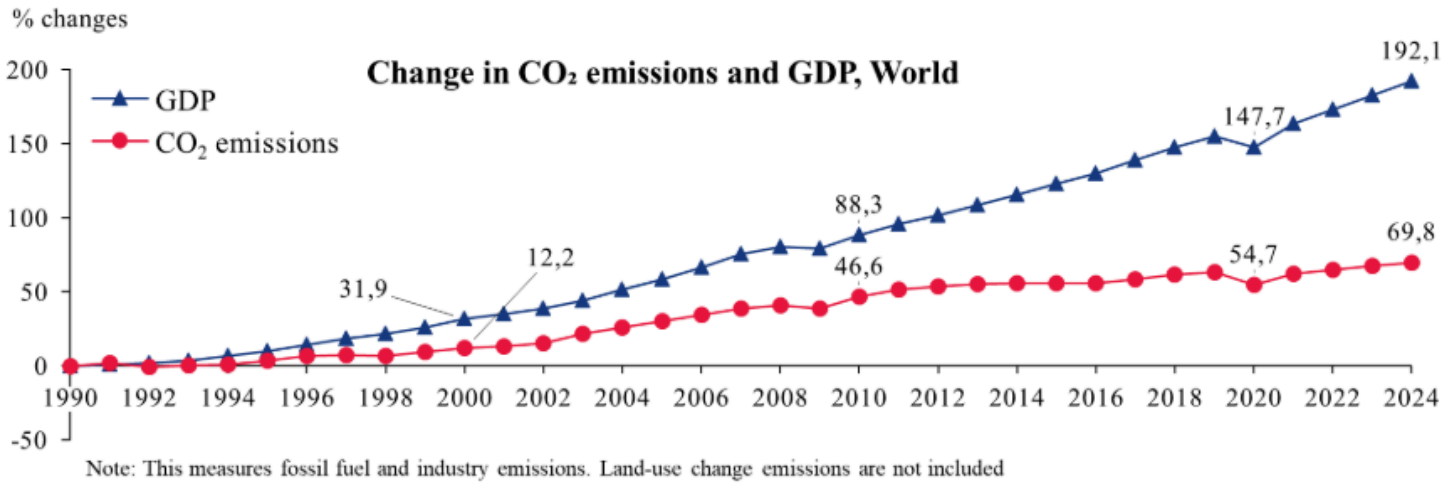


Figure 1

Changes in CO_2 emissions and GDP growth 1990-2024, World region, based on GDP data from Eurostat, OECD, IMF, and World Bank (2026) and CO_2 emission data by Global Carbon Budget (2025)