Ocean and Society
2025 • Volume 2 • Article 9411
https://doi.org/10.17645/oas.9411

cogitatio

ARTICLE

Open Access Journal

Decarbonising Maritime Transport: The Role of Green Shipping Corridors in Making Sustainable Port-City Ecosystems

Mina Akhavan

Faculty of Architecture and the Built Environment, TU Delft, The Netherlands

Correspondence: Mina Akhavan (m.a.akhavan@tudelft.nl)

Submitted: 14 October 2024 **Accepted:** 16 December 2024 **Published:** 6 February 2025

Issue: This article is part of the issue "Global Maritime Flows and Local Implications: A Worldwide Taxonomy and Glossary of Port City Regions" edited by Mina Akhavan (TU Delft), Yvonne van Mil (TU Delft), and Carola Hein (TU Delft) fully open access at https://doi.org/10.17645/oas.i442

Abstract

Maritime transport plays a crucial role in global trade and tourism, yet it significantly contributes to global greenhouse gas emissions, posing environmental challenges that demand urgent solutions. This article explores the innovative concept of maritime green shipping corridors, an emerging strategy aimed at decarbonising the shipping industry. By analysing the origins of green corridors from urban and transportation perspectives, the article outlines their evolution towards multimodal, zero-emission shipping solutions. It highlights the role of international frameworks, such as the International Maritime Organization Clydebank Declaration, in facilitating the transition to green shipping routes and the proliferation of zero-carbon fuels. The article also assesses the integration of renewable energy technologies, alternative fuels, and electrification in port operations, as well as the broader spatial and economic impacts on port-city ecosystems. With the potential to enhance urban sustainability, promote green logistics, and drive global decarbonisation efforts, maritime green shipping corridors represent a crucial framework for future research and policy development. However, the article highlights the need for further studies to evaluate the socio-economic and environmental impacts on local communities and regional planning.

Keywords

green shipping corridors; maritime transport decarbonization; renewable energy in ports; port-city ecosystem

1. Introduction: Green Corridors for Port-Cities in Transition

Maritime transport serves as the backbone of international trade and the global supply chain but also plays a pivotal role in the tourism industry. Shipping and ports are also essential elements of the blue economy—a concept that was drafted at the Rio+20 UN Conference on Sustainable Development in Rio de Janeiro in

June 2012; it is recognised as a framework for sustainable use of the ocean while balancing ocean-related economic activities with environmental concerns (Silver et al., 2015)—and play a vital function in maintaining blue growth across all sectors of the economy (Notteboom et al., 2022). Compared to bulk transportation, shipping is relatively energy efficient in terms of CO_2 emissions. Yet, maritime shipping, both for commodity and passenger flow, raises concerns about human health and environmental issues. Greenhouse gas (GHG) emissions from the maritime sector represent 2.8% of global emissions (Morante, 2022), with projections suggesting an increase to 17% by 2050 (Sinay, 2022). The shipping industry faces significant environmental challenges, including air and noise pollution, vessel discharges, port congestion, and marine ecosystem degradation (Jägerbrand et al., 2019).

To address these challenges, international frameworks such as the International Maritime Organization (IMO) 2020 and 2050 strategies have introduced tools and approaches aimed at sustainable practices in maritime operations. One of the most recent and innovative efforts towards decarbonising shipping and zero-emission fuels is to implement the "green shipping corridors" (hereinafter GSCs) concept, launched officially in 2021. Figure 1 shows the three phases of the shipping sector's transition to zero-emission fuels, highlighting the emergence of GSCs. In this preliminary phase, through national and international actions, learning and R&D, a complex framework of multiple technologies is tested in pilot projects. By 2023 (Phase 2), it was expected that technological developments and optimisation in the supply chain would help lower costs and, therefore, support the proliferation of zero-carbon fuel implementation and smoothen the transition process. In the final phase, the curve may reach a saturation point where zero-emission fuels become the primary shipping fuel (Smith et al., 2021).

Within the outlined framework, this article will provide a comprehensive review of the concept, tracing its origins from environmental, transportation, and planning perspectives, and discuss the potential impact on land and the sea. The aim is to understand the state-of-the-art studies and map a global taxonomy of the relatively new phenomenon of maritime green corridors, which can be used as a conceptual framework for future research lines in sustainable urban and regional studies. This article conducts a comprehensive desk research methodology to explore the concept and implementation of GSCs. Secondary data were collected from official documents, policy reports, and academic publications. The analysis incorporates a content review

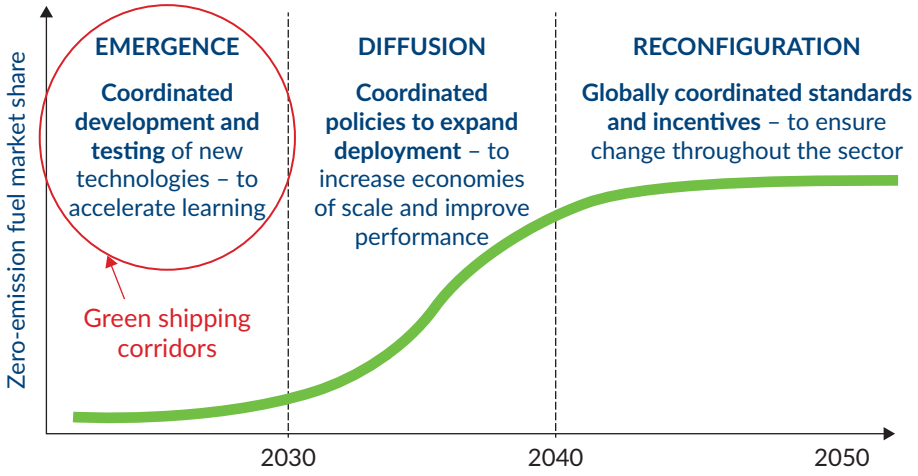

Figure 1. Three phases of the maritime industry transition to zero-emission fuels. Source: Talalasova and Fahnestock (2023, p. 2).

of international initiatives, such as the Clydebank Declaration, and a synthesis of multidisciplinary literature from environmental, urban planning, and transportation domains.

The structure of the article is as follows: Section 2 reviews the origins and conceptual foundations of green corridors (GCs), including urban and transportation perspectives. Section 3 focuses on the definition, implementation processes, and challenges of GSCs. Section 4 discusses the broader implications of GSCs for urban and spatial planning and port-city sustainability. Finally, Section 5 concludes with key findings, research gaps, and potential future directions.

2. Green Corridors: Origins, Concepts, and Definitions

2.1. Urban Green Corridors

The concept of GCs in transportation and shipping is relatively new, but its origins can be traced back to urban planning and design in the late 19th century. Early examples include Olmsted's "Parkways" in the United States and Ebenezer Howard's "Garden City" in England, regarded as pioneering visions of GCs in the early 20th-century town planning. These greenways were designed to create interconnected systems of environmental open spaces, integrating green infrastructure across urban and rural areas to combat air pollution (Hough, 1984). Over time, various movements and visions have emerged to minimise human environmental impact and preserve essential ecosystems by reimagining the relationship between cities and nature and linking natural elements into ecological corridors.

According to one of the forerunners of the contemporary GCs, they are "networks of land containing linear elements that are planned, designed and managed for multiple purposes including ecological, recreational, cultural, aesthetic, or other purposes compatible with the concept of sustainable land use" (Ahern, 1995, p. 134). In the literature, there are already many studies on the topic of GCs—especially from the 1990s onward—mainly from environmental and social science fields. A study by Aman et al. (2022) analysed 406 publications from the Scopus platform (up to mid-2022). Figure 2 shows a co-word analysis of the keywords, and five main clusters (topics) have been identified: (a) Agricultural land and ecology cluster (in red), (b) climate change and water conservation cluster (in green), (c) urban design and land use (in blue), (d) GC and transportation cluster (in yellow), (e) mining and soil erosion (in purple). The authors conclude that although the concept of GCs is not new, the literature is expanding slowly, and more interdisciplinary research is necessary.

2.2. Green Transport Corridors

As briefly discussed in the previous section, the significance of urban and ecological GCs is well documented in the literature (see also Korkou et al., 2023). For this study, it is worth making reference to transportation-related GCs. What is a transport corridor? Here, the definition of Arnold (2006) is used, which considers transport corridors as systems with two dimensions:

> Physical Dimension: one or more routes that connect economic centres within and across countries; these routes are composed of links and nodes that interconnect transport services; gateways are located at endpoints, connecting the corridor to the immediate hinterland.

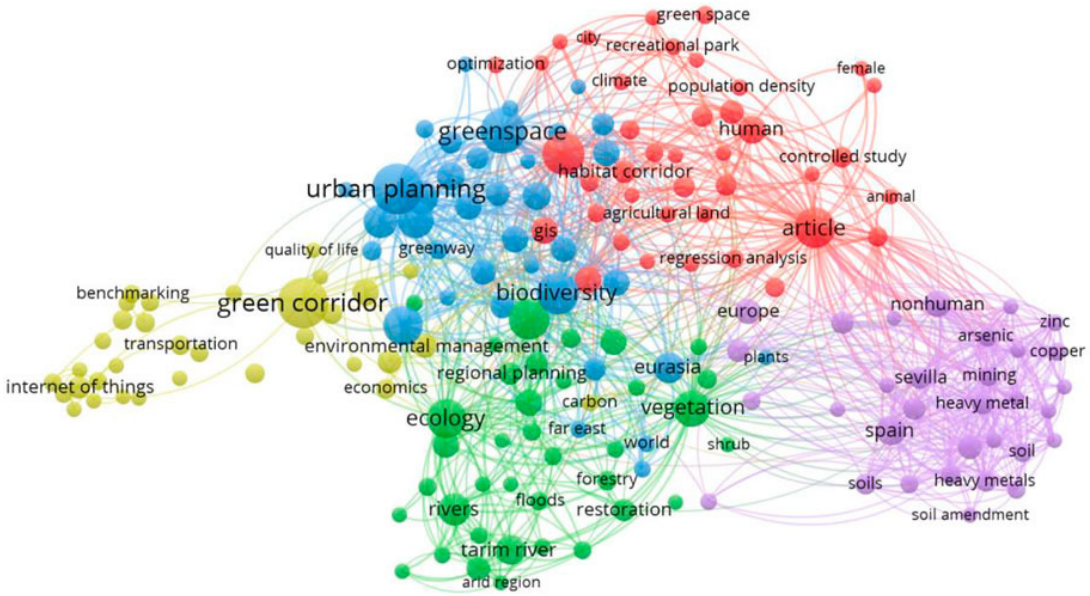

Figure 2. Co-word analysis of keywords from Scopus publications (1990–2022). Source: Aman et al. (2022, p. 2).

> Functional Dimension: as connectors between one or more countries or access providers to the sea for landlocked countries.

Moving from urban GCs to green transport corridors (GTCs), the concept evolves around the re-organisation of transportation systems regarding efficiency and sustainability issues. The initial ideas of GTCs were developed in North America and Scandinavian countries, which are traditionally "more environmentally sensitive." The initial concept concerned modes of transportation using clean energy (Miliauskaitė, 2011). What interests this study is GTC's more recent and developed vision in freight transport and supply chain: GTCs as integrated multimodal, efficient, and sustainable freight transportation solutions (Schröder & Prause, 2015). Freight-based GTCs in Europe were introduced as part of the EU's Freight Transport Logistics Action Plan in 2007: these integrated routes (GTCs) would enable freight to be transported with a reduced environmental impact via a combination of short sea journeys, rail, road, and inland waterways, and of relevant technologies, such as information and communications technology used in intelligent transport systems (European Commission, 2007).

According to the Swedish Logistics Forum, GTCs aim at reducing environmental and climate impact while increasing safety and efficiency and are characterised by:

- Sustainable logistics solutions with documented reductions of environmental and climate impact, high safety, high quality, and strong efficiency.
- Integrated logistics concepts with optimal utilisation of all transport modes, so-called co-modality.
- Harmonised regulations with openness for all actors.
- A concentration of national and international freight traffic on relatively long transport routes.
- Efficient and strategically placed trans-shipment points, as well as an adapted, supportive infrastructure.
- A platform for developing and demonstrating innovative logistics solutions, including information systems, collaborative models, and technology (Kyster-Hansen et al., 2011, p. 18).

3. Decarbonising the Global Maritime Sector: GSCs

3.1. Defining the Concept

Following long-term international efforts to reduce the environmental impact of maritime and shipping activities (e.g., since the 1970s, the International Convention for the Prevention of Pollution from Ships), the International Clydebank Declaration was launched at COP26 in November 2021, following the decarbonisation targets set by IMO. The Declaration aims to promote a coalition among ambitious governments, port(s), and operator(s) to reduce the GHG emissions of shipping routes (zero-carbo emissions ships) through public and private actions and policy measures. Being an innovative initiative, the first question here is the definition of "GSCs" and whether it is port-centric or cargo-centric.

For the Global Maritime Forum and Getting to Zero Coalition, maritime green corridors are specific shipping routes where zero-emission ships' technological, economic, and regulatory feasibility is catalysed by a combination of public and private actions (Global Maritime Forum, 2022). Others define such GCs as innovative systems of creating coalitions of stakeholders—to leverage national interest in the transition to zero-emission shipping in a way that impacts international shipping (Smith et al., 2021). GSCs are, in fact, specialised trade routes connecting major port hubs where zero-emission solutions have been implemented and supported (Talalasova et al., 2022).

Once fully developed, the green shipping corridor entails the different layers between two (major) ports as schematically drafted in Figure 3. Three main layers can be identified here: ports as nodes (land), shipping corridors and connectors (sea), and technology (energy, shipping, and land-based). The collaboration between

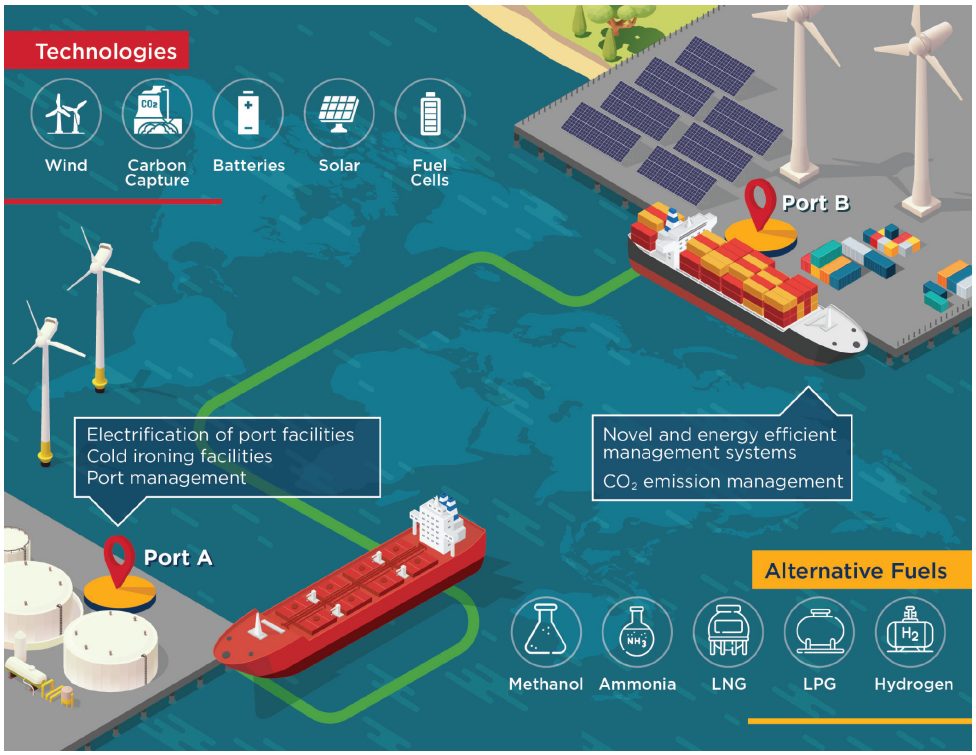

Figure 3. Schematic layers of the green corridor concept. Source: American Bureau of Shipping (2022, p. 2).

stakeholders will then leverage this system by creating a multilayer development plan where all the actors will follow a common objective(s) towards decarbonising maritime activities on land and sea.

The international organisation C40, which thrives on creating a global network of the world's leading cities that are united in action to confront the climate crisis, defines GSCs as "a shipping route on which zero-carbon emissions ships and other emissions reduction programmes are deployed, and emissions reductions are measured and enabled through public and private actions and policies" (C40 Cities, n.d.-a, para. 2). It is worth underlining that C40 has established the Green Ports Forum, which supports ports and cities in advancing maritime decarbonisation and the broader energy transition. It offers a platform for peer-to-peer learning, mobilising knowledge, and catalysing policies and programmes. Accordingly, C40 has created a network of 22 member cities—Auckland, Barcelona, Boston, Callao, Copenhagen, Dubai, Durban, Guangzhou, Los Angeles, Lima, New York, Newark, Oslo, Rotterdam, Seattle, Shanghai, Singapore, Stockholm, Sydney, Tokyo, Vancouver, and Yokohama—and their ports and support them in establishing their green shipping corridor and proposes the following actions:

- Developing special economic zones at the port-city interface to support innovative technologies and business models in tackling climate change.
- Considering best practices and successful programmes offered by C40 (e.g., Zero Emission Areas Programme of 2017; C40 Cities, n.d.-b).
- Tackling broader environmental issues by zero-emissions ships and green ports that contributes to reducing GHG.
- Fostering collaboration among ports and cities and public-private partnerships with the shipping and port-related industries.

3.2. State-of-the-Art Implementation Process and the Role of Actors

By 2023, 27 countries have signed the Clydebank Declaration: Europe (Belgium, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Norway, Spain, Sweden, Great Britain, and Northern Ireland); North America (Canada and the United States); South America (Chile and Costa Rica); Oceania (Australia, Fiji, New Zealand, Palau, and the Republic of the Marshall Islands); North Africa (Morocco); East Asia (Japan, Singapore, and Republic of Korea); and the Middle East (UAE; United Kingdom Government, 2021). About 30 initiatives on GCs have been introduced by public and private stakeholders worldwide (Figure 4). The geography of the announced GCs shows a concentration in North America, (North and Eastern) Europe, and East Asia, which aligns with the region's strategies to decarbonise their economy. Yet, there are huge gaps; being an international sector, maritime transport is regulated by IMO at a global scale, so more countries should engage for a faster transition to the process of decarbonisation (PierNext, 2022).

Collaboration between governmental organisations and other stakeholders is necessary to ensure a promising global impact of GCs. A digital platform called Missions Innovation (see https://mission-innovation.net) monitors GSCs and has mapped various stakeholders looking for partnerships and, therefore, is interested in forming or supporting such corridors. Here is a selection of these stakeholders for each category:

- Government or regulatory authority: for example, (a) Port of Antwerp (Bruges), (b)The Research Council of Norway (investing in R&I and supporting international research to accelerate demonstration

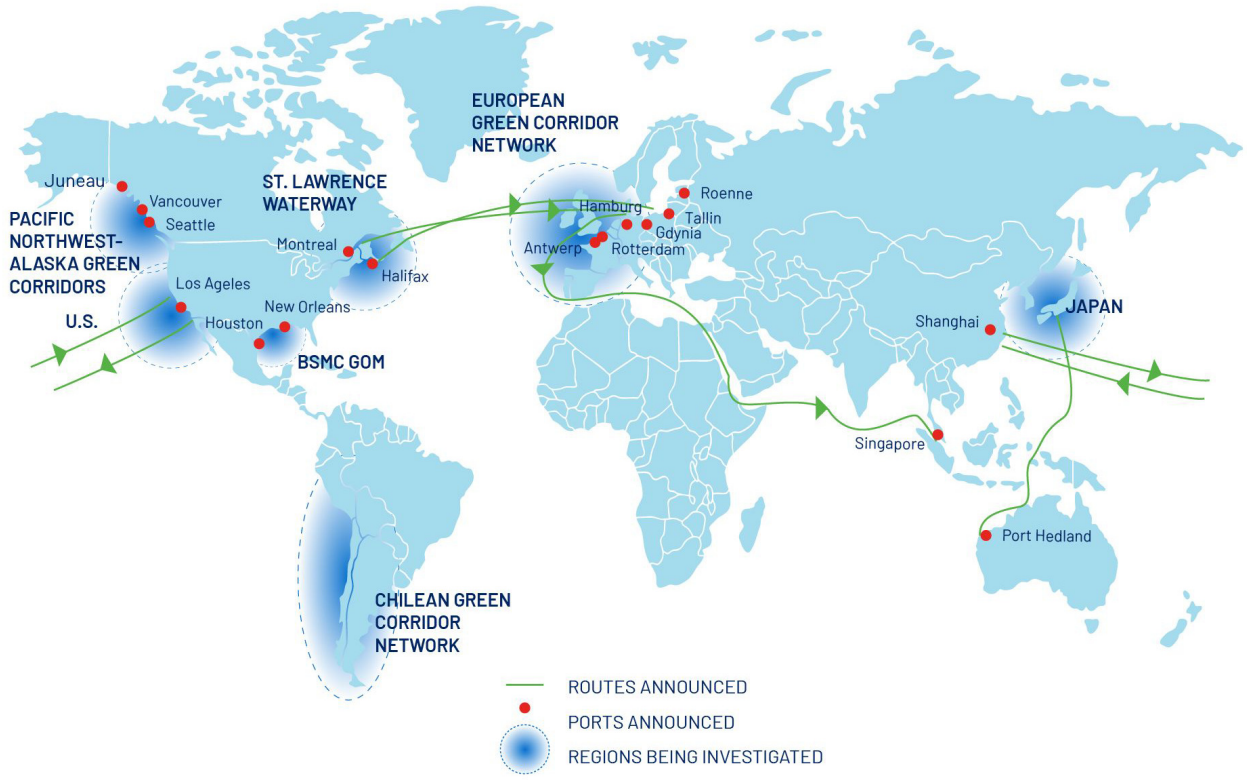

Figure 4. Global initiatives on GSCs (under development or established). Source: Hervas (2023).

and deployment of zero-emission fuel vessels and new ship technologies in GSCs); and (c) Korea Maritime Institute.

- Class society: for example, (a) ACUA Ocean, a UK-based start-up for zero-emission vessel provider that seeks the feasibility of a GSC between the Port of Aberdeen and Norway; and (b) ClassNK, a non-profit third-party certification body based in Japan, supporting stakeholders by providing knowledge and certifications to initiatives on environmental protection.
- Energy provider: For example, (a) Norwegian Hydrogen, which drives the green transition through the development and operation of green hydrogen infrastructure, aimed primarily towards heavy-duty transport and maritime customer segments; and (b) Australian-based Oceania Marine Energy, which is leading the decarbonisation of shipping in the Asia-Pacific.
- Knowledge community: For example, (a) C40 Cities (22 in total); (b) Newcastle University; (c) Fürstenberg Maritime Advisory; and (d) Institute of the North and SeaAhead in the United States.
- NGO: For example, Pacific Environment, a global environmental NGO based in the United States, focuses on empowering local communities with its Port for People campaign.
- Ports and terminal operators: For example, Thames Freeport and Dover Harbour Board in the UK, as well as the Port of Seattle and Port of Oakland in the United States.
- Shipyards and original equipment manufacturers: LR-Shipdesign AG based in Switzerland; Eltronic Fueltech A/S in Denmark; Azane Fuel Solutions AS in Norway.
- Technology provider: Spire Global based in Luxemburg; AMOGY and Zero Emission Industries based in the United States.
- Vessel owners and operators: Viridis Bulk Carriers AS, Amon Maritime AS, and Grieg Ammonia Distribution Vessels AS from Norway; E&S tankers based in Germany.

The geographic distribution of the proposed actors shows that (mainly Northern) Europe, the United States, and, to some extent, East Asia are taking the lead in showing interest in supporting such initiatives. The multiplicity of interested actors is promising. The knowledge community (including research institutions) shows a dominant interest in developing green maritime corridors. The balance between governmental, industrial, and research sectors (plus academia) has yet to be achieved by encouraging more stakeholders from various categories to collaborate in this initiative.

The world's first GSC was announced in January 2022 between two major ports in the United States (the Port of Los Angeles), China (Port of Shanghai), and C40 cities. This partnership between cities, ports, and maritime industries (including shipping companies and cargo owners) will create the first trans-Pacific GC in one of the world's busiest container routes, reduce GHG emissions from cargo flows, and support the shipping transition to decarbonisation. Based on their Green Shipping Corridor Implementation Plan Outline, the participants of this corridor strive to reduce carbon emissions from shipping and port activities and to address local community impacts. Figure 5 illustrates the conceptual framework of the Los Angeles–Shanghai Green Shipping Corridor, highlighting the collaborative process among key stakeholders and the "gate-to-gate" approach to emissions reduction. Focusing on emissions reductions at all stages of the shipping life cycle—from port operations to vessel transit—the corridor adopts a comprehensive approach that includes both on-land and at-sea solutions. This highlights its dual impact on local air quality and global decarbonisation.

The Los Angeles–Shanghai Green Shipping Corridor represents a pioneering collaboration among key stakeholders to achieve decarbonisation in maritime transport. Four stakeholder groups—carrier partners, port partners, cargo owner partners, and all partners—are tasked with specific goals to drive progress. Carrier partners aim to enhance technical and operational efficiency for participating shipping lines, targeting the deployment of zero-lifecycle carbon emission ships by 2030. They are also responsible for developing innovative solutions to improve the sustainability of shipping operations. Port partners play a crucial role by investing in clean marine fuelling infrastructure, ensuring reliable services for shore-based power, and reducing emissions from terminal operations. These efforts create the necessary foundation for adopting green technologies at ports. Cargo owner partners are tasked with contracting shipping services

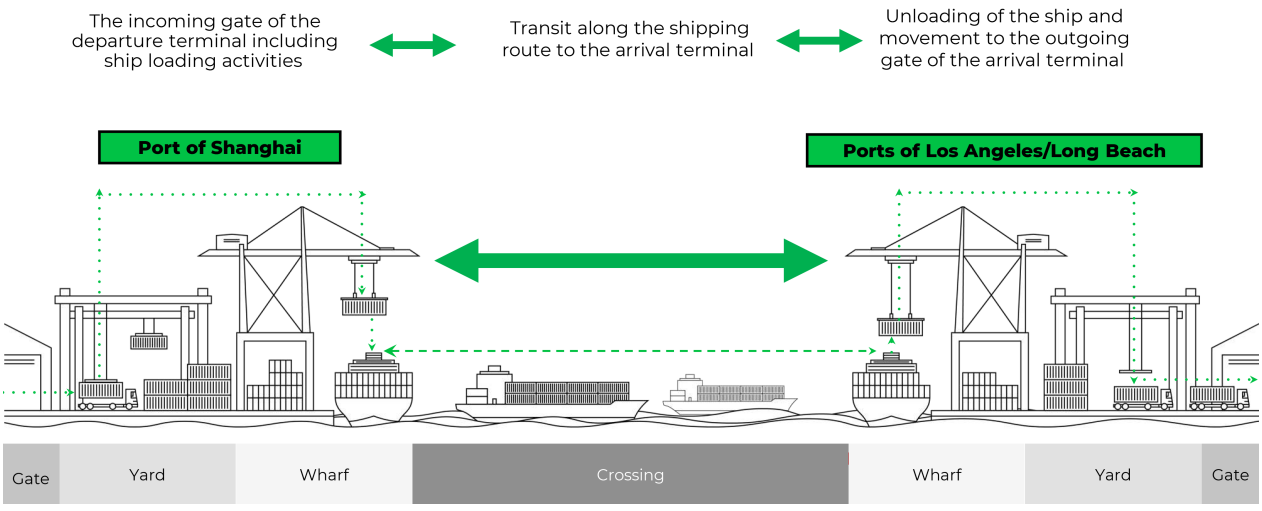

Figure 5. Schematic vision of the Port of Los Angeles–Port of Shanghai Green Shipping Corridor. Source: C40 Cities (n.d.-c).

that use zero-carbon emission technologies, committing to increased adoption over time. They also advocate for policy measures that make green solutions economically viable. All partners share responsibility for setting tangible CO_2 reduction goals, regularly reviewing progress, and identifying pathways for improvement. Together, they aim to support the feasibility and demonstration of the world's first zero-lifecycle carbon emission container ships, fostering innovation and sustainable practices across the shipping industry (C40 Cities, 2023).

This pioneering Los Angeles–Shanghai corridor is particularly significant as the initial foundation of an innovative framework for cross-value-chain collaboration starts at the local level: the cities and their ports in both cases of Los Angeles and Shanghai are run by their municipalities. In this regard, Alisa Kreynes, deputy director of ports and shipping for C40 Cities, stated at the C40 Ports Forum in 2021:

> We work at the city-to-city level, which makes things a lot more efficient than working at the state or national level. So, in the case of the United States and China, we were able to overcome some of the geopolitical tensions and complexities that were certainly not in our favour at that time. (LaBrecque, 2023, para. 7)

Therefore, in this example, the corridor is "port-centric" as it initiates from the port level, so the system priority settings and fuel choices are set based on the air quality issues and local community and environmental interests in both port-cities (Global Maritime Forum, 2022).

In contrast to the port-centric corridors are the "route-centric" ones (e.g., the West Australia-East Asia iron ore GC), which are not driven by the ports themselves but may originate from ambitious countries and their strategic interest, which vary from region to region. Here, GCs can contribute to national goals on sustainability in the following areas:

- Maritime competitiveness: GC strategy as a tool to modernise the country's maritime sector and to secure, future-proof, or strengthen the national maritime competitiveness.
- Energy leadership: GCs enable a country's transition by securing its position in the future energy market.
- Climate leadership: GCs contribute to the broader decarbonisation agenda and the global climate movement.
- Innovation and technology leadership: GCs secure the country's competitiveness in the global knowledge economy by entering into a new market for innovation and advanced technology.
- Strengthening trade partnerships: GCs secure national competitiveness in global trade flows by offering advantageous conditions for trade along significant routes (Talalasova & Fahnestock, 2023).

3.3. Green Shipping Corridors Implementation and Challenges in Energy Transition and Innovation

The implementation of such GCs is associated with adopting alternative fuels, renewable energy technologies, and the electrification of shipping operations. A significant aspect of establishing GSCs is the integration of renewable energy technologies within port operations. Ports are increasingly designed to minimise carbon footprint by optimising energy use and reducing reliance on fossil fuels. This transition is essential for achieving the decarbonisation goals set by international maritime organisations, which aim to substantially reduce GHG emissions from shipping activities (Camargo-Díaz et al., 2022). Incorporating renewable energy technologies

not only supports the operational efficiency of ports but also aligns with broader environmental objectives, such as those outlined in the European Green Deal, which emphasises the importance of sustainable energy practices in various sectors, including maritime transport (Ustolin et al., 2022).

Alternative fuels also play a crucial role in the decarbonisation of maritime transport. Fuels such as hydrogen, ammonia, and biofuels are being explored as viable options to replace traditional marine fuels. Studies indicate that the life cycle emissions of biofuels can significantly reduce GHG emissions compared to conventional fuels, showcasing their potential to achieve a more sustainable maritime sector (Q. Wang et al., 2023). Moreover, the use of ammonia as a shipping fuel has gained traction, although it raises concerns regarding secondary emissions and environmental impacts that must be addressed (H. Wang et al., 2023). IMO has set ambitious targets for reducing GHG emissions from shipping, with a commitment to at least a 50% reduction by 2050, necessitating the widespread adoption of these alternative fuels (Serra & Fancello, 2020).

The electrification of vessels is another critical component of maritime GCs. Hybrid electric systems and battery-powered ships are being developed to enhance energy efficiency and reduce emissions during operations (Torreglosa et al., 2022). The transition to electric propulsion systems not only lowers operational emissions but also aligns with the global push towards cleaner energy sources. However, the initial investment costs for these technologies can be high, which poses a challenge for widespread adoption (Y. Zhang et al., 2022). Economic incentives and supportive policies are essential to encourage investment in green technologies and infrastructure to facilitate this transition (see Qadir et al., 2021, for a review).

4. Potential Implications of Green Shipping Corridors for Urban/Spatial Planning and Sustainable Port-City Ecosystem

The implications of GSCs for cities and spatial planning are yet vague and to be discovered. However, GSCs may represent a shift towards sustainable urban development and integrated transport systems. Such corridors, which facilitate the movement of low-emission vessels and promote sustainable maritime practices, necessitate re-evaluating urban planning strategies to integrate these corridors effectively into territory and land use. This integration can enhance urban sustainability, improve connectivity, and foster economic growth while addressing environmental concerns.

The implementation of GCSs demands spatial planning and policy approaches that align transportation infrastructure with urban development goals. Jurković and Lovoković (2023) discuss that corridor planning should focus on creating synergies between transport systems and surrounding land uses, thereby enhancing the overall development value of cities. This approach ensures that GCs do not merely serve as transportation routes but also contribute to urban vitality and sustainability. For instance, integrating GCs can facilitate the development of multifunctional spaces that promote recreational activities, biodiversity, and community engagement (Z. Zhang et al., 2019). Moreover, planners and decision-makers must ensure that ports, as nodes of GSCs, are equipped with sustainable logistics infrastructure, including renewable energy facilities, alternative fuel storage, and electrification systems. Hence, GSCs will impact land use policies and redesign urban spaces to prioritise eco-friendly logistics hubs, improving connectivity between ports and hinterlands while minimising environmental impacts. As cities adapt to the increasing importance of maritime transport, there is a need to reserve spaces for port-related activities and infrastructure that support green shipping initiatives. H. Wang and Zhang (2020) highlight the importance of evidence-based

environmental planning in urban areas, which can guide city managers in enhancing and conserving GCs and ecological networks.

The establishment of GSCs also has implications for regional development. By enhancing connectivity between urban centres and ports, these corridors can stimulate economic growth and facilitate sustainable trade. Mao et al. (2023) show that developing international transport corridors (in the example of China–Europe) can improve regional green economic efficiency as a new overland trade between regions. Furthermore, the transition to GSCs can catalyse the development of green infrastructure, which is crucial for sustainable urban planning. Lennon (2014) discusses how green infrastructure can enhance ecological sensitivity in urban areas, promoting greater biodiversity and improving the quality of life for residents. Integrating GSC with the urban GCs can facilitate the establishment of ecological networks that connect green infrastructures, thereby enhancing biodiversity and providing essential ecosystem services.

GSCs can significantly impact the economic and logistical aspects of port-city interactions. Implementing such corridors encourages the use of advanced technologies and co-modality in freight transport, which can lead to increased efficiency and reduced GHG emissions (Penela et al., 2012). This shift towards greener logistics not only aligns with global decarbonisation goals but also enhances the competitiveness of ports by attracting environmentally conscious businesses and consumers (Song et al., 2023). Also, the development of green ports can serve as a model for sustainable development, providing valuable lessons for cities aiming to integrate sustainability into their economic frameworks (Nguyen et al., 2022). The strategic planning of GSCs can facilitate the integration of renewable energy technologies into port operations. Adopting renewable energy in ports is crucial for reducing the environmental impact of maritime logistics (Parhamfar et al., 2023). By aligning green shipping initiatives with urban energy strategies, cities can create a more sustainable and resilient infrastructure supporting economic growth and environmental stewardship.

Moreover, the governance and management of GSCs require collaboration among various stakeholders, including governmental bodies, private sector entities, and local communities. The involvement of diverse stakeholders is essential for successfully realising GTCs, as it fosters a sense of shared responsibility and collective action towards sustainability (Prause & Schröder, 2015). This collaborative approach can lead to the establishment of comprehensive policies that support sustainable urban development and enhance the resilience of port-city ecosystems against climate change.

GSCs can, therefore, represent a complementary effort for the complex and multidimensional concept of sustainability and sustainable development. Here, it is worth mentioning the three-pillar conception of sustainability (social, economic, and environmental)—introduced by Barbier (1987) in the mid-1980s, which today is known as a common view for a model of sustainable development (Purvis et al., 2019). While conceptualising the GSC, I suggest adding a fourth pillar to the sustainability concept: institutions and actors (governmental and non-governmental). Therefore, a schematic diagram of the four intertwined pillars for sustainable development of port-city regions connected to green maritime corridors and green ports is reimagined, as illustrated in Figure 6.

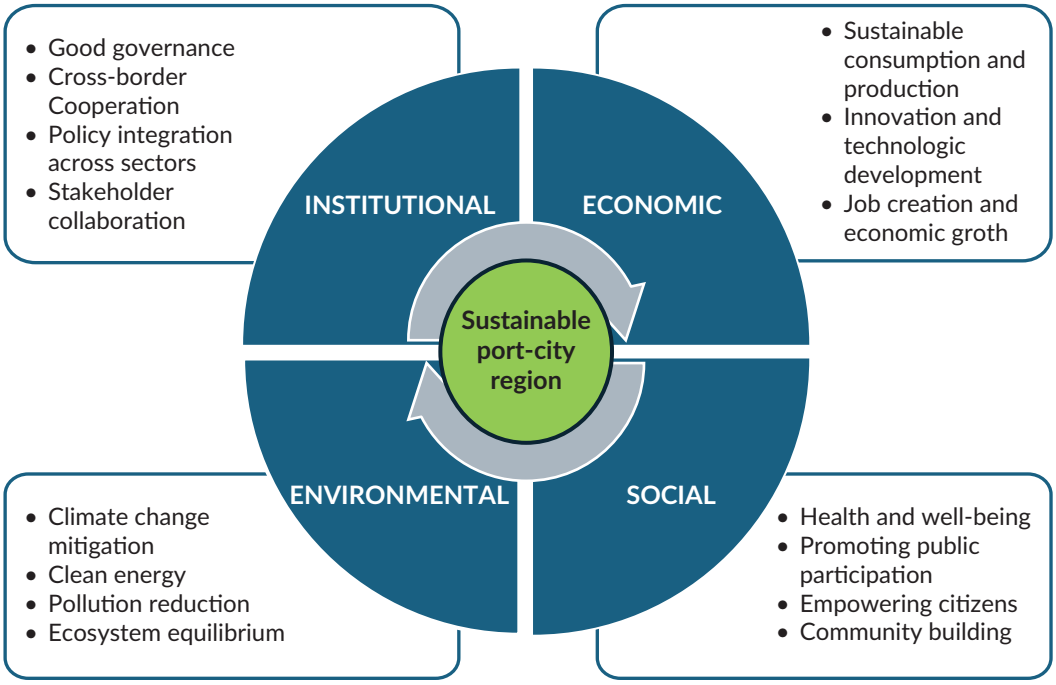

Figure 6. The four-pillar dimension of sustainable development of port-city regions connected to green maritime corridors.

5. Concluding Remarks: Rethinking Ports and Their Green-Blue Connection

The concept of GSCs and their environmental impacts within the broader topic of energy transition in the maritime sector is gradually gaining attention in different regions of the globe. Such corridors are pivotal in the ongoing transition towards sustainable shipping practices. They facilitate the movement of vessels with low-emission fuels and technologies, thereby reducing the environmental impact of maritime transport. The implementation of GCs is closely linked to the adoption of alternative fuels, renewable energy technologies, and the electrification of shipping operations.

On the other hand, GSCs create worldwide networks of nodes (ports and port-cities) and links (shipping routes), which necessitates a complex stakeholder configuration and collaboration. Offering favourable conditions for accelerated actions in terms of environmental policy, energy production, and shipping operations, GSCs can function as "special economic zones at sea," which should be expanded and linked to green ports on land. This will allow policymakers to enable an ecosystem with regulations and financial incentives to support the transition, for example, in lowering the cost of green fuel.

If we consider ports as nodes of connections and shipping corridors as links between these nodes, GSCs may also contribute to the energy transition of port-city-regions worldwide. However, disaggregated and transparent data is needed to undertake detailed studies on the extent of the state-of-the-art actions of such corridors and the technological and policy-related challenges. Moreover, being a new and rather complex global programme, no study is yet available on this concept's potential (positive and negative) impacts on the territory: port hinterland, their hosting city, and region. Empirical research is necessary to understand the spatial implication of the shipping energy transition on land (soil consumption, land use, etc.) and how it will be integrated (or not) with other GCs (urban and transportation). Although GSCs are turning points in the

zero-emission transition of the maritime sector and can create clusters of innovation for high-ambition ports and actors in the global supply chain, it is unclear to what extent local communities can benefit from such a transition. Here, I have outlined some challenges that raise questions for the future implementation and success of green maritime corridors, which would also become future research lines:

- Political and governmental support, along with the creation of a transborder collaboration among different countries: What is the role of regional policy and planning? Can the EU regional framework, such as the MSP, facilitate cross-border cooperation for implementing GSCs?
- A collaborative framework for joint action between various stakeholders: What tools and methods are needed to encourage cooperation among governments, industry, and academia? What are the implications for the private operators, and how does it impact the worldwide competitiveness of ports and shipping operators?
- Technological advancements and challenges: What is the role of the public sector in providing financial incentives and investing in R&I, start-ups, and the green technology industry?
- Interaction between the green maritime corridors, land, and local communities: How can community leaders be included in the implementation process for a just society?

Despite their potential, GSCs face significant challenges, including high implementation costs, technological uncertainties, and resistance to regulatory changes. More empirical research is needed to evaluate the socio-economic impacts of GSCs on local communities and regions. Studies on land use conflicts, soil consumption, and urban resilience are crucial to understanding how GSCs coexist with other urban green initiatives. Research on stakeholder collaboration is equally important to identify effective governance models that balance public and private interests while addressing the needs of vulnerable communities. Technological advancements in renewable energy, alternative fuels, and electrification must also be scaled up, requiring robust financial mechanisms and supportive policies.

Funding

This work was supported by Horizon.1.2—Marie Skłodowska-Curie Actions (MSCA), Project RePortFlows, under the Grant agreement ID: 101066680.

Conflict of Interests

In this article, editorial decisions were undertaken by Yvonne van Mil (TU Delft) and Carola Hein (TU Delft).

Data Availability

All data used in this research (mainly secondary) is open data, and relevant sources are provided in the text.

References

Ahern, J. (1995). Greenways as a planning strategy. *Landscape and Urban Planning*, *33*(1/3), 131–155. https://doi.org/10.1016/0169-2046(95)02039-v

Aman, A., Rafiq, M., Dastane, O., & Sabir, A. A. (2022). Green corridor: A critical perspective and development of research agenda. *Frontiers in Environmental Science*, *10*. https://doi.org/10.3389/fenvs.2022.982473

American Bureau of Shipping. (2022). *Green shipping corridors: Leveraging decarbonization to accelerate implementation*. American Bureau of Shipping. https://ww2.eagle.org/content/dam/eagle/publications/whitepapers/02-green-shipping-corridors-22380.pdf

Arnold, J. (2006). *Best practices in management of international trade corridors*. The World Bank Group. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/441171468315291413/best-practices-in-management-of-international-trade-corridors

Barbier, E. B. (1987). The concept of sustainable economic development. *Environmental Conservation*, *14*(2), 101–110. https://doi.org/10.1017/S0376892900011449

C40 Cities. (n.d.-a). *Decarbonising the global shipping industry*. https://www.c40.org/what-we-do/scaling-up-climate-action/ports-and-shipping/green-shipping-corridors/#:~:text=A%20green%20shipping%20corridor%20is,and%20private%20actions%20and%20policies

C40 Cities. (n.d.-b). *Zero emission area programme*. https://www.c40.org/what-we-do/scaling-up-climate-action/transportation/zero-emission-area-programme

C40 Cities. (n.d.-c). *Port of Los Angeles–Port of Shanghai green shipping corridor partnership implementation plan outline* [PowerPoint presentation]. https://www.c40.org/wp-content/uploads/2023/09/Green-Shipping-Corridor-GSC_presentation_V23_082123_ENG-compressed.pdf

C40 Cities. (2023, September 22). *Ports of Los Angeles, Long Beach, and Shanghai unveil implementation plan outline for first trans-Pacific green shipping corridor* [Press release]. https://www.c40.org/news/la-shanghai-implementation-plan-outline-green-shipping-corridor

Camargo-Díaz, C. P., Paipa-Sanabria, E., Zapata-Cortes, J. A., Aguirre-Restrepo, Y., & Quiñones-Bolaños, E. E. (2022). A review of economic incentives to promote decarbonization alternatives in maritime and inland waterway transport modes. *Sustainability*, *14*(21), Article 14405. https://doi.org/10.3390/su142114405

European Commission. (2007, October 10). *Freight transport logistics action plan* [Press release]. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex:52007DC0607

Global Maritime Forum. (2022). *Green corridors: Definitions and approaches*. https://www.globalmaritimeforum.org/news/green-corridors-definitions-and-approaches

Hervas, M. (2023). *Green shipping corridors: All hands on deck for maritime sustainability*. PierNext. https://piernext.portdebarcelona.cat/en/environment/green-shipping-corridors

Hough, M. (1984). *City form and natural process: Towards a new urban vernacular*. Croom Helm.

Jägerbrand, A. K., Brutemark, A., Svedén, J. B., & Gren, I. (2019). A review on the environmental impacts of shipping on aquatic and nearshore ecosystems. *Science of the Total Environment*, *695*, Article 133637. https://doi.org/10.1016/j.scitotenv.2019.133637

Jurković, Ž., & Lovoković, D. (2023). Corridor planning—Sustainable planning? *Sustainability*, *15*(21), Article 15502. https://doi.org/10.3390/su152115502

Korkou, M., Tarigan, A. K. M., & Hanslin, H. M. (2023). The multifunctionality concept in urban green infrastructure planning: A systematic literature review. *Urban Forestry & Urban Greening*, *85*, Article 127975.

Kyster-Hansen, H., Thisgaard, P., Henriques, M., & Niss, M. K. (2011). *Green corridor manual (draft)—Purpose, definition and vision for green transport corridors*. Danish Transport Authority. https://www.doc-developpement-durable.org/file/Culture/Arbres-Bois-de-Rapport-Reforestation/forets-preservation-restoration/Corridors%20biologiques/Green%20Corridor%20Manual.pdf

LaBrecque, S. (2023, July 3). Los Angeles and Shanghai port cities collaborating to cut shipping emissions. *Reuters*. https://www.reuters.com/sustainability/climate-energy/los-angeles-shanghai-port-cities-collaborating-cut-shipping-emissions-2023-07-03

Lennon, M. (2014). Green infrastructure and planning policy: A critical assessment. *Local Environment*, *20*(8), 957–980. https://doi.org/10.1080/13549839.2014.880411

Mao, Y., Xie, Y., & Zhuo, C. (2023). How does international transport corridor affect regional green

development: Evidence from the China-Europe railway express. *Journal of Environmental Planning and Management*, *67*(7), 1602–1627. https://doi.org/10.1080/09640568.2023.2176296

Miliauskaitė, L. (2011). Evaluation of the green transport corridor concepts in the EU area. In V. Bartulis (Ed.), *Proceedings of the 7th International Conference TRANSBALTICA 2011*(pp. 112–119). Warsaw University of Technology.

Morante, E. (2022). *Roadmap to decarbonize the shipping sector: Technology development, consistent policies and investment in research, development and innovation*. United Nations Transport and Development. https://unctad.org/news/transport-newsletter-article-no-99-fourth-quarter-2022

Nguyen, H. P., Nguyen, P. Q. P., & Nguyễn, T. P. (2022). Green port strategies in developed coastal countries as useful lessons for the path of sustainable development: A case study in Vietnam. *International Journal of Renewable Energy Development*, *11*(4), 950–962. https://doi.org/10.14710/ijred.2022.46539

Notteboom, T., Pallis, A., & Rodrigue, J-P. (2022). *Port economics, management and policy*. Routledge. https://doi.org/10.4324/9780429318184

Parhamfar, M., Sadeghkhani, I., & Adeli, A. M. (2023). Towards the application of renewable energy technologies in green ports: Technical and economic perspectives. *IET Renewable Power Generation*, *17*(12), 3120–3132. https://doi.org/10.1049/rpg2.12811

Penela, A. C., Mantecón, I. M., Doménech, J. L., & Coto-Millán, P. (2012). From the motorways of the sea to the green corridors' carbon footprint: The case of a port in Spain. *Journal of Environmental Planning and Management*, *55*(6), 765–782. https://doi.org/10.1080/09640568.2011.627422

PierNext. (2022). *Green shipping corridors: What does the Clydebank Declaration propose?* https://piernext.portdebarcelona.cat/en/mobility/green-shipping-corridors-clydebank-declaration

Prause, G., & Schröder, M. (2015). KPI building blocks for successful green transport corridor implementation. *Transport and Telecommunication Journal*, *16*(4), 277–287. https://doi.org/10.1515/ttj-2015-0025

Purvis, B., Mao, Y., & Robinson, D. (2019). Three pillars of sustainability: In search of conceptual origins. *Sustainability Science*, *14*, 681–695. https://doi.org/10.1007/s11625-018-0627-5

Qadir, S. A., Al-Motairi, H., Tahir, F., & Al-Fagih, L. (2021). Incentives and strategies for financing the renewable energy transition: A review. *Energy Reports*, *7*, 3590–3606. https://doi.org/10.1016/j.egyr.2021.06.041

Schröder, M., & Prause, G. (2015). Risk management for green transport corridors. *Journal of Security and Sustainability Issues*, *5*(2), 229–239.

Serra, P., & Fancello, G. (2020). Towards the IMO's GHG goals: A critical overview of the perspectives and challenges of the main options for decarbonizing international shipping. *Sustainability*, *12*(8), Article 3220. https://doi.org/10.3390/su12083220

Silver, J. J., Gray, N. J., Campbell, L. M., Fairbanks, L. W., & Gruby, R. L. (2015). Blue economy and competing discourses in international oceans governance. *The Journal of Environment & Development*, *24*(2), 135–160. https://doi.org/10.1177/1070496515580797

Sinay. (2022). *What are five environmental impacts related to shipping?* https://sinay.ai/en/what-are-five-environmental-impacts-related-to-shipping

Smith, T., Baresic, D., Fahnestock, J., Galbraith, C., Velandia Perico, C., Rojon, I., & Shaw, A. (2021). *A strategy for the transition to zero-emission shipping*. Global Maritime Forum. https://globalmaritimeforum.org/report/a-strategy-for-the-transition-to-zero-emission-shipping

Song, Z., Chhetri, P., Ye, G., & Lee, P. T. (2023). Green maritime logistics coalition by green shipping corridors: A new paradigm for the decarbonisation of the maritime industry. *International Journal of Logistics Research and Applications*. Advance online publication. https://doi.org/10.1080/13675567.2023.2256243

Talalasova, E., Boyland, J., Garvin, B., & Fahnestock, J. (2022). *2022 annual progress report on green shipping*

corridors. Global Maritime Forum. https://globalmaritimeforum.org/report/2022-annual-progress-report-on-green-shipping-corridors

Talalasova, E., & Fahnestock, J. (2023). *National and regional policy for green shipping corridors*. Global Maritime Forum. https://www.globalmaritimeforum.org/news/national-and-regional-policy-for-green-shipping-corridors

Torreglosa, J. P., González-Rivera, E., García-Triviño, P., & Vera, D. (2022). Performance analysis of a hybrid electric ship by real-time verification. *Energies*, *15*(6), Article 2116. https://doi.org/10.3390/en15062116

United Kingdom Government. (2021). *Cop 26: Clydebank Declaration for green shipping corridors*. https://www.gov.uk/government/publications/cop-26-clydebank-declaration-for-green-shipping-corridors

Ustolin, F., Campari, A., & Taccani, R. (2022). An extensive review of liquid hydrogen in transportation with focus on the maritime sector. *Journal of Marine Science and Engineering*, *10*(9), Article 1222. https://doi.org/10.3390/jmse10091222

Wang, H., & Zhang, P. (2020). Urban green corridors analysis for a rapid urbanization city exemplified in Gaoyou city, Jiangsu. *Forests*, *11*(12), Article 1374. https://doi.org/10.3390/f11121374

Wang, Q., Zhang, H., Huang, J., & Zhang, P. (2023). The use of alternative fuels for maritime decarbonization: Special marine environmental risks and solutions from an international law perspective. *Frontiers in Marine Science*, *9*. https://doi.org/10.3389/fmars.2022.1082453

Wang, H., Daoutidis, P., & Zhang, Q. (2023). Ammonia-based green corridors for sustainable maritime transportation. *Digital Chemical Engineering*, *6*, Article 100082. https://doi.org/10.1016/j.dche.2022.100082

Zhang, Y., Lin, S., Wu, Y., Jiang, W., & Fu, L. (2022). Collaborative optimization of the battery capacity and sailing speed considering multiple operation factors for a battery-powered ship. *World Electric Vehicle Journal*, *13*(2), Article 40. https://doi.org/10.3390/wevj13020040

Zhang, Z., Meerow, S., Newell, J. P., & Lindquist, M. (2019). Enhancing landscape connectivity through multifunctional green infrastructure corridor modeling and design. *Urban Forestry & Urban Greening*, *38*, 305–317. https://doi.org/10.1016/j.ufug.2018.10.014

About the Author

Mina Akhavan is a multidisciplinary researcher and lecturer in spatial planning and regional studies, currently based in TU Delft, Faculty of Architecture and the Built Environment. In 2022, she was awarded the Horizon Europe—Marie Skłodowska-Curie Action and led the project (Re)Connecting Maritime Ecosystems: Geospatial Mapping of the "Spaces of Flows" in Port-City Regions (RePortFlows; 2022–2024). She previously worked as a postdoctoral research fellow and adjunct professor at Politecnico di Milano, where she earned her PhD in spatial planning and urban development.