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Green Shipping Corridors: implementation barriers and strategic research directions

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ABSTRACT

Since the inception of the Green Shipping Corridor (GSC) concept in 2021, 126 GSCs have been initiated worldwide as of January 2026. However, significant misunderstandings have occurred regarding the naming of GSCs, their governance frameworks, the type of zero-emission vessels (ZEVs) with alternative fuels and ZEV fleet deployment on GSCs, and the greenhouse gas emissions computation from the fleet. To address these, this paper aims to conduct a systematic review of the development of GSCs by incorporating the most recent literature and policy developments. By doing so, it clarifies common misunderstandings of the GSC concept. This paper contributes to further refinement of GSC concept to enhance the implementation of GSCs in advancing the decarbonisation of the maritime industry. The paper also proposes research and policy agendas in implementing GSCs and optimizing ZEV fleet deployment.

KEYWORDS

Green Shipping Corridor; International Maritime Organization (IMO); maritime decarbonisation; zero-emission vessel; net zero framework

1. Introduction

The Clydebank Declaration at the 26th Conference of the Parties (COP26) in Glasgow, United Kingdom, in November 2021 initiated the '*Green Shipping Corridor* (GSC)[1]'. GSCs are defined as zero-emission maritime routes between two or more ports, with the aim of establishing at least six corridors by the mid-2030s to reduce greenhouse gas (GHG) emissions from international shipping"[2]. The GSC concept is based on five core pillars outlined in the updated policy paper, '*COP 26: Clydebank Declaration for green shipping corridors*' (Department for Transport, U.K. 2022): i) the Paris Agreement at COP21, ii) the IMO's Resolution MEPC.304(72), iii) the IMO's MARPOL Annex VI, iv) the Fourth IMO Greenhouse Gas Study 2020, and v) the Sixth Assessment Report (2021). The GSC initiative is gaining momentum to reduce GHG emissions from international shipping through

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multi-stakeholder coalitions. Song et al. (2025) thoroughly addressed the GSC concept, its 10 key stakeholders, its development status with leading routes, and the research agenda related to implementation challenges, the building and operation of ZEVs, and green fuel supply chains.

Despite overwhelming documentations issued by subsequent COPs (e.g. Shipping Challenge 2022, 2023, 2024), reports by knowledge institutes and think tanks, including the Global Maritime Forum (e.g. GMF 2025), and expanded academic literature (e.g. Lee 2023; Song et al. 2025), misunderstandings persist on the naming of GSCs, governance frameworks, the types of ZEVs with green (or alternative) fuels (e.g. methanol, ammonia, LNG), fleet deployment on shipping routes, and the calculation of GHG emissions from ZEV operations. Arguably, these misunderstandings pose numerous challenges to global promotion and implementation of GSCs, with the potential of misinformation and confusion for stakeholders, policymakers, and academia in the decision-making process. For example, Lyu, Jin, and Wang (2026) incorrectly used the term 'green maritime corridor' more than 50 times in their paper, rather than the accepted terms GSC or GDSC. Additionally, those authors calculated the GHG emission reductions of container ships ranging from feeder vessels to Super Panamax (i.e. 900– 15,000 TEU vessels), factoring in the use of methanol and ammonia, as well as the investment costs for green fuel bunkering facilities. However, as shown in Tables 5 and 6 in Section 3, container ships utilizing ammonia, along with the corresponding ammonia bunkering facilities at ports along the GSC routes described in their paper, are not yet in operation as of January 2026. Another misunderstanding concerns GSC governance. GSCs are not governed by the EU ETS or the IMO; rather, they are managed and monitored by the UNFCCC through its series of COP annual meetings. Lyu, Jin, and Wang (2026) applied the EU ETS and FuelEU Maritime frameworks to Transpacific routes when calculating the economic performance of ammonia and analysing financial incentives for switching from fossil fuels to alternative fuels. However, this approach is based on a fundamental misunderstanding of the EU ETS, FuelEU Maritime, and the GSC framework itself. This will be discussed further in the literature review section. Therefore, the aim of this paper is threefold: first, to update the development of GSCs from COP26 to COP30 across deep sea shipping (DSS), short sea shipping (SSS), and regional categories; second, to correct misunderstandings of GSCs in the existing literature while highlighting implementation challenges from the perspectives of key stakeholders; and third, to set out research agendas and future directions for decarbonizing the maritime industry in the context of GSCs, updating the work of Song et al. (2025).

The contributions of this paper are as follows: First, compared to existing research, this study is the first attempt to provide multi-layered, rich data on GSC as of January 2026. This includes data on origin-destination pairs, cargo types, deep-sea routes versus short-sea shipping, country-specific and green fuel type-specific ship orders, and statistics on ZEVs in operation. Second, this comprehensive information and rich data will contribute to modelling related to GHG emission reductions, optimizing the capital and operational costs of ZEVs associated with their fleet deployment on GSCs, positioning green fuel hub ports along the GSCs, estimating demand for green fuels, and establishing green fuel supply chains. Third, the research agendas presented in this study will provide useful insights for future researchers studying GSCs and policymakers implementing them. Fourth, it will serve as a guide for business practitioners—such as carriers, green fuel producers, and port operators conducting business through GSCs—in formulating management strategies and solving problems.

The rest of this paper is organized as follows. Section 2 revisits GSC issues with updated development and information from COP26 to COP30. Section 3 points out misunderstandings regarding the concept, scope, and application of GSCs, as well as their implementation and the calculation of GHG emissions using green fuel oils, drawing on cases from existing studies. Section 4 explores research agendas and directions for GSCs. Section 5 concludes this paper.

2. Conference of the Parties (COP) and its governance structure

This section aims to conduct a comprehensive review of the global and regional trends and developments of GSCs since their inception at COP26, held in Glasgow, United Kingdom, in November 2021. Figure 1 depicts three stages of decarbonisation in the context of maritime transport and logistics, along the spatial and functional continuum from the origin to the destination on the seaside, and into the hinterland of the destination port.

First, decarbonisation of international sea routes focuses on vessel operations along a green shipping corridor, including emission control areas (ECAs). This dimension primarily concerns the transition toward zero- or low-emission vessels through the adoption of alternative fuels (e.g. methanol, ammonia, LNG, hydrogen), energy-efficient ship design, slow steaming practices, and digital route optimization.

Second, decarbonisation within ports, particularly at terminals and on-dock yards, is concerned with reducing GHG emissions generated by cargo-handling equipment (e.g. gantry cranes, automated guided vehicles). In addition, shore-based power facilities

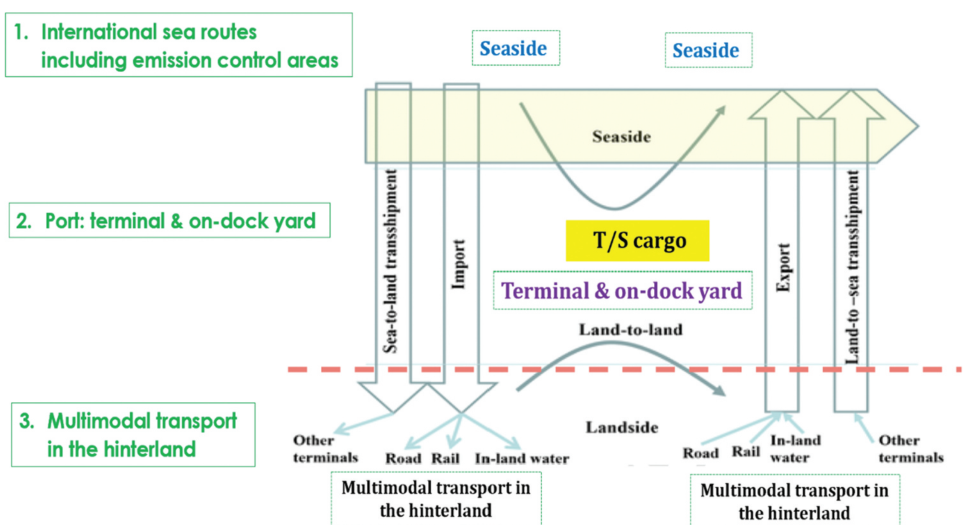


Figure 1. Decarbonisation subdivisions in maritime transport and logistics. Source: Modified based on Fig 1.3 in Kim (2023). Note: T/S indicates transshipment.

enable berthed vessels to switch off auxiliary engines, thereby significantly reducing air pollutants and GHG emissions.

Third, decarbonisation in a hinterland logistics network is achieved by reducing GHG emissions from land transport carriers (e.g. road, railway, river shipping) that form multimodal inland transport systems connecting seaports with cargo origins, such as dry ports, industrial clusters, and logistics parks.

These three divisions of decarbonisation (i.e. international sea routes, port terminals, and the hinterland) form an integrated decarbonisation framework in the context of maritime transport and logistics. The GSC initiative at COP26 initially aimed to decarbonise the first division of maritime transport and logistics. However, by COP29, GSCs extended their decarbonisation scope to include multimodal transport. Consequently, Figure 1 presents an integrated decarbonisation model paving the way ahead for future COPs.

2.1. A brief history of COP meetings between COP26 and COP30

COP26 adopted the Clydebank Declaration in Glasgow, United Kingdom, in November 2021, which initiated the definition of the Green Shipping Corridor (GSC). The Declaration is a voluntary, non-binding initiative led by the United Kingdom and initially signed by 24 signatories (three additional countries joined in 2022/2023). These included eight countries in the Asia-Pacific region (Australia, New Zealand, Singapore, Japan, the Republic of Korea, Fiji, the Republic of the Marshall Islands, and Palau), as well as the United Kingdom, the United States, Norway, and others. At COP28, seven Pacific island nations formed the Pacific Blue Shipping Partnership (PBSP): Fiji, Kiribati, the Republic of the Marshall Islands, the Solomon Islands, the Kingdom of Tonga, Tuvalu, and Vanuatu.

The Conference of the Parties (COP) is the supreme decision-making body of the United Nations Framework Convention on Climate Change (UNFCCC). It is held annually to assess progress and strengthen global action on climate change. The key functions of the annual COP include: i) negotiating and making decisions (e.g. the Kyoto Protocol at COP3 in 1997 and the Paris Agreement at COP21 in 2015); ii) setting rules and guidance; iii) overseeing and arranging climate finance (e.g. the Green Climate Fund established at COP16 in 2010, headquartered in Incheon, Republic of Korea); and iv) establishing and managing a platform for global cooperation.

Figure 2 illustrates key selective climate change-related events from COP1 to COP30, highlighting each major achievement.

COP3 adopted the Kyoto Protocol in 1997, which established the first legally binding GHG emission reduction targets for developed countries. The COP serving as the Meeting of the Parties to the Kyoto Protocol (CMP) governs the Kyoto Protocol. Another turning point among the series of COPs was the adoption of the Paris Agreement at COP21 in 2015. The COP serving as the Meeting of the Parties to the Paris Agreement (CMA) governs the Paris Agreement. Institutionally, the CMP and CMA operate under the COP framework, but both are specialized governing bodies created by two separate legal instruments: the Kyoto Protocol and the Paris Agreement, respectively. The CMP and CMA are neither regulators nor governance authorities; rather, they provide policy direction.

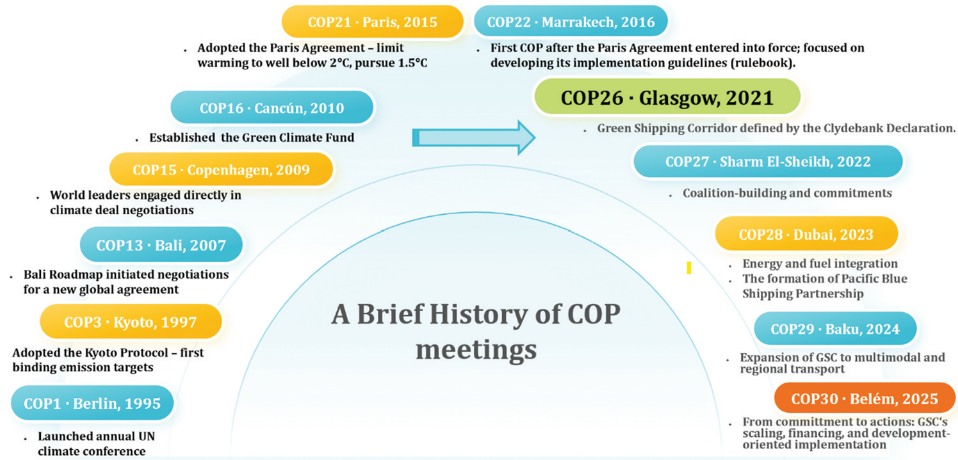


Figure 2. A brief history of COP meetings. Note: compiled by authors.

Since the inception of the GSC at COP26 in 2021, the key GSC-related outcomes of subsequent COPs are as follows:

- COP26 (Glasgow, United Kingdom, October 31 – November 13, 2021): The GSC was initiated via the Clydebank Declaration by 24 original signatories. Three additional countries joined in 2022/2023, bringing the total to 27. Eight signatories are from the Asia-Pacific region: Australia, New Zealand, Singapore, Japan, the Republic of Korea, Fiji, the Republic of the Marshall Islands, and Palau.
- COP27 (Sharm el-Sheikh, Egypt, November 6 – November 20, 2022): The 'Green Shipping Challenge' was initiated by the United States and Norway. It has continuously updated information on GSC developments and stakeholder commitments to decarbonizing maritime supply chains, monitoring the transition from commitment to action.
- COP28 (Dubai, United Arab Emirates, November 30 – December 12, 2023): The Pacific Blue Shipping Partnership (PBSP) was formed by seven Pacific island nations: Fiji, Kiribati, the Republic of the Marshall Islands, the Solomon Islands, the Kingdom of Tonga, Tuvalu, and Vanuatu. The GHG emission reduction targets of the PBSP are 40% by 2030, 80% by 2040, and 100% carbon-free by 2050. These countries form a focused coalition of Pacific Small Island Developing States (SIDS) aiming to degitalise domestic shipping within Pacific Island countries, with a strong emphasis on regional coordination, fleet renewal for small vessels, and securing financial support from the IMO for local maritime transformation.
- COP29 (Baku, Azerbaijan, November 11 – November 22, 2024): This meeting expanded GSCs to land transport, promoting green multimodal transportation under the motto 'Transport at the nexus.' Consequently, COP29 introduced the term 'Middle Corridor,' which comprises sea and land transport in the South and South-West Asia region, focusing on Türkiye, Iran, and Afghanistan.
- COP30 (Belém, Brazil, November 10 – November 21, 2025): This meeting further expanded the Middle Corridor into a 'Multimodal Decarbonisation Corridor,'

incorporating combined sea, river, and rail transport and promoting port-hinterland connectivity in emerging economies. Discussions included establishing Amazon-Atlantic maritime-river corridors and promoting South-South corridor connectivity within the Global South corridors linking Latin America, Africa, and Asia. Another notable point at COP30 was the reframing of GSCs as trade and industrial enablers. Ports and corridors were positioned not only as decarbonisation instruments but also as platforms for sustainable trade, industrial upgrading, and green fuel production and supply chains (e.g. green methanol and ammonia). Furthermore, a 'shipping—energy—nature nexus' positioned GSCs within renewable energy hubs, biofuels, and nature-based solutions, reflecting the perspective of the Amazon's biodiversity.

Table 1 shows a summary of the above in terms of key agenda, key actions and developments, and perceived challenges.

The progression of COP discussions shows a clear evolution of GSCs: from the initial conceptualization of the GSC (COP26), to coalition-building and commitments

Table 1. A summary of key GSC-related outcomes of subsequent COPs.

COP Event	Key Agenda	Key Action / Development	Perceived Challenge
COP26 Glasgow (2021)	Initiation of Green Shipping Corridors	Launch of the Clydebank Declaration with 24 signatories (now 27); commitment to establish GSCs to accelerate maritime decarbonisation; participation from Asia-Pacific countries including Australia, New Zealand, Singapore, Japan, and Republic of Korea.	Early-stage implementation; limited infrastructure and financing; need for broader international participation and coordination.
COP27 Sharm el-Sheikh (2022)	Coalition-building and stakeholder commitments	Launch of the Green Shipping Challenge by the US and Norway; monitoring commitments from governments, ports, shipping companies, and cargo owners to decarbonise maritime supply chains.	Translating commitments into concrete projects; coordination among diverse stakeholders; lack of binding accountability mechanisms.
COP28 Dubai (2023)	Regional collaboration and green fuel transition	Establishment of the PBSP by Pacific Island countries; ambitious emission reduction targets (40% by 2030, 80% by 2040, carbon-free by 2050); focus on domestic shipping decarbonisation and financial support mechanisms.	Financial constraints for SIDS; limited technological capacity; dependence on external funding and IMO support.
COP29 Baku (2024)	Expansion to multimodal transport corridors	Introduction of green multimodal transport corridors linking sea and land transport; development of the Middle Corridor connecting regions in South and South-West Asia (Türkiye, Iran, Afghanistan).	Cross-border policy alignment; infrastructure integration across transport modes; geopolitical and regulatory coordination challenges.
COP30 Belém (2025)	Scaling and integration with trade, energy, and development	Expansion toward multimodal decarbonisation corridors (sea–river–rail); focus on Amazon–Atlantic corridors and South–South connectivity; positioning GSCs as platforms for sustainable trade, green fuel production (e.g., green methanol and ammonia), and industrial development.	Large-scale financing needs; balancing environmental protection with infrastructure development; complex coordination across energy, transport, and trade systems.

(COP27), energy and fuel integration (COP28), expansion to multimodal and regional transport (COP29), and finally to scaling, financing, and development-oriented implementation (COP30). However, future COP meetings face persistent challenges in financing, infrastructure development, regulatory alignment, and translating global commitments into GSCs.

2.2. Governance of the COP in the context of the GSC

Since the inception of the GSC at COP26 in 2021, the United States and Norway have continuously co-led the 'Green Shipping Challenge' (GS Challenge). Launched at COP27 (https://greenshippingchallenge.org/), this initiative encourages 10 key actors—including governments, port authorities, shipping companies, major cargo owners, and others—to degitalise the maritime industry. It serves as a political coordination mechanism for monitoring and updating the commitments of these key actors involved in the announcement and launch of GSCs across successive COPs.

2.2.1. The role of key bodies in decarbonizing GHG emissions at sea

The IMO has taken numerous measures to reduce GHG emissions at sea and in ports. After COP26 initiated the GSC in 2021, the IMO announced the 2023 GHG Strategy to accelerate GHG emission reductions in international shipping, establishing clear targets for 2030, 2040, and 2050.

Regarding the 10 stakeholders (or actors) of the GSC, the COP to the UNFCCC does not act as a regulatory body. Instead, the IMO formulates resolutions that regulate shipping companies, ports, shipbuilders, and classification societies. To promote GSCs, the IMO has developed several capacity-building projects and resolutions, including:

(a) Resolution MEPC.323(74): Aims to reduce GHG emissions from ships through cooperation between the port and shipping sectors.
(b) Resolution MEPC.366(79) (supersedes MEPC.323(74)): Encourages cooperation across the entire value chain, including shipping routes and hub ports.
(c) The IMO-Norway GreenVoyage2050 Project: Partners with selected developing countries to establish collaborations with the maritime industry for reducing GHG emissions at sea.
(d) The IMO-Singapore NextGEN Project: Aims to 'catalyse impactful partnerships among the stakeholders for developing a collaborative global ecosystem of maritime transport decarbonisation initiatives' (DITRDCA 2024, 6).

In Figure 3, the solid line from the IMO indicates the IMO's regulatory position, while the dotted line from the IMO represents non-regulatory influence. As the supreme decision-making body of the UNFCCC, the COP plays a catalytic, indirect, and facilitative role in implementing GSCs.

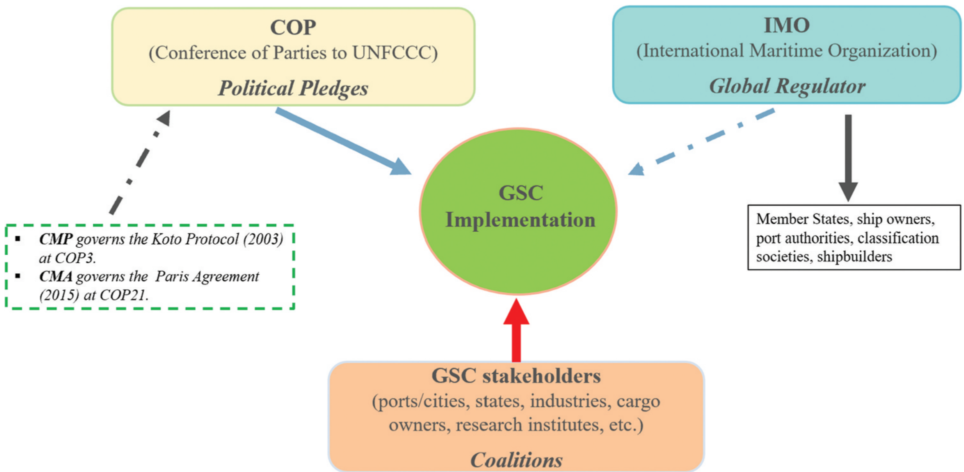


Figure 3. Governance structure of the Green Shipping Corridor.

The 2023 revised IMO GHG Strategy targets net-zero emissions by around 2050, with indicative checkpoints (representing reductions in total annual GHG emissions compared to 2008 levels) of at least 20% by 2030 (striving to achieve 30%) and at least 70% by 2040 (striving to achieve 80%). It directly regulates GHG emissions from all vessels at sea, including both existing ships and ZEVs operated by shipping companies, regardless of their participation in GSCs. Furthermore, regional mechanisms such as the EU ETS and FuelEU Maritime (Christodoulou and Cullinane 2022; Lin et al. 2025) do not apply to ships navigating exclusively within Asia, the Americas, or Africa, unless they call at EU ports. Table 2 provides a governance comparison between the COP and the IMO in the implementation of GSCs.

In summary, the COP encourages sectoral decarbonisation initiatives through declarations (such as the Clydebank Declaration adopted at COP26), action agendas, and voluntary initiatives. It mobilizes finance, partnerships, and political commitments, providing a global platform for governments, ports, shipping lines, fuel producers, and financiers to announce new initiatives. However, the COP can neither regulate international shipping emissions, nor impose technical or operational standards on ships or ports, nor enforce compliance with GSC implementation.

Table 2. Governance comparison between the COP and the IMO in implementing GSCs.

Item	COP (UNFCCC)	IMO
Legal authority	Political / voluntary	Binding regulations
Role in GSC	Agenda-setting, facilitation, encouraging commitments of stakeholders	Technical standards, compliance
Instruments	Declarations, action agenda, partnerships	MARPOL, EEDI/EEXI, CII, future fuel standards
Enforcement	None	Flag State, Port State Control
Main focus	Climate change ambition	Shipping operations, GHG emissions, Safety, Port State Control
Funding	Donations from countries, industries, international and regional banks, donors	Net-Zero Framework (NZF)*

Note: The adoption of the NZF has been delayed for one year by the IMO's MEPC meeting in October 2025.

3. Update development of GSCs worldwide

3.1. Development of GSCs by region and sea condition

The Clydebank Declaration at COP26 in 2021 did not specify individual routes but set a collective objective to support the establishment of at least six green shipping corridors by the mid-2020s, with plans to expand their number and scale by 2030. However, the number of GSCs has increased sharply, reaching a total of 126 initiatives by 2025 (Table 3). This growth can be attributed to two main sources. The first comprises GSC announcements and commitments made through a series of COP meetings, while the second consists of non-COP initiatives, including memoranda of understanding (MoUs) between ports, intergovernmental MoUs, and GSC initiatives led by think tanks and feasibility studies. Table 3 presents the distribution of GSCs by these two sources. Between 2021 and 2025, 30 GSCs were initiated through COP26–COP30, accounting for 23.8% of the total, whereas 96 GSCs were initiated through non-COP channels during the same period, representing 76.2% of the total.

Table 4 shows a total of 126 GSCs worldwide, categorized by region and sea condition (i.e. deep-sea and short-sea shipping). The number of deep-sea GSCs is 71, accounting for 56.3% of the total, while short-sea GSCs number 55, representing 43.7% of the total. A notable feature in Table 4 is that Asia initiated 13 and 17 deep-sea GSCs connecting to Europe and North America, respectively, alongside 11 within the Intra-Asia region. In other words, Asia is involved in 41 out of the 71 total deep-sea GSCs, demonstrating its leading role in GSC establishment. Regarding short-sea shipping, Intra-Europe and Intra-America feature 31 and 11 GSCs, respectively, accounting for 42 of the 55 total short-sea GSCs. Meanwhile, Intra-Asia and Intra-Africa account for 5 and 1 GSCs, respectively. Notably, the Pacific region has a relatively high number of short-sea corridors (seven GSCs) compared to Intra-Asia, which is due to the high density of scattered islands in the region.

Several key points can be drawn from Table 4 that illustrates the global development of GSCs by region and sea condition, as follows:

First, there is a stark contrast between Asia's dominance in deep-sea shipping and Europe's leadership in SSS. Broadly speaking, Table 4 highlights a clear functional

Table 3. Annual increase of GSCs by COP and non-COP (2021 to 2025).

	No. of GSCs					
	2021	2022	2023	2024	2025	Total
COP	0 (COP26)	15 (COP27)	9 (COP28)	2 (COP29)	4 (COP30)	30 (23.8%)
Non-COP	0	8	23	23	42	96 (76.2%)
Total	0	23	32	25	46	126 (100%)

Data sources: COP27, COP28, and COP29 documents; GMF annual reports (2022–2025), "Annual progress report on green shipping corridors".

Notes: Among the GSCs mentioned at the COPs and in the GMF reports (2024, 2025), we excluded initiatives that do not include actual operating vessel routes. Specifically, we removed items primarily framed as alliances (e.g. SILK Alliance), task forces (e.g. UK–US Green Shipping Corridor Task Force, the QUAD Shipping Taskforce, and the Bilateral Green Corridors Taskforce [UK–France]), consortia or networks (e.g. North Pacific Green Corridor Consortium [Canada], the European Green Corridor Network, and Green Corridors Spain), solutions (e.g. GREENBOX), or individual companies (e.g. La Méridionale).

Table 4. Distribution of 126 GSCs by regional category and sea condition (as of January 2026).

Sea condition	Regional Category	No. of GSCs	Composition ratio (%)
Deep sea	Asia-Europe	13	10.3
(Sub-total:	Asia-North America	17	13.5
71 GSCs, 56.3%)	Asia-South America	3	2.4
	Asia-Africa	1	0.8
	Europe-Africa	4	3.2
	Europe-North America	7	5.6
	Europe-South America	4	3.2
	Europe-Central America	2	1.6
	Intra-America	6	4.8
	Intra-Asia*	11	8.7
	Intra-Europe	1	0.8
	Intra-Pacific	2	1.6
Short-sea	Intra-Africa	1	0.8
(Sub-total:	Intra-America	11	8.7
55 GSCs, 43.7%)	Intra-Asia*	5	4.0
	Intra-Europe	31	24.6
	Intra-Pacific	7	5.6
	Total	**126**	**100%**

Source: compiled by authors.
Note: *The Intra-Asia category covers corridors involving Australia and New Zealand.

distinction: deep-sea GSCs are driven by global shipping routes, particularly the Asia—Transpacific and Asia—Europe routes. Conversely, SSS GSCs are predominantly concentrated in Europe. This implies that GSCs are being developed along both main trunk routes and regional shipping corridors within advanced economies to digitalise the maritime sector.

Second, a notable trend emerges regarding the types of ZEVs deployed on GSCs. Container ships and bulk carriers are the primary vessel types utilized in deep-sea corridors, whereas ferries and Ro/RoPax vessels dominate short-sea routes. Major container shipping companies, in collaboration with major container hub ports, have committed to deploying ZEVs and installing green fuel bunkering facilities along the Asia—Europe and Asia—Transpacific (North America) routes. In other words, the origins and destinations (O-D) of deep-sea GSCs are primarily located at major container hub ports in Asia, Europe, and North America. Meanwhile, shipping companies aiming to maximise profits prioritise minimising costs, such as fuel and fixed expenses. In particular, they may choose to reduce direct trips between EU ports or redesign their routes to avoid EU ETS costs (Wang et al. 2026).

Third, deep-sea GSCs are also being developed within the Intra-Asia region, specifically covering the deep-sea routes between Australia and the CJK (China, Japan, and the Republic of Korea) countries. This is supported by the fact that the CJK nations—which rank among the top importers of energy and raw materials globally—import significant volumes of these commodities from Australia.

Finally, although the number of short-sea GSCs in the Intra-Asia region is currently marginal compared to Intra-Europe, this figure is gradually increasing. New corridors are emerging on connecting routes between Singapore, Indonesia, Thailand, Vietnam, and the Philippines, as well as on intra-island routes within the archipelago nations of Indonesia and the Philippines.

3.2. Development of zero-emission vessels by green fuel type and ship type

As of January 2026, Table 5 provides an overview of the ZEVs status, categorised by alternative fuel type (e.g. LNG, methanol, and ammonia), operational status, and order book numbers. LNG-powered vessels represent the dominant type in the maritime industry, accounting for a total of 1,488 vessels (846 currently in operation and 642 on order).

ZEVs are actively being deployed on GSC routes. Stakeholders involved in the Singapore—Rotterdam GDSC and the Shanghai—Los Angeles/Long Beach GSC Partnership have committed to deploying ZEVs according to their respective timeframes. This deployment requires a steady supply of green fuels and technologies, such as LNG, methanol, ammonia, hydrogen, and electrification. Table 5 outlines a total of 1,987 ZEVs, both in operation and on the order book, as of 6 January 2026, classified by ship type and alternative fuel.

As noted, LNG-powered vessels lead with 1,488 total units. Out of the 450 total methanol-powered vessels, 106 are currently in operation, while 344 are on order. The total number of methanol-powered vessels amounts to roughly one-third of the LNG-powered fleet. However, the ratio of operating to ordered methanol vessels is approximately 1:3.3, implying a remarkable increase in new orders over the coming years compared to LNG-powered vessels.

Ammonia-powered ships remain at an embryonic stage, with a total of 49 vessels (three in operation and 46 on order). However, the ratio of operating to ordered vessels (1:15.34) is highly skewed toward new builds, representing the highest order-growth trajectory among the three fuel types. This implies that while the current total number of ammonia-fueled ships is marginal, the growth trend is expected to curve sharply upward, largely because the anticipated fuel price of green ammonia is much lower than that of green methanol.

Out of the 1,987 total ZEVs in operation and on order, container vessels account for the largest share at 879 (44.2% of the total). These are followed by car carriers (244), oil/chemical tankers (173), bulk carriers (156), and crude/oil tankers (145). The ranking of vessel orders across the three alternative fuels generally follows this same distribution by ship type. As for gas tankers, there are 23 ammonia-powered gas tankers on order; this is the highest order record for this specific fuel category, even though the overall fleet size remains limited.

Table 6 summarises the data presented in Table 5. Across all three alternative fuel categories, container ships represent the largest vessel type.

Figure 4 presents an overview of the development of major ZEV ship types. The data reveal a clear and consistent increase in the total number of ships of different types during this period. This trend demonstrates that GSC development is moving from early planning stages to active implementation.

Table 5. ZEVs in operation and order book by alternative fuel (as of 6 January 2026).

	LNG			Methanol			Ammonia			Total			
Ship type	In operation	On order	Sub-total	In operation	On order	Sub-total	In operation	On order	Sub-total	In operation	On order	Total by ZEV type (No., %)	
Container ship	229	395	**624**	55	199	**254**	0	1	**1**	284	595	879	44.2%
Car carrier	124	98	**222**	2	16	**18**	0	4	**4**	126	118	244	12.3%
Crude oil tanker	82	48	**130**	1	11	**12**	0	3	**3**	83	62	145	7.3%
Oil / Chemical tanker	80	39	**119**	36	16	**52**	0	2	**2**	116	57	173	8.7%
Bulk carrier	68	16	**84**	1	60	**61**	0	11	**11**	69	87	156	7.9%
Car / Passenger ferry	49	3	**52**	0	0	**0**	0	0	**0**	49	3	52	2.6%
Cruise ship	31	27	**58**	1	5	**6**	0	0	**0**	32	32	64	3.2%
Offshore supply ship	36	0	**36**	0	0	**0**	1	1	**2**	37	1	38	1.9%
Other offshore vessel	0	0	**0**	2	14	**16**	0	0	**0**	2	14	16	0.8%
Tug	32	0	**32**	1	3	**4**	2	0	**2**	35	3	38	1.9%
RoPAX	30	8	**38**	1	11	**12**	0	0	**0**	31	19	50	2.5%
Ro-Ro cargo ship	14	1	**15**	2	3	**5**	0	0	**0**	16	4	20	1.0%
Gas tanker	16	2	**18**	0	0	**0**	0	23	**23**	16	25	41	2.1%
General cargo ship	21	0	**21**	0	0	**0**	0	1	**1**	21	1	22	1.1%
Fishing vessel	7	0	**7**	0	0	**0**	0	0	**0**	7	0	7	0.4%
Others	27	5	**32**	4	6	**10**	0	0	**0**	31	11	42	2.1%
Total	**846**	**642**	**1488**	**106**	**344**	**450**	**3**	**46**	**49**	**955**	**1032**	**1987**	**100.0%**

Source: Compiled by authors (2026) based on DNV Vessel Statistics 2026. https://afi.dnv.com/statistics.

Table 6. Summary of the ZEV fleet in operation and on the order book by green fuel type (as of 6 January 2026).

Fuel type status	LNG	Methanol	Ammonia	Total
In operation	846 (56.9%)	106 (23.6%)	3 (6.1%)	955 (48.1%)
On order	642 (43.1%)	344 (76.4%)	46 (93.9%)	**1,032 (51.9%)**
Sub-total by fuel type	**1,488 (100%)**	**450 (100%)**	**49 (100%)**	**1,987 (100%)**
Top 3 Dominant ship types	• Container ships (624) • Car carriers (222) • Crude oil tankers (130)	• Container ships (254) • Bulk carriers (62) • Oil/Chemical tankers (52)	• Gas tankers (23) • Bulk carriers (11)	

Source: Compiled by authors (2026) based on DNV Vessel Statistics 2026. https://afi.dnv.com/statistics.
Note: Based on Table 5 in this paper.

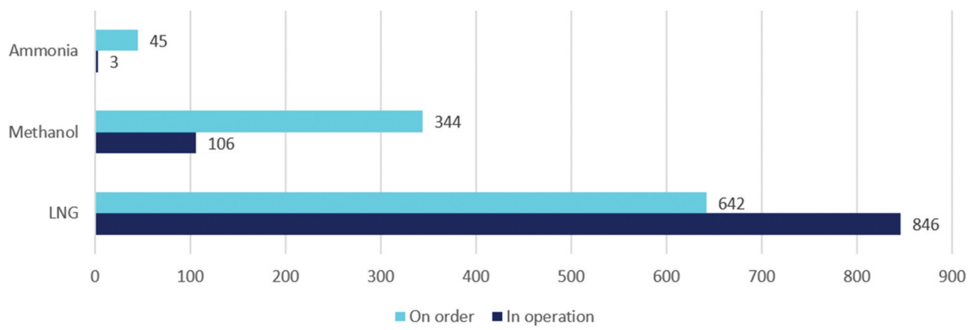


Figure 4. ZEVs in operation and on order by alternative fuel. Source: Compiled by the authors (2026) based on DNV Vessel Statistics 2026(https://afi.dnv.com/statistics), Tables 5, and 6.

Different ship types show clear differences in their levels of activity. Container ships and roll-on/roll-off (Ro-Ro) ships have consistently dominated in terms of initiative quantity and order volume. This may be due to their fixed service routes, high levels of coordination with port infrastructure, and significant decarbonisation pressure within the global supply chain. As a result, this sector aligns well with current decarbonisation strategies and is the most active in GSCs. During this same period, bulk carriers and tankers have shown steady growth. In contrast, the involvement of Ro-Ro ferries and cruise ships in GSC projects has been limited in scale. While growing slowly, these projects are mostly restricted to short-sea and regional routes.

Overall, the distribution of ship types indicates that early participants in the development of GSCs were ships with higher commercial maturity and stronger port governance coordination, particularly in the container shipping sector.

3.3. Development of GSCs by cargo type

Upon the initial introduction of GSCs, the corridors were predominantly driven by container ports and shipping companies, in association with commitments from major cargo owners. As a representative example, the GDSC between Singapore and Rotterdam was launched specifically for containerized cargo movements (MPA 2022). Over the last

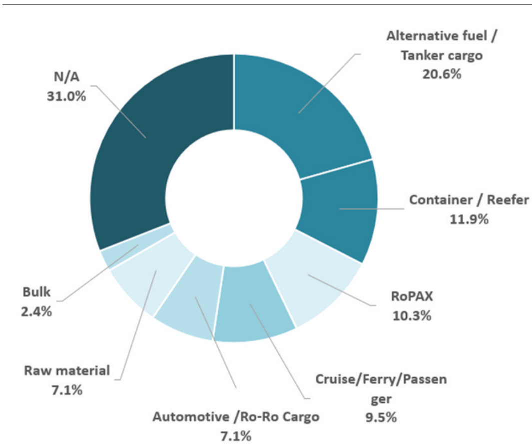
Table 7. Regional distribution of GSCs by cargo type (as of January 2026).

Region Category	Alternative fuel / Tanker cargo	Automotive / Ro-Ro Cargo	Bulk	Container / Reefer	Cruise/Ferry /Passenger	RoPAX	N/A	Total
Asia-Europe		4		2			7	13
Asia-North America		4	1	8			4	17
Asia-South America	1		2					3
Asia-Africa	1							1
Europe-Africa	2		1	1				4
Europe-North America	1		2	1			3	7
Europe-South America	2			2				4
Europe-Central America				2				2
Intra-Africa							1	1
Intra-America	12				2		3	17
Intra-Asia	1		5	2		1	7	16
Intra-Europe	3	1		3	6	12	7	32
Intra-Pacific	3		1	1	4			9
Total	**26**	**9**	**12**	**22**	**12**	**13**	**32**	**126**

Note: RoPAX refers to Roll-on Roll-off Passenger; N/A: not available.

five years, however, GSCs have expanded to include ferry services, car carrier services, cruises, energy transport, and raw materials (e.g. iron ore, LNG, coal, and bauxite).

Table 7 shows the distribution of the 126 GSCs by cargo type, as declared in publicly announced MOUs, COP documents (such as the Shipping Challenge 2022, 2023; 2024; Global Maritime Forum 2025), feasibility studies, and research reports from think tanks. The primary cargo types, listed in descending order by the number of GSCs, are as follows: alternative fuel and liquid tanker cargo (26 GSCs), container/reefer (15 GSCs), RoPAX (13 GSCs), automotive/Ro-Ro cargo (9 GSCs), and raw materials (9 GSCs). Notably, a substantial proportion of short-sea shipping corridors (39 corridors, or 31.0%) are classified as 'N/A.' This is because short-sea shipping services in Europe are not always categorized by specific cargo types in the same manner as ocean-going shipping,



Cargo type	No. of GSCs
Alternative fuel / Tanker cargo	26
Container / Reefer	15
RoPAX	13
Cruise/Ferry /Passenger	12
Automotive /Ro-Ro Cargo	9
Raw material	9
Bulk	3
N/A	39
Total	**126**

Figure 5. Distribution of GSCs by cargo type. Sources: Compiled by the authors based on the Green Shipping Challenge Annual Announcements at COP (2022, 2023, 2024), the Global Maritime Forum Annual Edition (2022, 2023, 2024, 2025), and various newspaper reports. Note: N/A indicates "not available".

meaning the transported cargo types cannot be clearly identified from currently available sources. Figure 5 summarises the data in Table 7.

3.4. Global network visualization of GSCs based on origin-destination nodes

Figure 6 presents a global network analysis of 126 GSCs using NetMiner 4.0. In this figure, the nodes represent the O-D ports of the GSCs in which countries participate. The directed edges illustrate the specific routes between these O-D pairs. The size of each node is proportional to the number of GSCs connecting it, as an origin, to its destinations. The global network visualization in Figure 6 reveals six regional clusters: Europe, Asia, North America, South America, Oceania, and Africa. These clusters clearly display the GSC networks within each region as well as between inter-cluster regions. This implies that a larger circle for a given country indicates a higher number of established GSCs. Furthermore, self-looping arrows (e.g. for the U.S., the U.K., and SIDS) indicate domestic GSCs and intra-regional GSCs. The Europe cluster has the highest number of GSC networks, most of which involve SSS, while the Africa cluster has the lowest. The Asia cluster exhibits the strongest overall GSC networks among the six clusters.

Three key metrics, node scaling, connectivity, and domestic initiatives (represented by circular self-looping arrows), are used to visualize the global GSC network based on O-D connectivity:

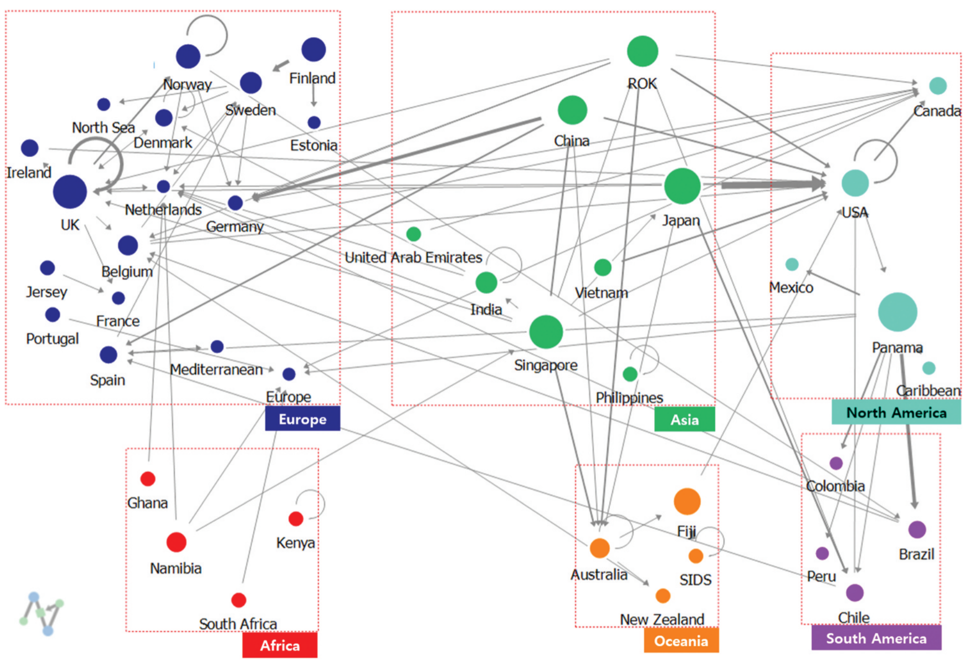


Figure 6. Global network visualization of GSCs based on origin-destination. Note: SIDS stands for “Small Island Developing States” in the Pacific region.

- **Node scaling**: The first metric means the size of each node is proportional to the frequency of GSCs for a country acting as an origin, helping to identify key 'source' nations in the network.
- **Connectivity**: The second metric represents the movements of ZEVs connecting the two end ports of a GSC. This captures both dense intra-cluster activities within regions like Europe and Asia (via short-sea vessels) and strategic intercontinental connections between distant trade partners (via ocean-going vessels).
- **Domestic initiatives**: The third metric consists of circular arrows showing self-loops, which indicate domestic GSC initiatives operating strictly within the same national borders (see Figure 6).

Therefore, this global network visualization provides a spatial understanding of how maritime decarbonisation is being operationalized worldwide across both deep-sea shipping and SSS.

The global network reveals strong hub dominance by Panama, Japan, Singapore, the United Kingdom, China, the Republic of Korea, and the United States, all of which function as primary origin nodes connecting multiple regional clusters. Europe exhibits dense intra-regional SSS connectivity, particularly among Northern and Western European countries (e.g. the U.K., Netherlands, Denmark, Sweden, and Norway). This implies that the maturity of SSS as a 'blue highway' contributes to accelerating maritime decarbonisation initiatives within the intra-European region. In contrast, GSCs in Asia are developing following a different pattern than those in Europe. Asian maritime powers —such as China, Japan, and the Republic of Korea (the CJK countries)—host eight of the world's top ten container ports and possess robust shipbuilding industries, repair and maintenance services, and merchant fleets. Consequently, they operate long inbound and outbound trunk routes to and from Europe and North America. For example, routes such as Singapore—Rotterdam, Shanghai—L.A./L.B., Singapore—L.A./L.B., and Busan to U.S. West Coast ports serve as long-distance liner routes for carrying container cargoes by major carriers. Additionally, Australia maintains long trading routes with the CJK countries for raw materials and energy. These GSCs serve as best practices for achieving remarkable GHG emission reductions by operating ZEVs through coalitions of major stakeholders.

In contrast to Asia and Europe, where dense O-D networks are driven by major container hub ports, high international trade volumes, major container carriers, and national green shipping policies—the O-D connectivity of GSCs within Africa and South America, as well as between these regions and the rest of the world, remains limited. This weaker connectivity reflects structural constraints, including lower trade density, inadequate port facilities, and comparatively slower progress in green fuel production capacity and infrastructure deployment.

3.5. Misunderstanding of implementing GSCs

Based on the findings from field interviews and stakeholder workshops, many stakeholders expressed a limited understanding of the concept of GSCs, its scope of implementation, and the roles expected of different actors. One source of confusion relates to terminology. The term 'green maritime corridor' is occasionally used in academic studies—for instance, Lyu, Jin, and Wang (2026) developed a multi-level optimisation model for 'green maritime corridors' that incorporated green fuel bunker networks, container shipping routes, and fleet deployment. However, official UNFCCC documents since COP26, including the Clydebank Declaration, consistently use the standardised term 'green shipping corridor.' In contrast, Singapore promotes the concept of 'Green and Digital Shipping Corridors' (GDSCs), emphasising the role of digitalisation in improving operational efficiency and reducing greenhouse gas emissions between ports and vessels.

As illustrated in Figure 7, the concept of GSC has evolved through time. While Green Shipping Corridors (GSCs) are the most widely recognised policy concept following the Clydebank Declaration, they are conceptually linked to earlier frameworks such as Green Transport Corridors (GTCs) and Green Corridors (GCs). More recent variations like Green and Digital Shipping Corridors (GDSCs) extend the concept by incorporating digitalisation and smart logistics technologies. Despite differences in scope and implementation context, these concepts are converging toward a common objective: creating coordinated transport corridors that enable low- or zero-emission freight movement across integrated logistics systems (See Table 8).

Lyu, Jin, and Wang (2026) included the FuelEU for the ships from Asia to the U.S. in the context of GSCs. Singapore uses green shipping and digital corridors (GDSCs) instead of GSCs. However, although China, Singapore, R.O. Korea have opened GSCs with the ports in the U.S. (e.g. L.A., L.B., Seattle), the Asia-Pacific routes have nothing to do with FuelEU application. Therefore, future research should consider the scope and objectives of GSCs, EU regulations, and policies before setting a modelling with numerical experiments. In addition, the above paper considered 'ammonia fueled container

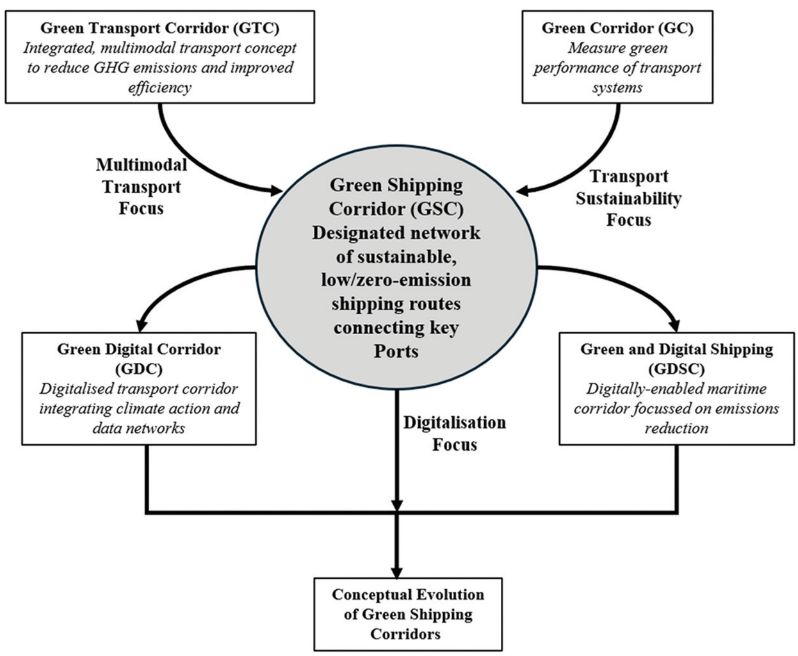


Figure 7. Conceptual evolution of green shipping corridors. Note: On the references of GTC, GC, GDC, and GDSC, see Lee and Song (2023) and Song et al. (2025).

Table 8. Definitions, differences and similarities of Green Shipping Corridors.

Concept	Definition	Key Differences from Green Shipping Corridors (GSCs)	Similarities with GSCs	Examples / Policy Context
Green Shipping Corridor (GSC)	A designated network of maritime routes, ports, and supporting logistics infrastructure designed to promote sustainable shipping practices and enable the transition toward low- or zero-emission shipping between two or more ports.	Broader than a single route; involves multiple actors including ports, shipping lines, fuel suppliers, and regulators. Focuses on system-level decarbonisation rather than route optimisation alone.	Central concept linking maritime decarbonisation with logistics infrastructure, fuel supply chains, and regulatory frameworks.	Clydebank Declaration (COP26) initiatives such as the Los Angeles–Shanghai corridor or Rotterdam–Singapore corridor.
Green Shipping Route (GSR)	A specific maritime path optimised for sustainability parameters such as fuel efficiency, emissions reduction, and navigational efficiency.	Narrower scope; focuses on route optimisation rather than an integrated logistics and infrastructure system. Does not necessarily involve port infrastructure or fuel transition frameworks.	Both aim to reduce shipping emissions and improve environmental performance of maritime transport.	Operational route optimisation strategies used by shipping lines or maritime analytics platforms.
Green Transport Corridor (GTC)	An integrated transport system where multiple transport modes (short-sea shipping, rail, inland waterways, and road) complement each other to provide environmentally sustainable freight movement.	Multimodal rather than maritime-focused; includes inland logistics networks and supply chains. Developed earlier in EU transport policy.	Both emphasise decarbonisation of freight movement and improved logistics efficiency across corridors.	Introduced in the EU Freight Transport Logistics Action Plan and integrated into EU transport policy targeting 60% GHG reduction by 2050.
Green Corridor (GC)	A broader concept measuring environmental performance across transport systems or logistics corridors, often using indicators such as emissions, energy use, and logistics efficiency.	Less maritime-specific and often used as a performance measurement framework rather than an operational decarbonisation initiative.	Shares the goal of improving environmental performance and sustainability across transport networks.	Used in EU research projects and logistics performance studies evaluating transport sustainability.
Green and Digital Corridor (GDC)	A transport corridor integrating environmental sustainability with digital technologies such as data platforms, smart logistics, and digital monitoring systems.	Stronger focus on digitalisation and data-driven optimisation alongside environmental objectives.	Supports emission reduction, efficiency, and coordination across logistics systems similar to GSCs.	Emerging policy and research initiatives linking digital logistics systems with green transport strategies.
Green and Digital Shipping Corridor (GDSC)	A maritime corridor that integrates decarbonisation with digital technologies for ship-port connectivity, logistics efficiency, and emissions monitoring.	Emphasises digital infrastructure and smart shipping technologies in addition to decarbonisation.	Similar objective to GSCs—reducing emissions in maritime transport while enabling coordinated port-to-port operations.	Promoted by Singapore through initiatives focusing on digitalised maritime operations and emissions reduction.

ships' in their modelling. However, at the time of writing this paper, to the authors' knowledge, a terminal-to-ship bunkering operation of ammonia was demonstrated on Jurong Island, Singapore, but it has not yet been finalized, requiring safety standards. It is noted that ship-to-ship ammonia bunkering would be available in Singapore by 2027 (MPA 2026). Moreover, there are a few ammonia vessels operating due to the limited bunkering facility, which are not long-distance serving container ships. Tables 5 and 6 show such evidence. It is also necessary to avoid misunderstanding of 'ammonia-ready vessels,' which still uses fossil oils. The definition of ammonia-read vessels is as follows:

> 'Fuel ready (Ammonia)' means that the future alternative fuel design has been examined and found to comply with the rules for ammonia in force at the time of newbuilding, and the ship's main engine is of a type approved to be convertible to ammonia or ammonia dual-fuel. (DNV, 2025, p. 280)

As can be seen in Tables 5 and 6, most container ships use currently methanol dual-fuel engines because methanol bunkering is broadly and practicably available between Asia and Europe routes, including Singapore. Having said that, we argue that the numerical experiment should focus more on the ZEVs fleet deployment, considering methanol-fueled ships rather than ammonia-fueled ships. A study of the latter case may consider unrealistic assumptions of ammonia fuel costs and fuel consumptions and consequently, its test results may be far from reality and does not give any meaningful insights to the field industry and policy makers.

Another misunderstanding concerns implementation requirements. Participation in GSC initiatives does not require shipping companies to immediately deploy ZEVs; rather, vessels operating within these corridors are expected to ensure that their emissions do not exceed the current baseline. In addition, the scope of these corridors is evolving beyond maritime routes to include river and land-based transport systems. Recent COP discussions, particularly COP29 and COP30, have integrated sea routes within broader multimodal transport networks, with examples such as the 'Middle Corridor' in South and South-West Asia. As seen in the case of the Mekong River basin, the Green Transport and Logistics Chains (GTLC) model, which links seaports, river ports, and dry ports, provides a specific methodology to support decarbonisation across the Greater Mekong Subregion (GMS) by integrating maritime routes with land and river transport. (Lee et al. 2026). Finally, GSC implementation is not directly governed by either the IMO or the European Union. Regulatory mechanisms such as the EU ETS and FuelEU Maritime apply only when vessels call at European ports and therefore do not govern ships operating entirely outside European jurisdictions. In particular, regarding the impact of the EU ETS on shipping networks, Wang et al. (2026) pointed out that shipping companies may change their routes to reduce EU ETS emission costs. They noted that while this could decrease marine pollution within the EU, it might actually lead to an increase in total global emissions.

4. Exploring research agendas

IMO and the EU have proposed different decarbonisation policies (i.e. NZF, EU ETS, and FuelEU Maritime). However, numerous barriers exists and they should be resolved by stakeholders (e.g. shipping companies, ports, governments). The most significant challenge is the high level of capital investment and high operational cost associated with green fuel and the installation of new engines from the perspective of shipping companies. Additionally, establishing a sustainable supply chain for green fuel is critical for port authorities, as is planning refuelling infrastructure investments to meet demand the following year, provided that shipping companies have designed their deployment strategies in accordance with the decarbonisation policies. Additionally, governments should design an incentive policy to encourage the involvement of other stakeholders in GSCs. In order to solve these challenges, this study suggests several research agendas in this section.

4.1. Green Shipping Corridors for liner shipping alliance

Shipping companies inevitably face financial burdens and cash flow concerns when expanding their fleets with zero- and near-zero-emission (ZNZE) vessels, as the operating and capital costs of ZNZE vessels are generally twice those of traditional fossil-fueled ships. Although this might yield a high tax deduction effect through depreciation costs, it is evident that shipping companies could fear a shortage of financial liquidity following such green investments. Consequently, investing in ZNZE vessels poses a significant barrier for shipping companies operating within GSCs.

To address this challenge, developing an operational strategy from the perspective of liner shipping alliances could be an effective starting point for fleet replacement, assuming the alliance operates routes within established GSCs and GDSCs. Given that the types of ZNZE vessels owned by each alliance member vary, a new research problem emerges as how to allocate these costs in a fair and sustainable manner without requiring

Table 9. A comparison of fuel cost and consumption by green fuel type on the Singapore-Rotterdam GDSC.

Singapore-Rotterdam (8,607 nm)	Volumetric Energy Density (MJ/L)	Fuel Consumption (Metric Tonne)	Fuel Cost (USD)	CO2 Emissions (Well-to-wake) (Tonne)	CO2 Emissions (Tank-to-wake) (Tonne)	Shipbuilding Cost (million USD)	Retrofitting Cost (million USD)
VLSFO+MGO*	34	1,271	1,301,364 (base: 100)	8,045 (base: 100)	6,926 (base: 100)	100	–
LNG Dual Fuel (DF)**	22.79	1,460	1,133,038 (87)	5,078 (63)	4,866 (70)	145	35–50
Grey Ammonia DF**	16.52	4,211	1,743,364 (134)	6,797 (84)	5,924 (86)	155	10–30
Blue Ammonia DF**	16.52	4,211	2,451,448 (188)	2,436 (30)	5,927 (86)	–	–
Green Ammonia DF**	16.52	4,211	3,743,601 (288)	1,516 (19)	5,924 (86)	–	–
Grey Methanol DF**	13.86	3,830	1,455,857 (112)	7,702 (96)	687 (10)	150	24
Bio Methanol DF**	13.86	3,830	3,930,367 (302)	1,365 (17)	687 (10)	–	–
E-Methanol DF**	13.86	3,830	6,647,359 (501)	1,064 (13)	687 (10)	–	–

Notes: *VLSFO-Very Low Sulfur Fuel Oil, MGO-Marine Gas Oil.
**For ammonia, methanol, and LNG DF ships, we assume that a ship burns 95% ammonia, methanol, or LNG, respectively, while burning 5% traditional fossil fuels.
Source: adapted from (S.-J. Lee and Meng 2026).

a fundamental transformation of the alliance. The bunker costs and capital costs (i.e. shipbuilding and retrofitting costs) are illustrated in Table 9.

CO2 emissions can be calculated using either the well-to-wake (WtW) or tank-to-wake (TtW) approach. The former covers emissions from manufacturing, transportation, and burning the fuel on a vessel, while the latter only involves emissions directly resulting from burning the fuel on a vessel. It should be noted that the EU ETS is based on the tank-to-wake approach (European Commission 2025, 43), while FuelEU Maritime, which went into effect in January 2025, follows the WtW approach (Korean Register of Shipping 2025). According to our interviews with a shipping company, operators of methanol DF ships currently only burn methanol when calling at European ports to take advantage of the carbon tax deduction.

Therefore, optimising the operation of ammonia or methanol DF ships to comply with the EU ETS and FuelEU Maritime presents a highly significant research agenda. However, when applying these concepts to GSC-related topics, researchers must recognise that these European measures do not apply to non-European regions, such as GSCs in the Transpacific or Intra-Asia regions. Researchers should use reliable data and realistic, commercially available ZEV types, demonstrating an understanding of the technical characteristics of green fuels. These characteristics include energy density, performance, required fuel tank size, and the availability of gensets within a port to support frequent maneuvering during berthing and engine run-up upon departure.

Unfortunately, some existing studies fail to account for this. For instance, Lyu, Jin, and Wang (2026) applied the EU ETS and FuelEU Maritime to GSCs in the Asia-North America region when calculating the GHG emissions, capital expenditure (CAPEX), and operating expenditure (OPEX) of ZEVs and designing incentivization policies. Furthermore, they utilized ammonia-fueled container ships—currently an unrealistic ZEV type—based on outdated data from Brouer et al. (2014), and their modeling incorrectly applied European regulatory frameworks to non-European GSCs. These methodological mistakes should be rigorously avoided in GSC-related research; otherwise, such results risk misleading both the shipping industry and policymakers.

Currently, shipping alliances operate under the framework of a gentlemen's agreement. Each member claims the voyage cost for each of its vessels on a pre-determined, collaborative service route. Subsequently, the members determine how to allocate capacity and establish the capacity price—commonly referred to as the slot price—for exchange. For the cost allocation problem, the game theoretical approach can be applied to construct a shipping alliance satisfying stable and budget-balanced conditions without reforming due to the cost issue. Although some experts have emphasized that currently most shipping companies have not considered cost allocation of ZEV's higher CAPEX and OPEX on the slot price. The impact of increased CAPEX and OPEX from ZEVs on the slot price from the viewpoint of game theory or optimization approach could be an interesting topic.

4.2. Decarbonisation of maritime transport in the Pacific

Due to the emerging threat of sea-level rise in the Pacific Islands, several Pacific Island Countries (PICs) signed the PBSP at COP28 in November 2023. Currently, four shipping commissions operate within the Pacific Islands, as shown in Figure 8, the Central Pacific

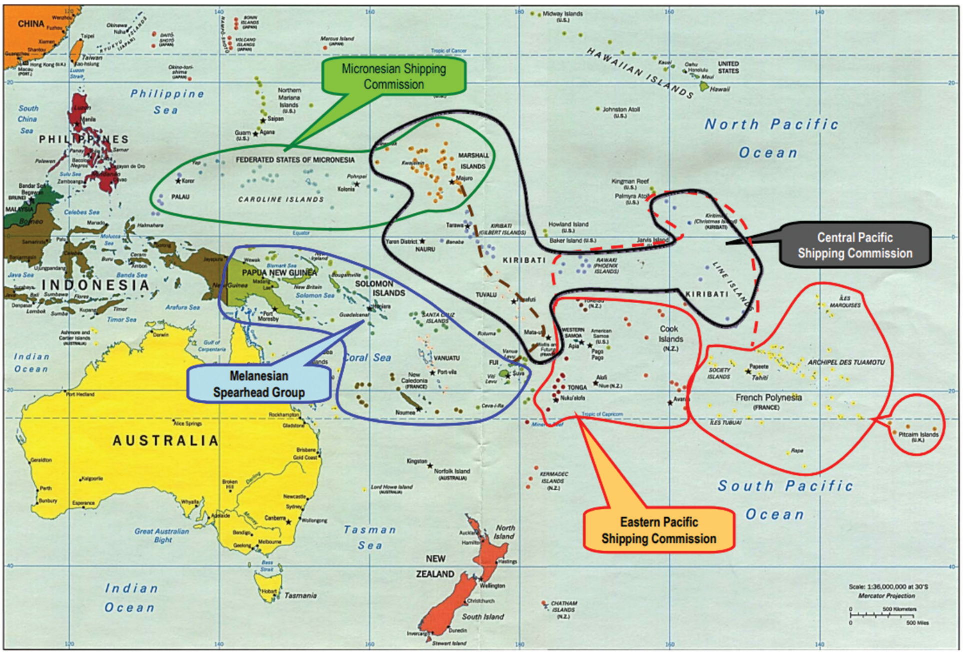


Figure 8. Shipping commissions in the Pacific. Source: The map taken from (https://www.unescap.org/sites/default/files/II.1.Shipping-Commissions-SPC_0.pdf (accessed 27 December 2025)).

Shipping Commission (CPSC), the Micronesian Shipping Commission (MSC), the Melanesian Spearhead Group (MSG), and the Eastern Pacific Shipping Commission (EPSC). Furthermore, Fiji, the Republic of the Marshall Islands, and Palau became signatories to the Clydebank Declaration in 2021 with the primary objective of decarbonizing Pacific maritime shipping.

A major driver of high GHG emissions in the islands is the elevated carbon output resulting from frequent, multiple port calls by shipping lines such as Kyowa Shipping, Swire Shipping, and Matson. These three companies operate their own independent service routes across the Pacific, as depicted in Figure 9. Therefore, a key research question is how to effectively reduce GHG emissions in the Pacific by redesigning the regional shipping network. One potential solution is the establishment of logistics distribution centers (LDCs) on select islands capable of accommodating large container ships (P. T-W. Lee et al. 2022). This hub-and-spoke approach would significantly reduce the need for multiple, inefficient port calls by these regional carriers. Network reconfiguration with ZEVs fleet deployment problem could be incorporated to reduce carbon emissions, compared to the current shipping networks. There are many papers regarding the hub-and-spoke problem, but they did not consider ZEVs fleet deployment with the objective of minimising carbon emissions. Therefore, optimisation approach regarding the revised hub-and-spoke problems should be applied.

Figure 9. Shipping lines in the Pacific.

4.3. Green fuel hub port and green fuel supply chains

Following the establishment of the Singapore-Rotterdam GDSC via a MOU signed by the Maritime and Port Authority (MPA) of Singapore and the Port of Rotterdam Authority, it is clear that Singapore aims to position the Port of Singapore as a next-generation green fuel hub. In addition to the establishment of the GDSC, zero- and near-zero GHG technologies and green fuel supplies have been advanced by the launch of the Australia-Singapore Low Emissions Maritime Technology Partnership (ASLET) in July 2024. Singapore currently provides refueling services for methanol and plans to offer bunkering services for ammonia by 2027. However, the Port of Singapore competes with other global ports to secure its status as a primary green fuel hub. Furthermore, developing a robust supply chain for green methanol and ammonia remains a critical challenge. For instance, the Han-Ho (Korea-Australia) Hydrogen Consortium was launched in September 2022 to export over 1 million tonnes of hydrogen per year from Australia to the Republic of Korea by 2032. Decision-making should be based on the specific criteria of each stakeholder involved in GDSCs. Therefore, a key research objective is to identify these criteria, evaluate their significance in decarbonisation, and determine how to build a green ammonia/methanol supply chain based on the 6th-generation port (6GP) model (Lee et al. 2025). There are multiple criteria over multiple stakeholders in the GDSCs. In order to properly evaluate those criteria, multi-criteria decision-making (MCDM) methods can be applied such as the Multi-Objective Optimization by Ratio Analysis (MOORA) method and the VIKOR method (Lee and Yang 2018).

4.4. Green intermodal logistics: ship, train, and truck

In land transport logistics, significant efforts are currently underway to achieve decarbonisation. For example, a growing number of studies explore the application of electric trucks and autonomous hydrogen fuel cell trucks (AHFCTs) equipped with Level 4 autonomous driving software within logistics systems. Although implementation faces several challenges—such as high capital costs, a lack of charging infrastructure, and vehicle height constraints—managing truck freight within green logistics remains a key research question in land transport. Therefore, future research should consider the ship-truck intermodal routing problem by combining ZNZE vessels in GDSCs with electric trucks or AHFCTs. The objective is to minimise total costs and carbon emissions across both land and sea to build a fully integrated intermodal green logistics system. In this regard, Parvasi, Lam, and Psaraftis (2025) empirically demonstrated that a logistics system combining autonomous electric feeder ships with green-fueled mother vessels can reduce pollutant emissions from 55% to complete elimination and decrease energy consumption by 60% compared to traditional truck-based transport.

Additionally, a hybrid green sea-and-land model could be considered to establish an intermodal network in association with the China-Pakistan Economic Corridor (CPEC) under the Belt and Road Initiative (BRI) (Lee and Song 2023). Notably, Gwadar Port could serve as a potential hub by providing a direct connection to China's Xinjiang province (Khan and Khan 2019). This corridor could provide China with a more efficient, alternative green route to Europe, significantly improving overall connectivity.

4.5. Incentivization policies and strategies for promoting GSC

Governments play a crucial role in reducing the cost gap between zero-emission vessels and conventional fossil-fuel ships. However, the transition from conventional shipping to low- and zero-emission operations cannot be achieved by individual actors or single jurisdictions alone. It requires coordinated policy interventions that bring together multiple stakeholders across the maritime value chain, including governments, port authorities, shipping companies, fuel suppliers, financial institutions, and logistics providers. Given the transnational nature of maritime transport, effective implementation of GSCs also demands regional and cross-country collaboration to align regulatory frameworks, infrastructure investments, fuel supply systems, and market incentives. Yang, Cullinane, and Ge (2026) also confirmed that green innovation in the dry bulk shipping market is more likely to emerge under regulatory pressure and the pursuit of regulatory compliance. This process can ultimately lead to a win-win situation for all stakeholders involved. Therefore, policy interventions should adopt a multi-faceted and collaborative approach that integrates technological innovation, financial mechanisms, governance coordination, and stakeholder engagement to enable the successful development and scaling of GSCs, responding the port development policy (Lee and Flynn 2011; Lee and Lam 2017). In addition, inefficient ports should implement practical guidelines to reduce energy waste by optimising their logistics operation processes. They should achieve this by leveraging advanced scheduling algorithms and real-time monitoring systems to minimize waiting times and deadhead distances (Liu et al. 2025).

The policies listed below in Table 10 primarily target two major barriers: i) the high capital cost of building new vessels; and ii) the higher operational costs associated with green fuels. Capital subsidies, concessional financing, and green shipbuilding grants directly reduce CAPEX, while fuel subsidies, carbon pricing, and port incentives address

Table 10. Incentivisation policy for promoting GSCs with mitigating CAPEX and OPEX of ZEVs.

Policy Title	Key Objectives	Key Benefits	Risks	Mitigation Measures
Capital Subsidy or Green Shipbuilding Grant	Reduce upfront capital costs for building or retrofitting ZEVs	Accelerates fleet renewal; encourages shipowners to adopt green technologies; supports domestic shipbuilding industry	Risk of inefficient allocation of public funds; technology lock-in	Performance-based grants tied to emissions reduction targets; periodic technology review
Green Fuel Production Subsidies	Support large-scale production of green fuels such as green methanol, ammonia, and hydrogen	Policy development	Market distortion; supply chain dependency	Gradual subsidy reduction as technology matures; promote competitive green fuel markets
Port Fee and Dues Incentives	Offer discounted port charges or priority berthing for ZEVs using green fuels	Encourages early adoption; improves operational cost competitiveness	Revenue loss for port authorities	Co-financing through government or climate funds; phased incentive schemes
Carbon Pricing or Emissions Trading Scheme (ETS)	Internalise environmental costs of fossil-fuel shipping	Creates market incentives to shift toward low-carbon vessels; supports decarbonisation targets	Higher shipping costs potentially passed to exporters and consumers	Gradual implementation; revenue recycling to support maritime decarbonisation
Green Shipping Corridor Public–Private Partnerships (PPP)	Mobilise investment from governments, ports, energy companies, and shipping firms	Reduces investment risk; accelerates infrastructure deployment for green fuels	Coordination complexity among stakeholders	Clear governance frameworks; long-term contractual commitments
Green Freight Incentives for Cargo Owners	Encourage cargo owners to commit cargo volumes to ZEV-operated routes	Creates demand certainty for green shipping services; supports corridor viability	Higher logistics costs for cargo owners	Freight-sharing schemes; green certification and sustainability branding
Low-interest Green Maritime Finance	Provide concessional loans or green bonds for vessel construction and retrofitting	Reduces financing costs; attracts institutional investors to maritime decarbonisation	Financial exposure for public lenders	Risk-sharing mechanisms with private banks and multilateral institutions

OPEX by improving the economic competitiveness of green shipping operations. Several real-world examples illustrate these approaches. For instance, Norway introduced green maritime funding programs and carbon taxes that support zero-emission ferry deployment. The EU ETS for shipping and the Fuel EU Maritime initiative are designed to incentivise low-carbon fuels; whilst penalising high-emission vessels. Singapore implemented green port incentives through its MPA to encourage low-carbon shipping practices. Similarly, Japan and the Republic of Korea are investing in green ammonia and hydrogen supply chains to support future maritime decarbonisation corridors. Together, these policies demonstrate that a combination of financial incentives, regulatory frameworks, and industry partnerships is required to reduce the CAPEX and OPEX barriers and enable the large-scale deployment of GSCs.

5. Conclusions

The rapid expansion of green shipping corridor (GSC) initiatives has created new opportunities for maritime decarbonisation, while exposing conceptual ambiguities and governance challenges that require a systematic scholarly action for their clarity and standardization, if possible. By compiling the first comprehensive global data bank of GSCs, including routes, cargo types, ZEVs fleet deployment, order books, port infrastructure, and green fuel supply chains, this paper provides a robust analytical foundation for evaluating the decarbonisation potential of the currently identified and future potentially proposed GSCs. The dataset also enables improved modelling of greenhouse gas emission reductions and associated investment requirements. Through empirical evidence and stakeholder insights, its findings have further revealed the importance of consistence in the use of GSC terminology for future study, correction of misconceptions about the mandatory deployment of ZEVs, evolving interpretations of GSC scope within multimodal transport systems, and affirmation about regulatory authority, all of which help reduce uncertainty among the GSC perspectives of policymakers, industry stakeholders, and researchers.

Within this context, it outlines future research directions to advance the decarbonisation agenda of the maritime sector, including optimizing ZEV fleet deployment, expanding green fuel bunkering infrastructure, strengthening supply chains for alternative fuels, and developing effective green financing mechanisms. Implementation of GSC, however, is constrained by risks of inefficient subsidy allocation, market distortion, and coordination complexity, which collectively slow the transition to ZEV adoption. Capital subsidies and green fuel incentives, while accelerating early uptake, risk technology lock-in and long-term dependency without adaptive policy design. Market-based instruments such as carbon pricing and port incentives face resistance due to cost pass-through effects and revenue implications for key stakeholders. Strategic research thus should prioritise performance-based policy calibration, including dynamic subsidy reduction and emissions-linked funding mechanisms. Future directions should also focus on integrated governance models, risk-sharing financial instruments, and demand-side interventions to ensure scalable and sustainable maritime decarbonisation. By highlighting the importance of such research directions, the paper contributes to shaping a forward-looking research and policy agenda that supports the practical implementation of GSCs and advances the transition toward a net-zero maritime sector.

Notes

1. In this paper, the term GSC encompasses similar corridor concepts, such as the Green and Digital Shipping Corridor (GDSC) initiated by Singapore and Rotterdam, the Green Shipping Corridor Partnership led by China and the U.S., etc.
2. Its target is 'to hold the increase in the global average temperature to well below 2°C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels' (Department for Transport 2022, 1).

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Data availability statement

The data that supports the findings of this study are available from the corresponding author, upon reasonable request.

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