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DECARBONIZING DOMESTIC SHIPPING:
INSIGHTS FROM AFRICA AND THE CARIBBEAN

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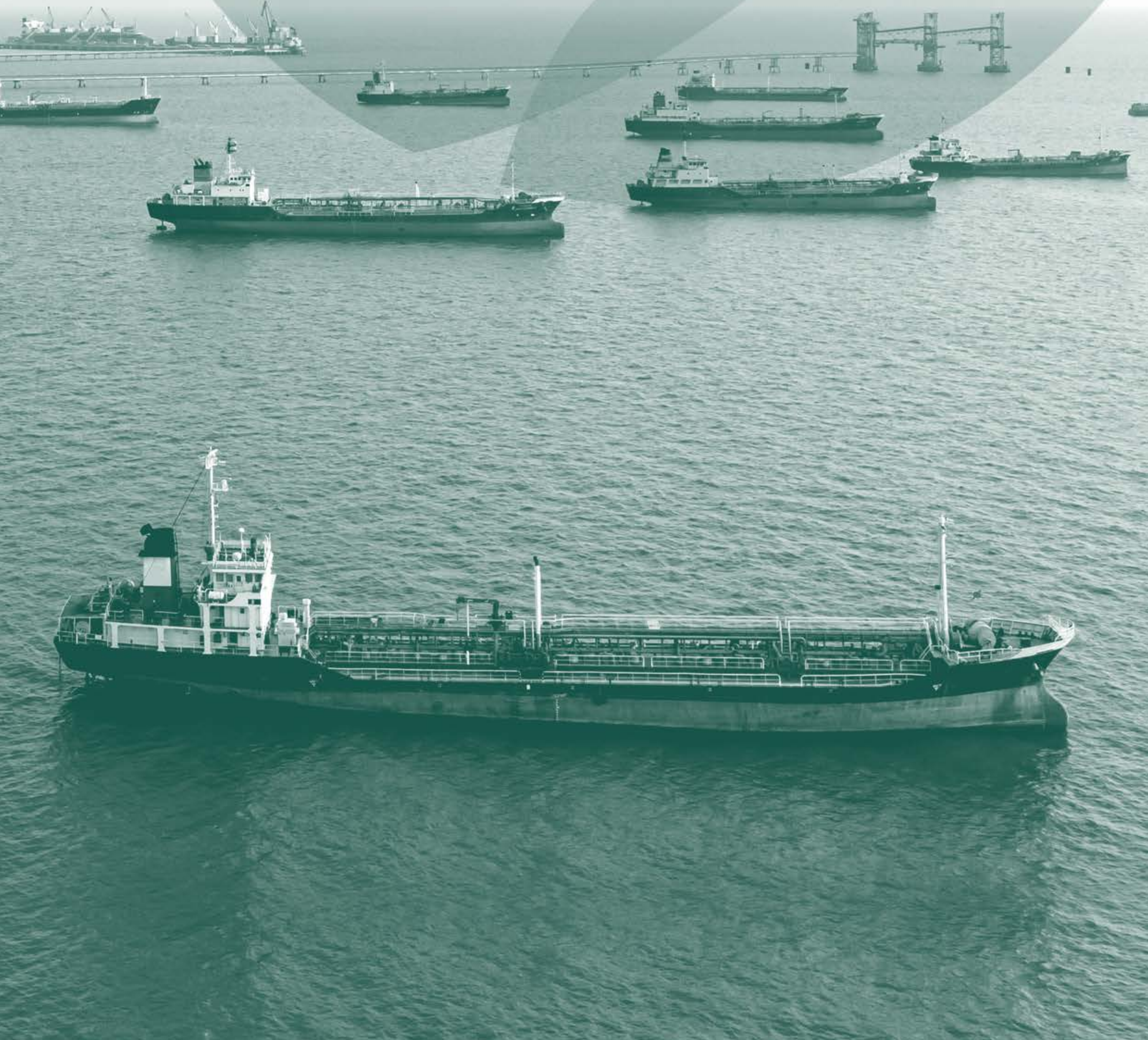

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LIST OF ABBREVIATIONS

AIS	Automatic Identification System
CII	Carbon Intensity Indicator
CO_2	Carbon dioxide
DCS	Data collection system
EEDI	Energy Efficiency Design Index
EEXI	Energy Efficiency Existing Ship Index
ESS	Energy storage system
FAO	Food and Agriculture Organization of the United Nations
GFS	GHG Fuel Standard
GHG	Greenhouse gas
GT	Gross tonnage
HFO	Heavy fuel oil
IMO	International Maritime Organization
JIT	Just in time
LDCs	Least Developed Countries
LFO	Light fuel oil
LNG	Liquid natural gas
LPG	Liquid petroleum gas
MBM	Market-based measures
MDO	Marine diesel oil
MGO	Marine gas oil
MTCC	Maritime Technology Cooperation Centre
NAP	National Action Plan
NDC	Nationally determined contributions
NGO	Non-governmental organization
NOx	Nitrogen oxide
SEEMP	Ship Energy Efficiency Management Plan
SIDS	Small Island Developing States
SOx	Sulphur oxide
WHR	Waste heat recovery

EXECUTIVE SUMMARY

Domestic shipping[1] plays a crucial role in ensuring food and energy security, creating employment opportunities and enhancing connectivity, especially for Small Island Developing States (SIDS) and Least Developed Countries (LDCs). Despite its significance to SIDS and LDCs, the International Maritime Organization (IMO) Fourth Greenhouse Gas Study (2020) revealed that domestic shipping contributes significantly to the share of shipping emissions in the anthropogenic emissions of global greenhouse gas (GHG) emissions. Based on 2018 estimations, domestic shipping was responsible for approximately 29.9% of the total CO_2 emissions from shipping when estimated based on voyage-based calculations (12.9% based on vessel-based allocations). Decarbonization trends, facilitated by measures like EEDI, EEXI, CII, MBM and GFS, are expected to indirectly influence emission reductions in this portion of domestic shipping. However, ships engaged in domestic voyages, and less than 400 GT in size, are often required to follow measures as required by their respective administrations. As a result, these ships may not experience decarbonization trends similar to international shipping. This report provides a comprehensive review of domestic ship types in the African and Caribbean regions and technologies and operational strategies aimed at decarbonization of domestic shipping, with a particular focus on assessing and tailoring these measures for implementation in the African and Caribbean region SIDS and LDCs.

Achieving zero-emission domestic shipping demands collaborative efforts among stakeholders across various sectors within countries, both horizontally and vertically. Substantial support from governments in both the African and Caribbean regions is imperative to realize this goal. The creation of a National Action Plan (NAP) tailored to the the domestic maritime sector is a pivotal step in facilitating this transition. However, effective implementation of such a plan requires significant resource allocation. The unique characteristics of domestic vessels must be carefully considered to ensure maximum effectiveness. Additionally, conducting a comprehensive impact assessment is crucial to accurately gauge the potential effects of the emission reduction measures on the individual states and stakeholders involved. The decarbonization of domestic shipping necessitates substantial investments in both new fleets (especially considering the ageing nature of existing domestic fleets) and port infrastructure. Given the unique characteristics of domestic shipping (small size of ships and short journey distances), this sector of maritime shipping is an ideal place to test out zero-emission technologies and alternative fuels.

As the transition to zero-emission shipping progresses, the role of ports has evolved from being mere cargo transfer hubs to becoming energy hubs. As with international shipping, ports serving domestic ships are crucial nodes in the supply chain and therefore play a vital role in the decarbonization of this sector. When considering the decarbonization of ports, three key areas must be taken into consideration: the port–ship interface, port activities, and port-cities interface. Ports can support and speed up the transition to zero-emission domestic shipping through port–ship operational measures and the establishment of sustainable infrastructure, such as alternative fuel and shore power systems. Additionally, embracing automation, digitalization, electrification and the use of cleaner fuels can effectively reduce emissions from port activities.

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[1] In the context of this study, which centres on African and Caribbean states, the following considerations have been made:

1. **Domestic shipping: Trade or services conducted by vessels operating exclusively within a single country.**
2. **Regional shipping: Trade or services conducted by vessels operating across multiple countries within the same region.**

1.0

INTRODUCTION

Maritime is the most energy efficient type of transportation, accounting for 80% of freight volume (UNCTAD, 2019) while contributing 2.89% of global greenhouse gas (GHG) emissions (IMO, 2020). The International Maritime Organization (IMO), as the regulatory body for international shipping in addressing GHG emissions, has established a comprehensive regulatory framework, encompassing the following components:

1. Energy Efficiency Design Index (EEDI): New ships exceeding 400 gross tonnes must be designed and constructed with a focus on enhanced energy efficiency.
2. Ship Energy Efficiency Management Plan (SEEMP): Ship owners use this practical tool to manage environmental performance and enhance operational efficiency for ships exceeding 400 gross tonnes.
3. Energy Efficiency Existing Ship Index (EEXI): Started in 2023, EEXI enforces similar design standards as EEDI for existing ships over 400 gross tonnes with adjustments for situations where design data may be limited.
4. Fuel Oil Consumption Data Collection System (DCS): Requires annual reporting of CO_2 emissions, activity data and ship particulars for vessels exceeding 5,000 gross tonnes.
5. Carbon Intensity Indicator (CII): Rates ships above 5,000 gross tonnes on an A to E scale, measuring their annual performance in terms of CO_2 emissions per deadweight tonnage and distance travelled (IMO, 2022). The CII determines the annual reduction factor needed to ensure continuous improvement of a ship's operational carbon intensity within a specific rating level.

The IMO's target-based approach enables ship owners to select the most cost-effective options based on their priorities for enhancing energy efficiency on board, considering factors such as the vessel's size, type, age and trading area (IMO, 2021a). In line with the IMO's commitments to curtail GHG emissions from the maritime industry and align with the objectives of the 2015 Paris Agreement, the IMO updated its initial GHG strategy in 2023 to aim for achieving net-zero GHG emissions by or around 2050. To achieve this ambitious goal, significant investments in technical and operational measures within the industry's value chain are required.

Furthermore, the IMO is working on a basket of candidate mid-term GHG reduction measures, including a technical element – a goal-based marine fuel standard regulating the phased reduction of marine fuel GHG intensity – and an economic element (a form of maritime GHG emission pricing mechanism to ensure that the industry meets the revised GHG strategy goals).

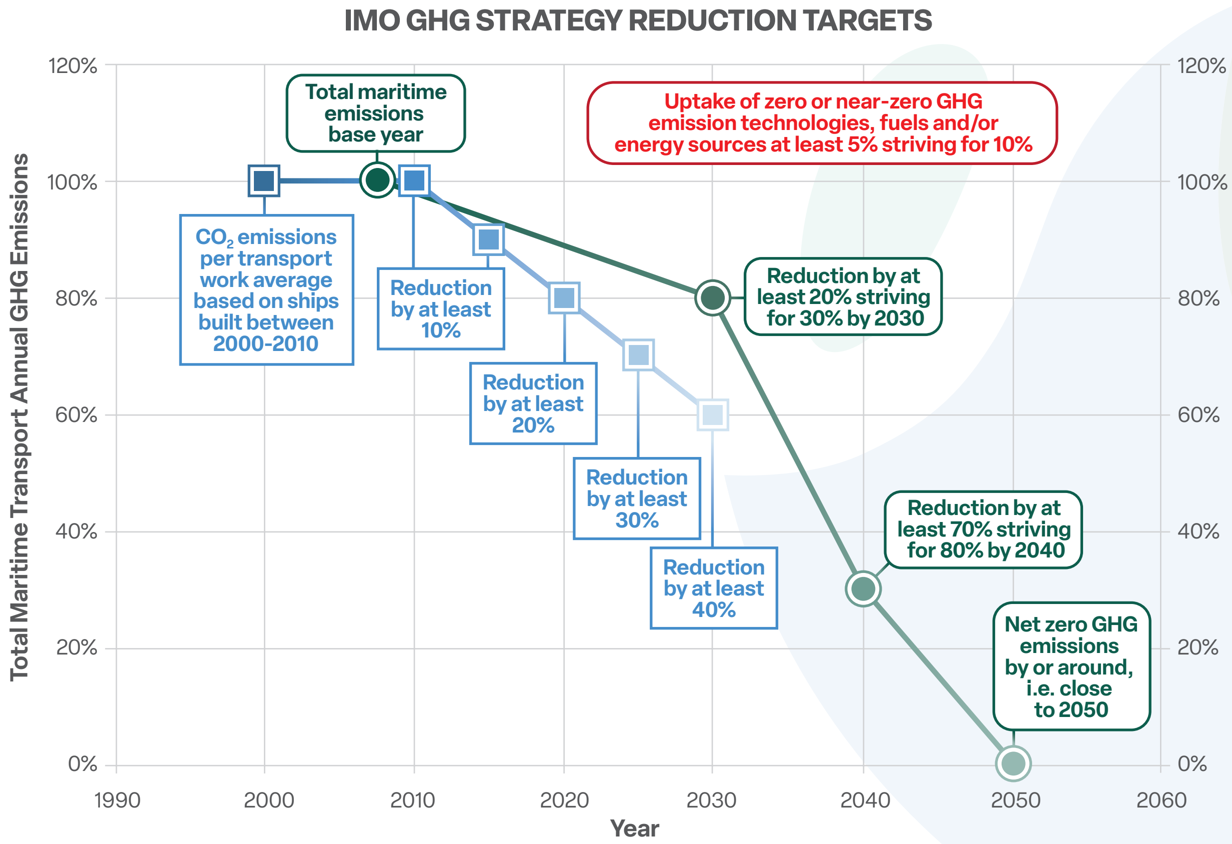


***FIG 1:** 2023 IMO Strategy on Reduction of GHG Emissions from Ships (IMO, 2023)*

The IMO Fourth Greenhouse Gas Study (2020) sheds light on the underestimated role and contribution of domestic shipping to global GHG emissions, estimated to account for 26.2% of total shipping emissions when considering domestic voyage-based shipping calculations and 9.2% of total shipping emissions when assessed on ship emissions involved in domestic shipping only (IMO, 2021). As 17% of global shipping emissions stem from domestic voyages of the IMO-regulated international ship fleet, the trends in decarbonization of international shipping, facilitated by implementing measures such as EEDI, EEXI, CII, market-based measures (MBM) and the GHG Fuel Standard (GFS), are poised to indirectly influence emission reductions in this portion of domestic shipping. But the emissions by ships involved in domestic shipping only, i.e. 9.2% of total shipping emissions, will be regulated as per the local administrations requirements as these ships are not directly regulated by the IMO regulations. Additionally, with the ongoing transition of international shipping toward becoming a zero-emission industry, the percentage of emissions from domestic shipping in the total global emissions from shipping is expected to rise unless proactive measures are adopted by governments.

Domestic shipping is of significant importance in the economies of states, particularly SIDS and LDCs. Acting as the primary mode of transportation for cargo and passengers, this sector fosters connectivity, spurs economic development, generates employment opportunities and enhances social well-being across various regions. Tourism and fishing are probably the most important economic activities in SIDS and LDCs. As nations undergo population and economic expansion, the domestic shipping industry must scale up to meet escalating demands. However, governments must concurrently implement measures to mitigate the adverse environmental impacts stemming from the sector's growth, especially in regions where a substantial portion of domestic shipping operates along coastal areas.

Domestic shipping decarbonization aims include not only the reduction of GHG emissions from the maritime sector but also enforcing the commitments of SIDS and LDCs under the United Nations Framework Convention on Climate Change, through nationally determined contributions (NDCs). Most of these countries have very ambitious NDCs for limiting the global temperature. These ambitious NDCs encompass both mitigation and adaptation objectives, including transitional risks, inclusivity for vulnerable groups, gender-responsive strategies, youth engagement and avenues for local enterprise investments. Domestic shipping and port decarbonization is implicitly integrated into NDCs.

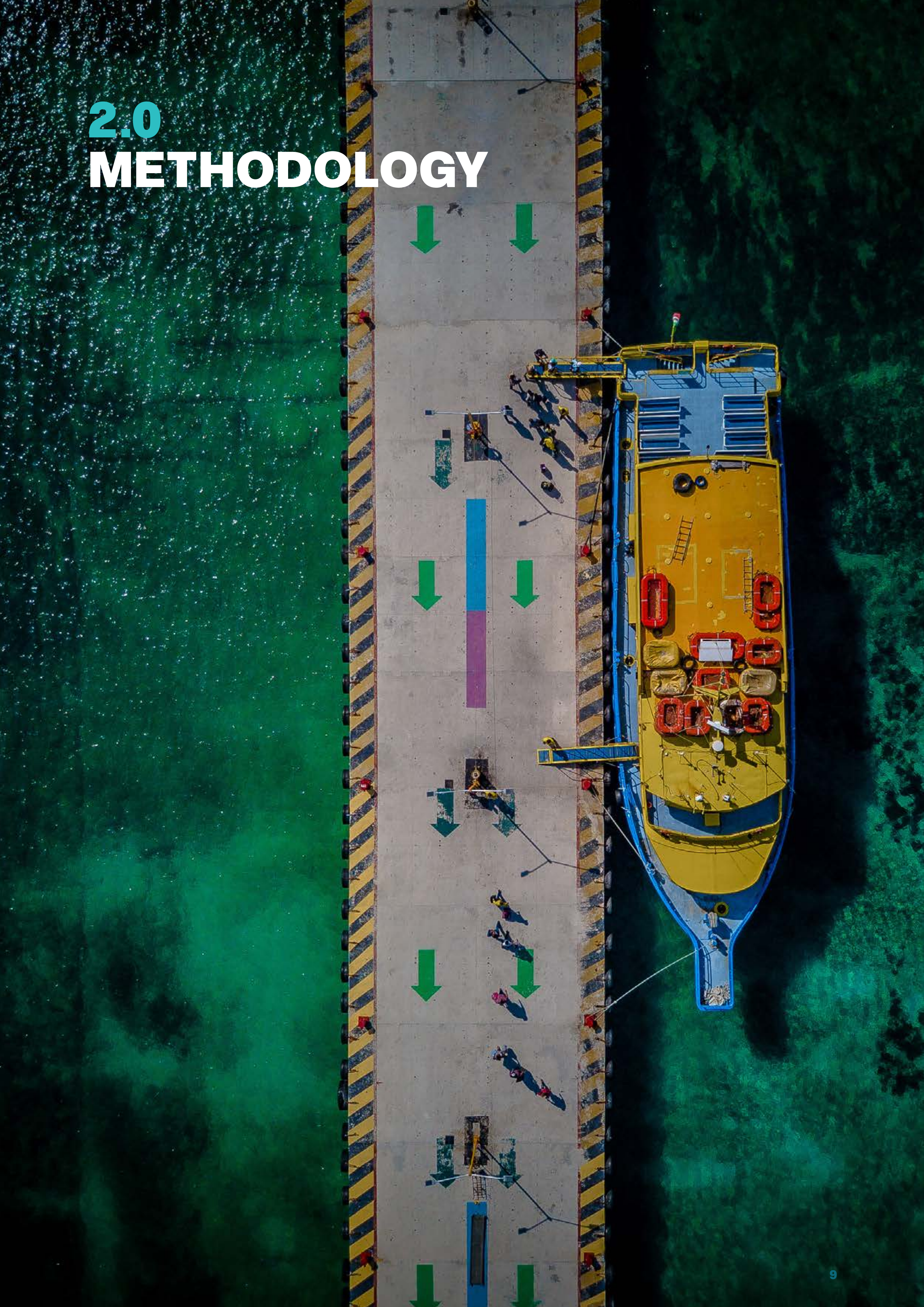
Port infrastructures are presently reliant on fossil fuel-based technologies – the ports' operations emit pollutants that impact air, water and noise quality. The significant potential for port decarbonization, combined with domestic shipping decarbonization, will help the SIDS and LDCs reach their NDCs. Furthermore, these actions offer not only environmental rejuvenation but also significant cost savings, chances to generate sustainable fuels within the area, improved competitiveness, and expanded opportunities for local businesses.

Considering the above, this study aims to raise awareness about decarbonization in domestic shipping within LDCs and SIDS, identifying current optimal operational practices and green technologies globally within the sector. Moreover, this report also explores their future potential in the context of domestic shipping in the Africa and Caribbean regions.

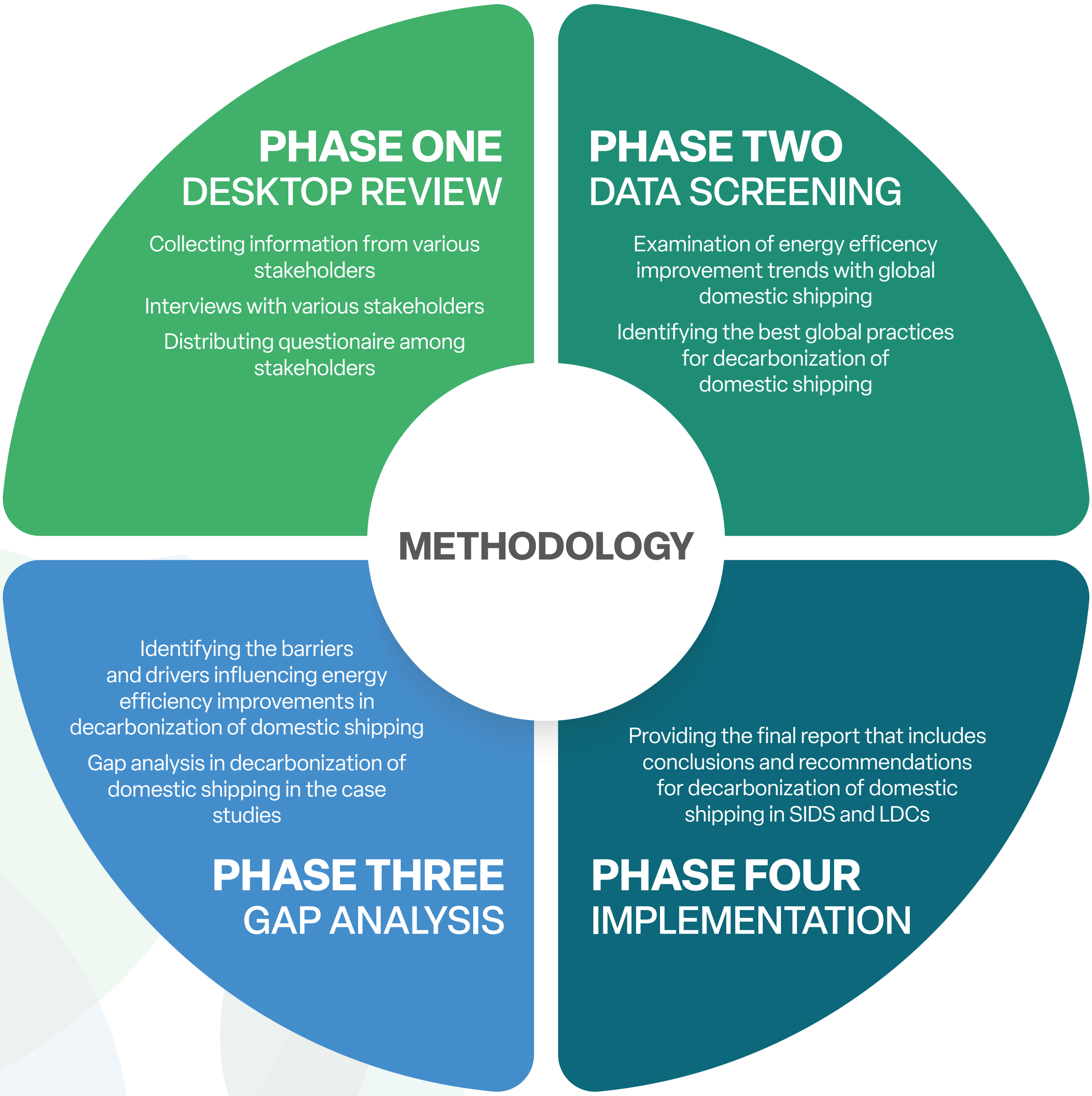
Section 2 outlines the methods employed in this study, while Sections 3 delves into a comprehensive literature review focusing on technical and operational measures aimed at enhancing energy efficiency and decarbonization within the domestic shipping sector. Section 4 presents an analysis of domestic shipping, including ship types. Section 5 offers an estimation of GHG emissions from the domestic ships in the Africa and Caribbean regions. Section 6 provides an overview of energy-efficient technology uptake in domestic shipping. Section 7 starts the discussion addressing the various options for decarbonization and challenges within domestic shipping fleets. Section 8 encapsulates the study's conclusions and offers actionable recommendations.

2.0

METHODOLOGY



The methodology in this study is composed of four distinct phases: the desktop review, data screening, gap analysis and implementation planning. Each phase employs specific methods tailored to its unique requirements.



PHASE ONE
DESKTOP REVIEW

Collecting information from various stakeholders

Interviews with various stakeholders

Distributing questionaire among stakeholders

PHASE TWO
DATA SCREENING

Examination of energy efficency improvement trends with global domestic shipping

Identifying the best global practices for decarbonization of domestic shipping

METHODOLOGY

Identifying the barriers and drivers influencing energy efficiency improvements in decarbonization of domestic shipping

Gap analysis in decarbonization of domestic shipping in the case studies

PHASE THREE
GAP ANALYSIS

Providing the final report that includes conclusions and recommendations for decarbonization of domestic shipping in SIDS and LDCs

PHASE FOUR
IMPLEMENTATION

FIG 2: *Methodology for the purpose of this study*

Desktop review: In this phase, information and data are collected from various stakeholders. Literature on the pathways for the decarbonization of shipping is reviewed to determine the global approach to decarbonization of both international and domestic shipping. The strategic goals of the IMO, the current and expected regulatory framework for global maritime transport, are also reviewed. The data related to use of energy efficient technologies and alternative fuels for international shipping is explored to determine its suitability to the domestic shipping. The analysis provided insights into aligning decarbonisation solutions in international and domestic shipping. Data gathering is accomplished through collaboration with Maritime Technology Cooperation Centres (MTCCs) and various stakeholders, such as administrators, shipowners, port authorities, shipyards and technology providers. This involves interviews and the distribution of questionnaires to acquire relevant data. Interviews were made with both MTCCs (African and Caribbean) separately and included:

- MTCC staff
- Representative administrations in the region
- Representative ship operators
- Representative port operators

The stakeholders were chosen based on the recommendations of the MTCC staff in both cases.

The interviews were focused on understanding the domestic shipping in the region, fleet and ports in the region, current decarbonization efforts, any barriers and current strategy. A questionnaire was also distributed to both MTCCs, to receive data and comments from the wider stakeholder community in both MTCC regions.

Data screening: This phase involves a comprehensive examination of energy efficiency trends, best practices in domestic shipping globally and case studies to review the existing literature. The domestic vessels are subdivided into functional groups of cargo carriers, passenger ships and ferries, fishing vessels, port utility vessels (tugs, pilot boats etc.) and leisure vessels.

Gap analysis: During this phase, the study identifies the barriers and drivers influencing energy efficiency improvements in the decarbonization of domestic shipping within the selected case studies. It also involves a comparative assessment of the information collected in phases one and two to pinpoint the gaps that hinder the achievement of zero-emission domestic shipping within the selected cases. The development of international shipping is considered for the technology transfer but the relevant considerations of differences in finance and regulatory frameworks are kept in mind.

Implementation: This phase provides the final report that includes conclusions and/or recommendations for the decarbonization of domestic shipping.

Geographic scope of the study: The focus of this study is SIDS and LDCs, with an emphasis on the Caribbean and African regions as per the Appendix 1 list of SIDS and LDCs.

3.0

LITERATURE REVIEW ON DECARBONIZATION OF DOMESTIC SHIPPING

Addressing climate change stands as a paramount objective for states worldwide, necessitating decarbonization across various economic sectors, including domestic shipping. Domestic shipping, often situated in close proximity to coastal areas, significantly impacts local populations, which makes it imperative to undertake every possible measure to reduce GHG emissions to lessen domestic shipping's negative socio-economic impacts. Decarbonizing the shipping industry presents substantial challenges, due to its inherent complexities. Factors such as extensive infrastructure requirements with long lifespans, uncertainties surrounding future maritime fuel options, and the diverse priorities and objectives of stakeholders contribute to the industry's high cost, complexity and risk (Vakili and Ölçer, 2023).

With the ambitious goal of achieving zero-emission shipping by approximately 2050, there is a pressing need for the industry to reassess its operations and adopt measures aligned with the updated IMO strategy. Recognizing the complexity of decarbonizing the maritime sector and the absence of a 'silver bullet' and 'one-size-fits-all' solution, various strategies have emerged, each showing considerable potential for reducing emissions. While the challenges of decarbonizing domestic shipping are formidable, the potential benefits, including economic development, job creation, reduced emissions and innovative technological advancements, underscore the importance of concerted efforts to overcome these barriers and transition towards a sustainable shipping industry. However, achieving this requires collaboration among stakeholders and significant changes in the domestic shipping sector.

Implementing appropriate technical and operational measures holds promise for significantly reducing air emissions from the shipping industry (Shi, 2016; Wan et al., 2018). Moreover, synergizing these measures can further amplify their effectiveness in mitigating emissions. Scholars have classified these measures in various ways; for example, Bouman et al. (2017) categorized them into six groups, encompassing hull design, economic scale, power and propulsion, speed, fuels, and weather and voyage planning, suggesting that a combination of these measures could potentially reduce GHG emissions by 75%. Similarly, Smith et al. (2015) delineated four categories, focusing on technologies to enhance energy efficiency, operational and behavioural changes, alternative fuels and technologies for exhaust emissions treatment. Meanwhile, Det Norske Veritas (DNV; 2022) adopted five distinct categories to classify GHG emission reduction measures, namely operation, hydrodynamics, machinery, energy and after-treatment, and Valdenaire (2022) employed seven different categorizations for the decarbonization of shipping, including voyage optimization, energy carriers, alternative propulsion technologies, power assistance, engine technology, vessel design and carbon capture. In a recent study, Vakili et al. (2023) introduced a classification framework comprising machinery, energy, vessel design and hydrodynamics, and voyage optimization, each encompassing a range of technical and operational measures.

In the quest for achieving zero-emission shipping by 2050, predictions indicate that alternative fuels could constitute approximately 64% of the solution, with speed reduction potentially contributing around 8% (IMO, 2018). Nonetheless, the realization of this ambitious goal is beset by numerous challenges, encompassing cost, availability, infrastructure limitations, logistical constraints and technological readiness. Consequently, it is anticipated that carbon-neutral fuels will yield only a modest contribution to industry decarbonization before 2030 (DNV, 2022). Their pivotal role is envisioned to materialize post 2040, potentially accounting for approximately 60% of the CO_2 emission reduction by 2050.

By 2030, there is a burgeoning emphasis on augmenting energy efficiency, estimated at around 32%, with speed reduction alone projected to contribute approximately 23% to emission reduction, alongside logistical optimizations, by 2050 (DNV, 2022; Vakili et al., 2023). This projection considers the expected development and adoption of energy efficiency measures and technologies, such as batteries and waste heat recovery systems, by 2025. Moreover, technological advancements are anticipated to persist beyond 2030, introducing innovations like wind propulsion systems, air lubrication systems, solar panels, advanced waste heat recovery systems and enhancements in ship design (DNV, 2022). Additionally, the integration of digitalization, artificial intelligence (AI) and deep learning techniques is expected to further enhance efficiency. Furthermore, economies of scale are forecasted to contribute to fleet efficiency improvements, with projected increases in the size of ships across various vessel types, thereby optimizing vessel utilization for both deep-sea and short-sea (domestic) shipping routes.

Decarbonizing domestic shipping is a crucial step towards reducing GHG emissions and mitigating climate change. This process will involve implementing a range of technical, operational and regulatory measures to transition from fossil fuel dependency to more sustainable practices.

However, due to the characteristic features of domestic shipping, which often involve fixed routes and shorter distances, the application of operational and technical solutions will require case-by-case assessments to evaluate optimal solutions. Short-sea and domestic shipping operations may not yield the same level of feasibility and effectiveness from such measures as deep-sea shipping. Successful execution of the measures also requires collaborative efforts among shipping lines, ports and terminals to facilitate the exchange of necessary data and information, enabling ships to optimize their voyages.

4.0

DECARBONIZATION ANALYSIS OF DOMESTIC SHIPPING FLEET IN SIDS AND LDCS

Even though international shipping is responsible for the moving of world trade between countries and continents, there is also trade on the domestic or regional scale. A number of terms are used for such trade: domestic shipping, short-sea shipping, coastal shipping or inter-island shipping. In this study, the following definitions are used:

- Domestic shipping: Trade or services conducted by vessels operating within one country only.
- Regional shipping: Trade or services conducted by vessels operating across multiple countries within the same region, as applied in this study to Caribbean intra-regional voyages.

IMO GHG studies have adopted two different approaches. The IMO Third GHG Study divided ships into international and domestic ships, and emissions were calculated based on this assumption. Meanwhile the IMO Fourth GHG Study adopted a voyage-based division: every voyage is separated into international or domestic voyage rather than a ship-based approach. Although the IMO Fourth GHG study approach can separate international and domestic emissions more clearly, the purpose of this report is to provide a description and understand the development of energy-efficient technologies in domestic shipping. Hence ships involved in partly international shipping could be decarbonized using the initiatives for international shipping, and this report aims to target ships involved in domestic shipping only, or regional shipping in the case of the Caribbean.

The main functions of domestic ships can be categorized as:

- Carriage of passengers and vehicles
- Carriage of goods (container, liquid bulk, dry bulk, general cargo etc.)
- Port services such as tugboats, pilot tenders
- Offshore services
- Fishing activities
- Leisure activities
- Marine construction

Comprehensive databases of ships exist for ships involved in international trade. However, a ship database for domestic shipping could not be identified within this work. The Clarksons World Fleet Register has been used in this study by filtering ships deployed only in one SIDS or LDC country during the past 12 months, and ships involved in regional shipping for the Caribbean during the past 12 months. In the Caribbean region, ships involved in regional shipping with countries outside SIDS and LDCs were excluded, hence regional shipping from countries other than SIDS and LDCs were excluded. Fishing vessels are not included in the Clarksons World Fleet Register; hence they are analysed separately.

According to the Clarksons World Fleet Register, a total of 28,627 ships of more than 100 gross tonnage operate in domestic voyages only. The main domestic shipping fleet is in Asia with 61%, followed by the Mediterranean/Middle East/Black Sea with 13%, the North, central and south America with 12%, Europe with 8% and Africa with 3%.

FIG 3: ***Distribution of domestic shipping across continents***

The largest ship type in domestic shipping is tugs with 10,188 ships, followed by passenger ships/ferries with 3,020 ships, small product tankers with 1,696 ships and general cargo ships with 1,642 vessels.

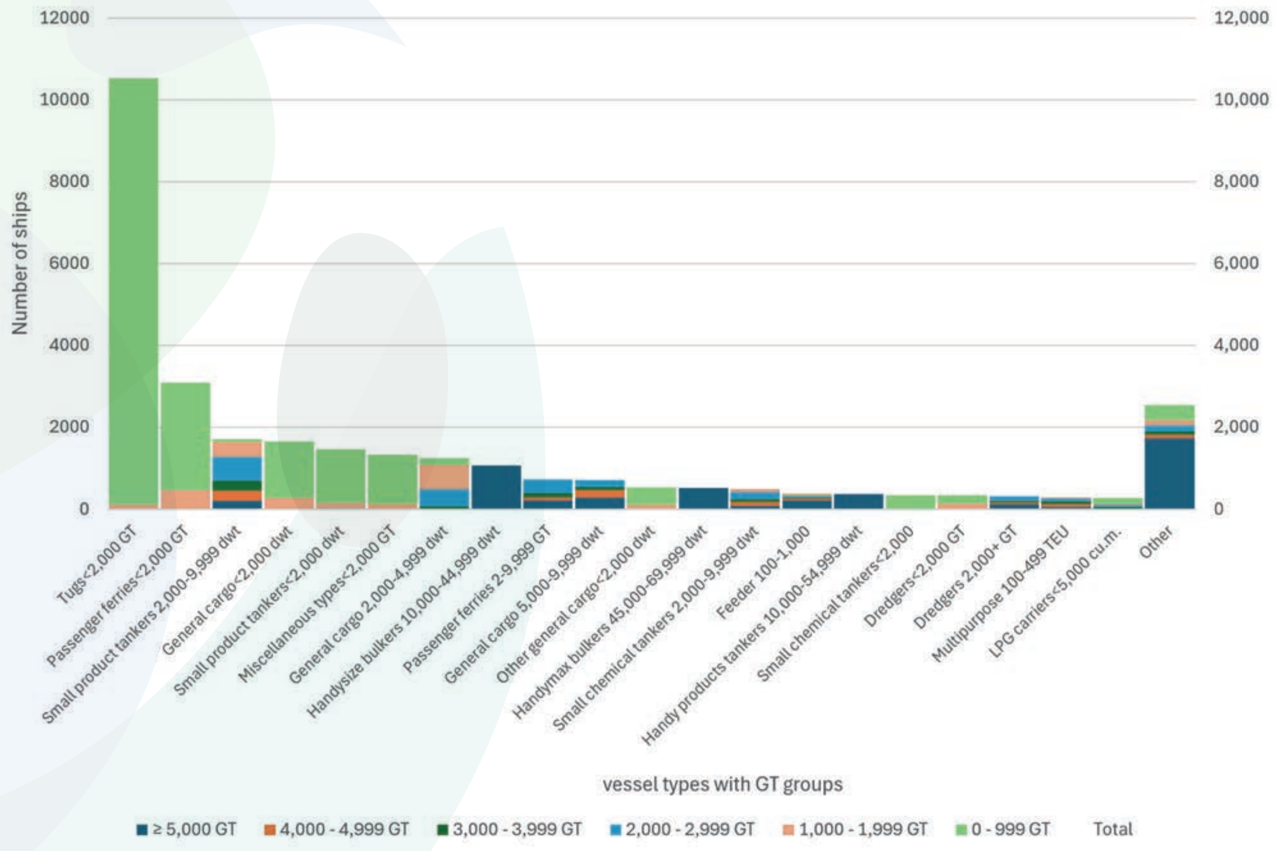


FIG 4: ***Ship type distribution for domestic shipping***

Where age distribution is concerned, 17.76% of domestic ships are built before 1990, hence aged more than 35 years. More than 25% of the domestic ship fleet is over 20 years of age for all ship types. There is a clear trend that when ships exceed 25 years in age, the recycling process starts and the number of ships in this age group is reduced. However, some ships are not scrapped, and continue to operate over long periods of time.

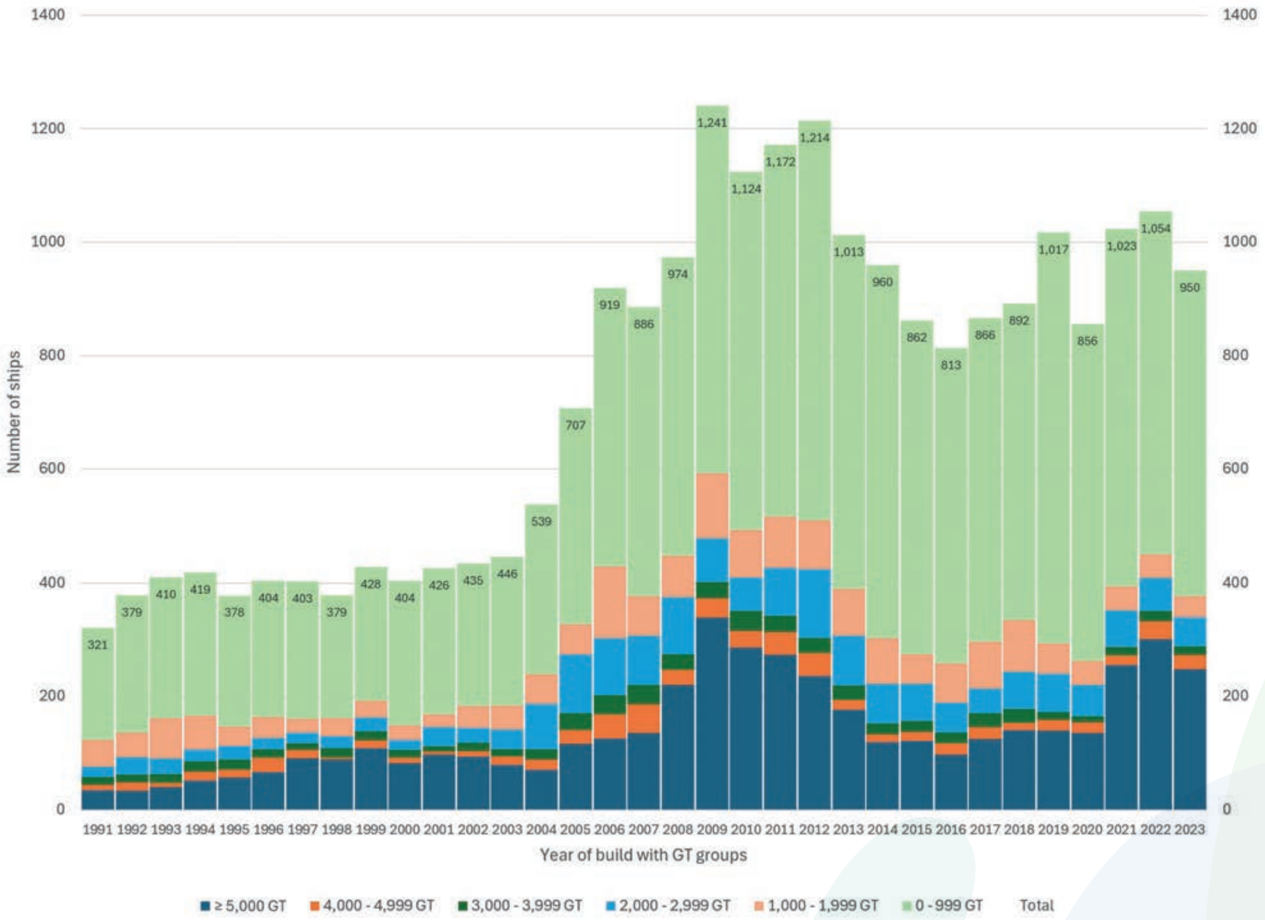


FIG 5:* *Year of build distribution for domestic shipping

The majority of domestic ships are shorter than 100 metres in length, and tugs are generally shorter still.

4.1 DOMESTIC SHIP TYPES

African domestic ships over 100 gross tonnage other than fishing vessels were derived from the Clarksons World Fleet Register by filtering ships solely operating in one African country according to AIS records; 312 ships operating regionally and 770 ships operating in national waters were determined. These ships include the ships operating in countries other than SIDS and LDCs. Ships within the operation area of SIDS and LDCs were checked, and 319 were determined to be operating solely in one of the SIDS or LDCs of Africa. The absolute values of fuel consumption and emission are dependent on the number of ships found in the database. There may be further ships in the actual fleet that could not be determined from the database.

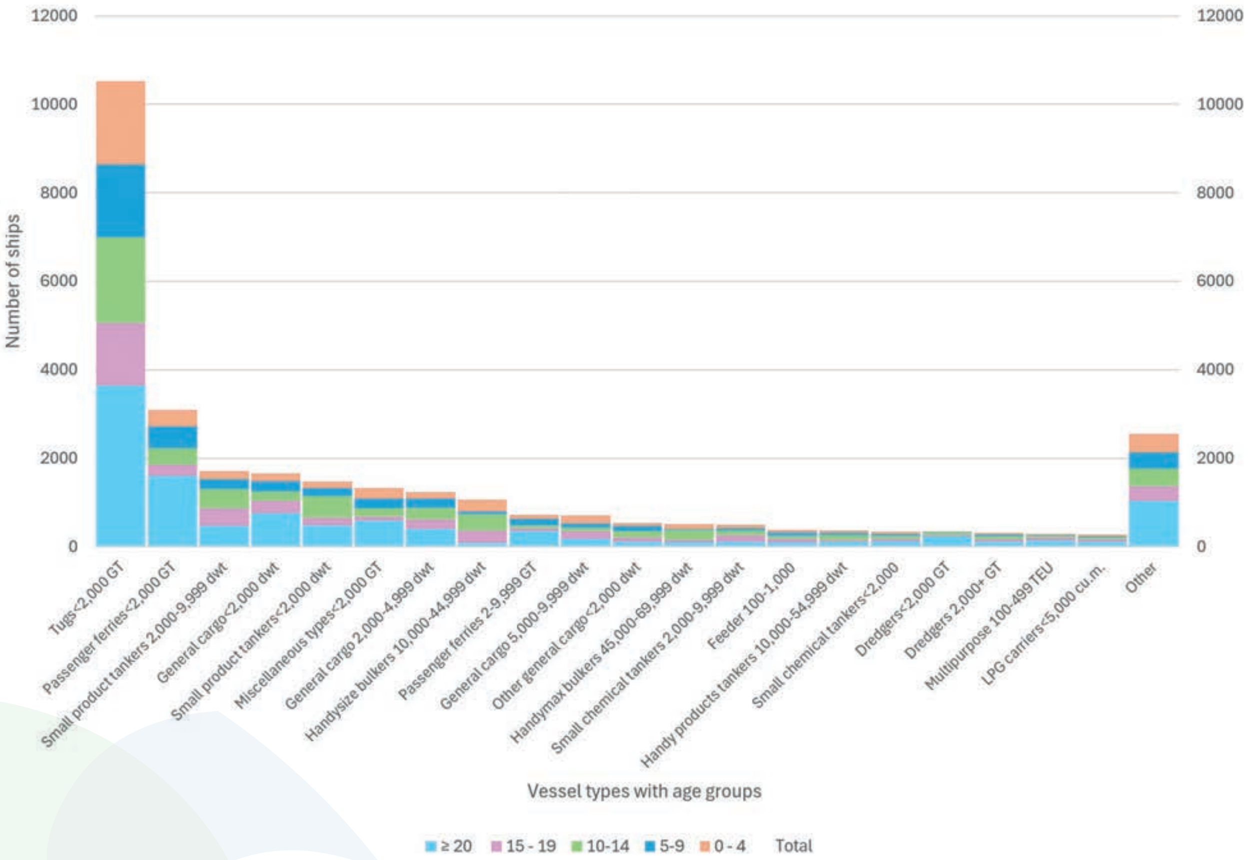


FIG 6: *Age distribution for domestic shipping by ship type*

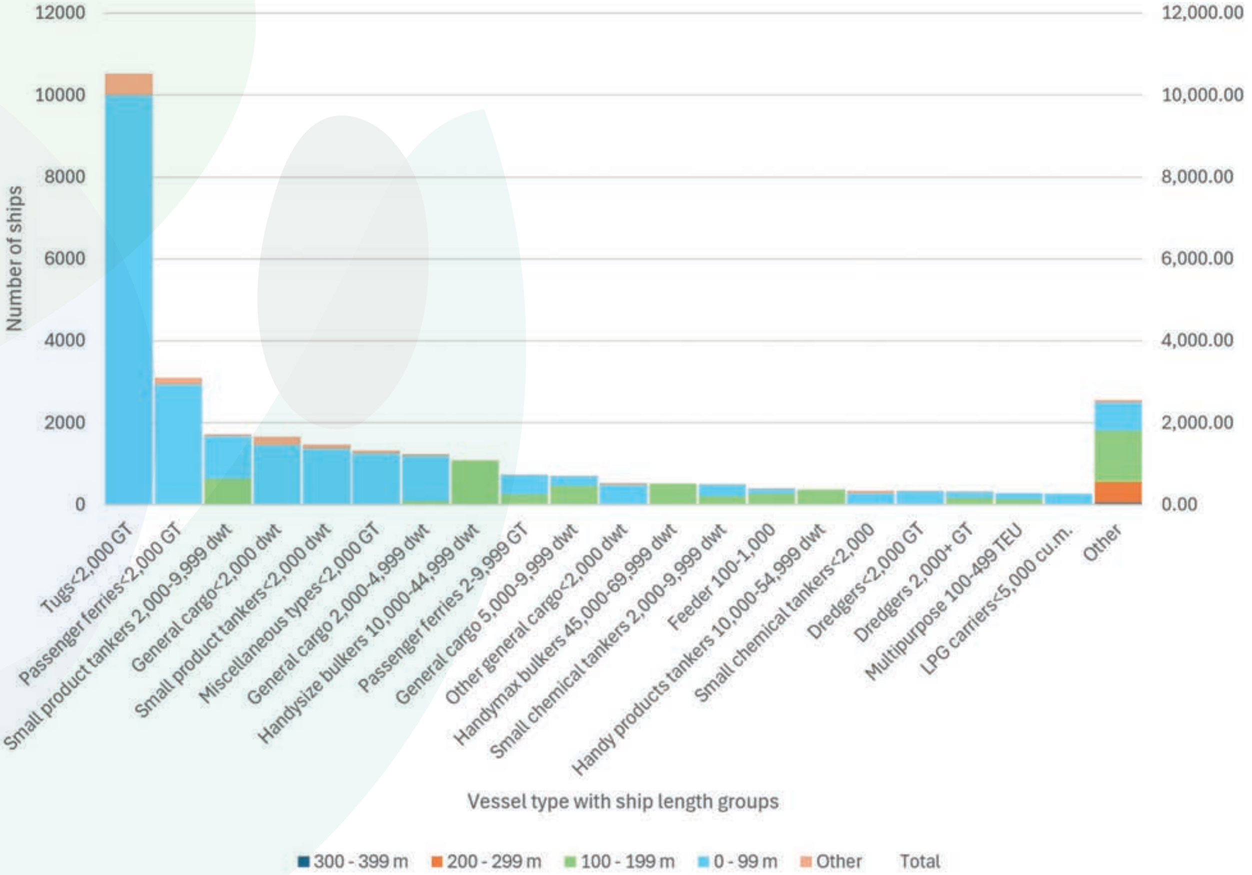


FIG 7: *Length distribution for domestic shipping*

Ship type distribution is given in Figure 7. More than half of the fleet consists of tugs. The second largest number of ships are general cargo vessels, followed by ferries, product tankers and chemical tankers.

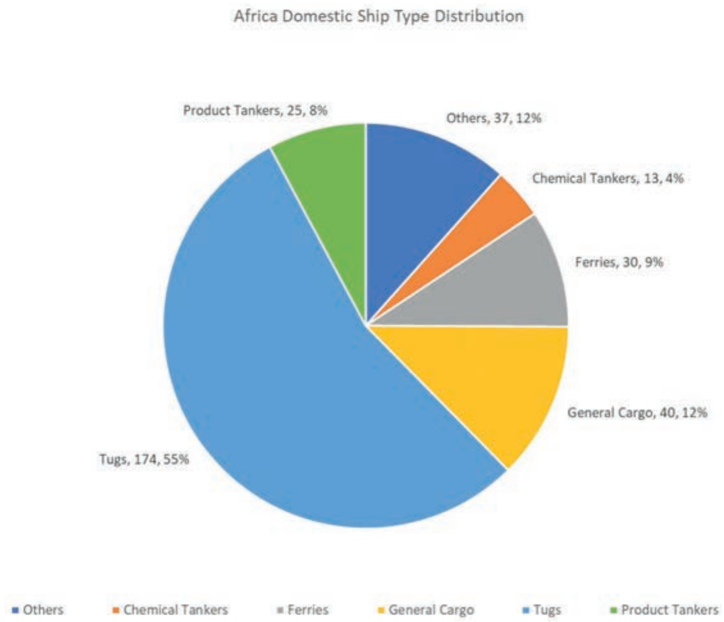


FIG 8:* *Ship type distribution for domestic vessels in African SIDS and LDCs (over 100 gross tonnage)

In the case of the Caribbean, both domestic vessels and regionally operating ships were included in the database. Ships operating between Caribbean countries and the USA, Mexico and North/South American countries are excluded – only ships operating within Caribbean countries are included.

There were 824 ships identified as being involved in American (East and West Coast) regional shipping, and 3214 ships involved in domestic shipping in North, Central and South America. These ships were individually checked as to whether they operate in Caribbean SIDS and LDCs: 120 were operating regionally and 210 were operating solely within the national borders of SIDS and LDCs in the Caribbean.

Ship type distribution is given in Figure 9. Tugs are the most common ship type at 44%. The second largest number of ships are ferries, followed by general cargo, product tankers and chemical tankers. Ro-ros and container ships are also visible in the Caribbean.

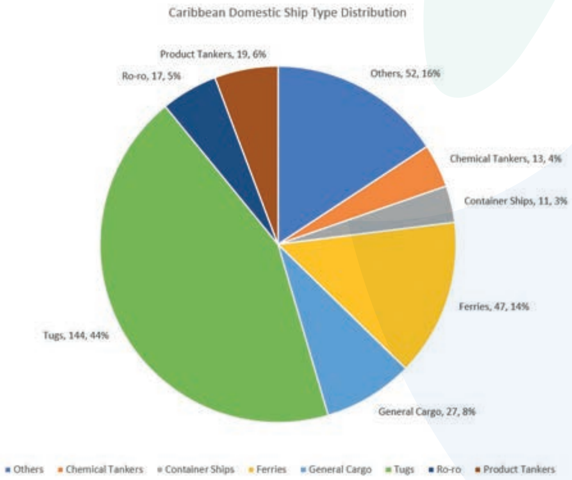


FIG 9:* *Ship type distribution for SIDS and LDCs of Caribbean nationally or regionally (over 100 GT)

4.1.1 TUGS

The most common domestic ship types in both African and Caribbean SIDS and LDCs are tugs and offshore support vessels.

In terms of age, 18% of tugs in Africa are more than 20 years old, as are 47% of Caribbean tugs (Figure 10). Figure 11 shows a comparison of gross tonnage distribution between Africa and the Caribbean. The most common weight for tugs is 250–300 gross tonnage for both cases.

As some of the Caribbean countries and neighbouring countries in the southern Caribbean are part of an oil-producing region, there are also offshore supply vessels.

4.1.2 DOMESTIC CARGO CARRIERS

According to Clarksons World Fleet Register data, the main ship types under cargo carriers are general cargo ships and chemical/product tankers on the African and Caribbean geographic regions (see Figures 13 and 14).

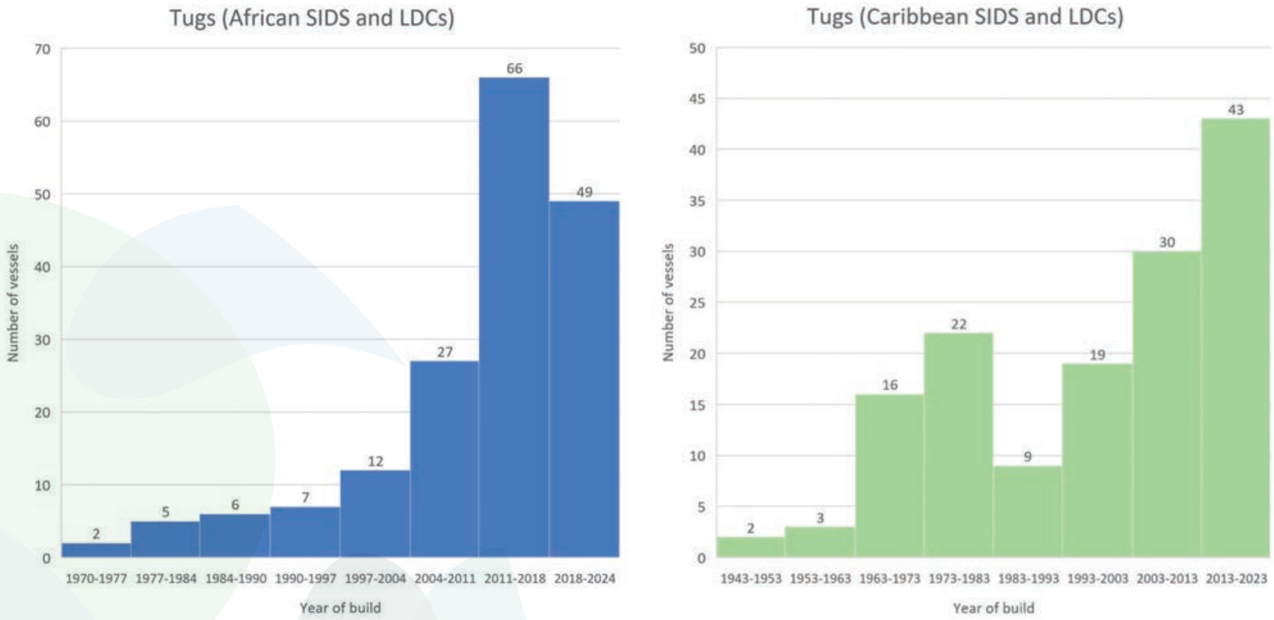


FIG 10: *Age distribution of tugs in domestic shipping*

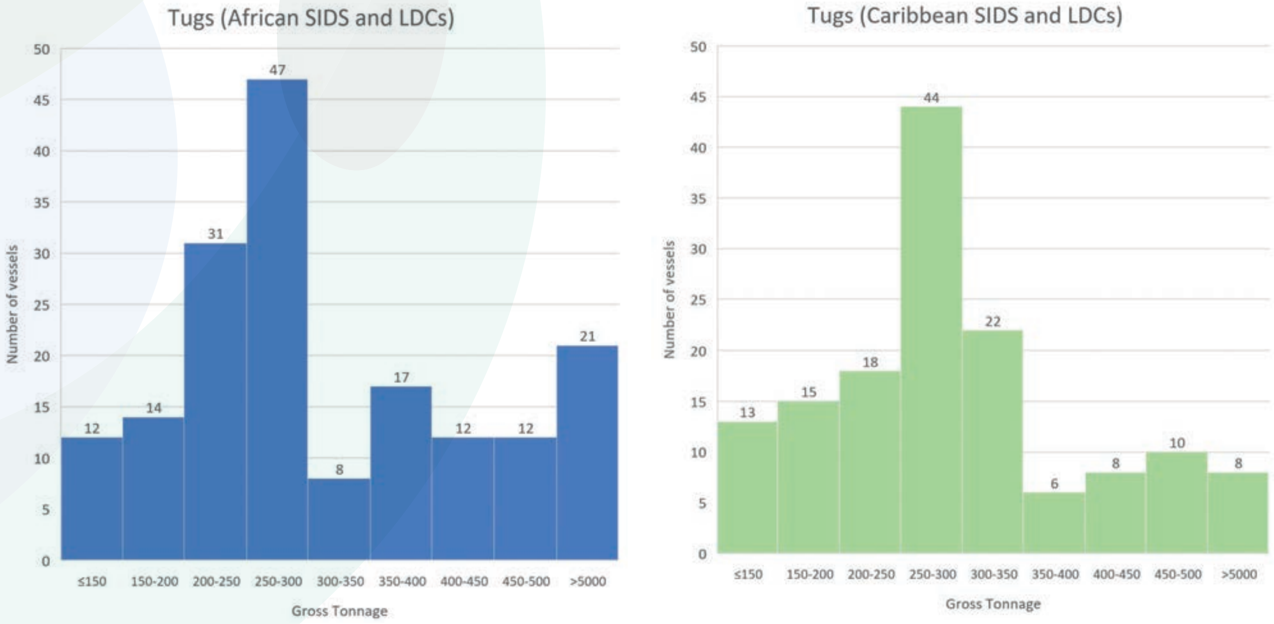


FIG 11: *Gross tonnage distribution of tugs in domestic shipping*

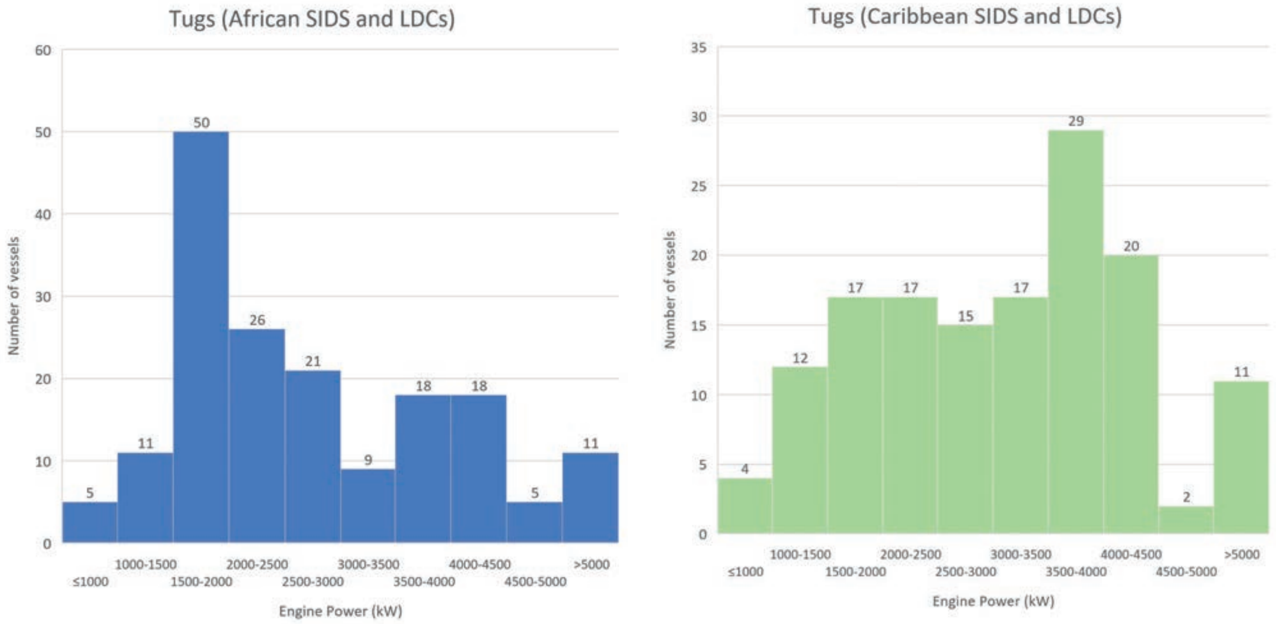
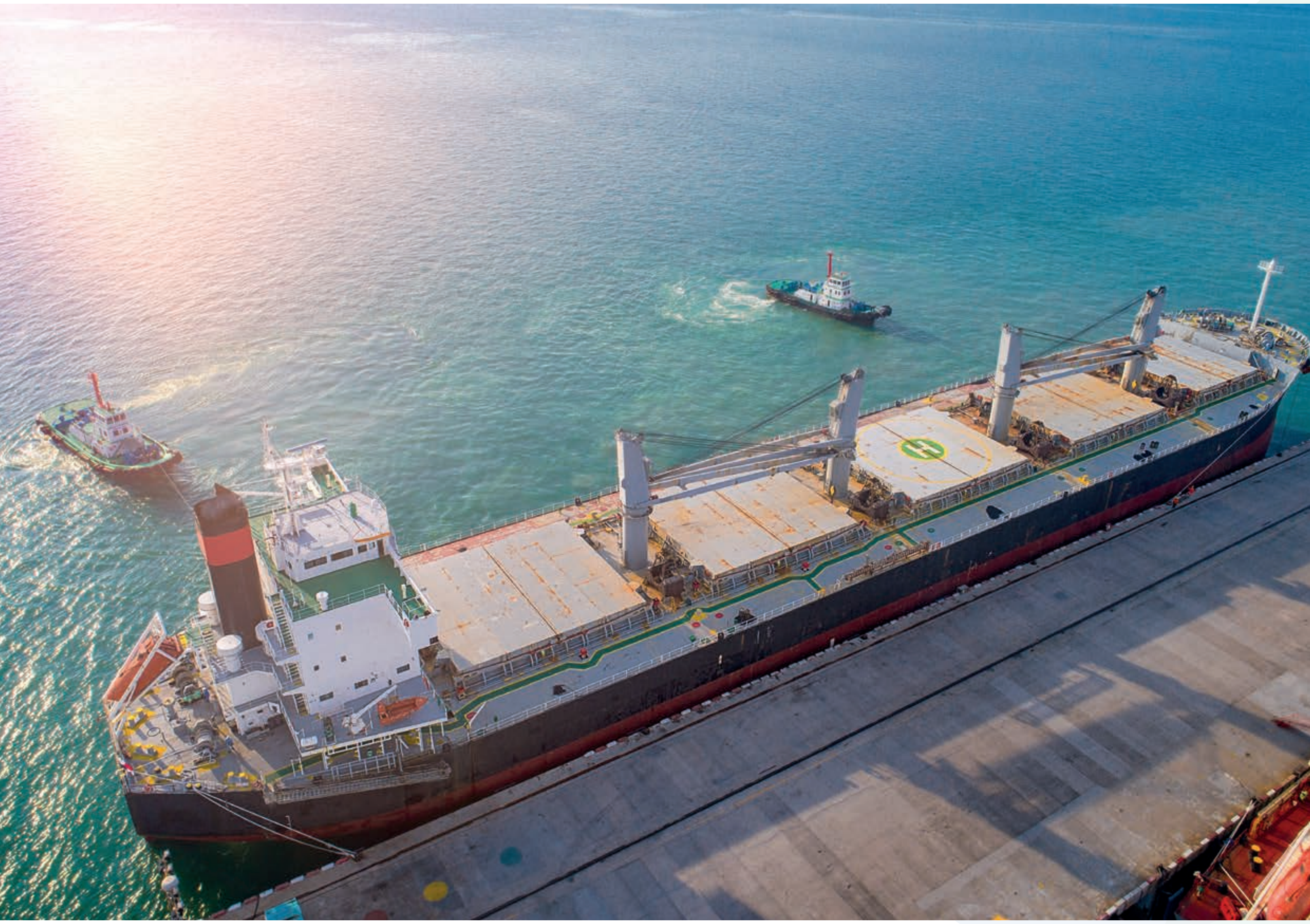


***FIG 12:** Engine power distribution of tugs in domestic shipping*



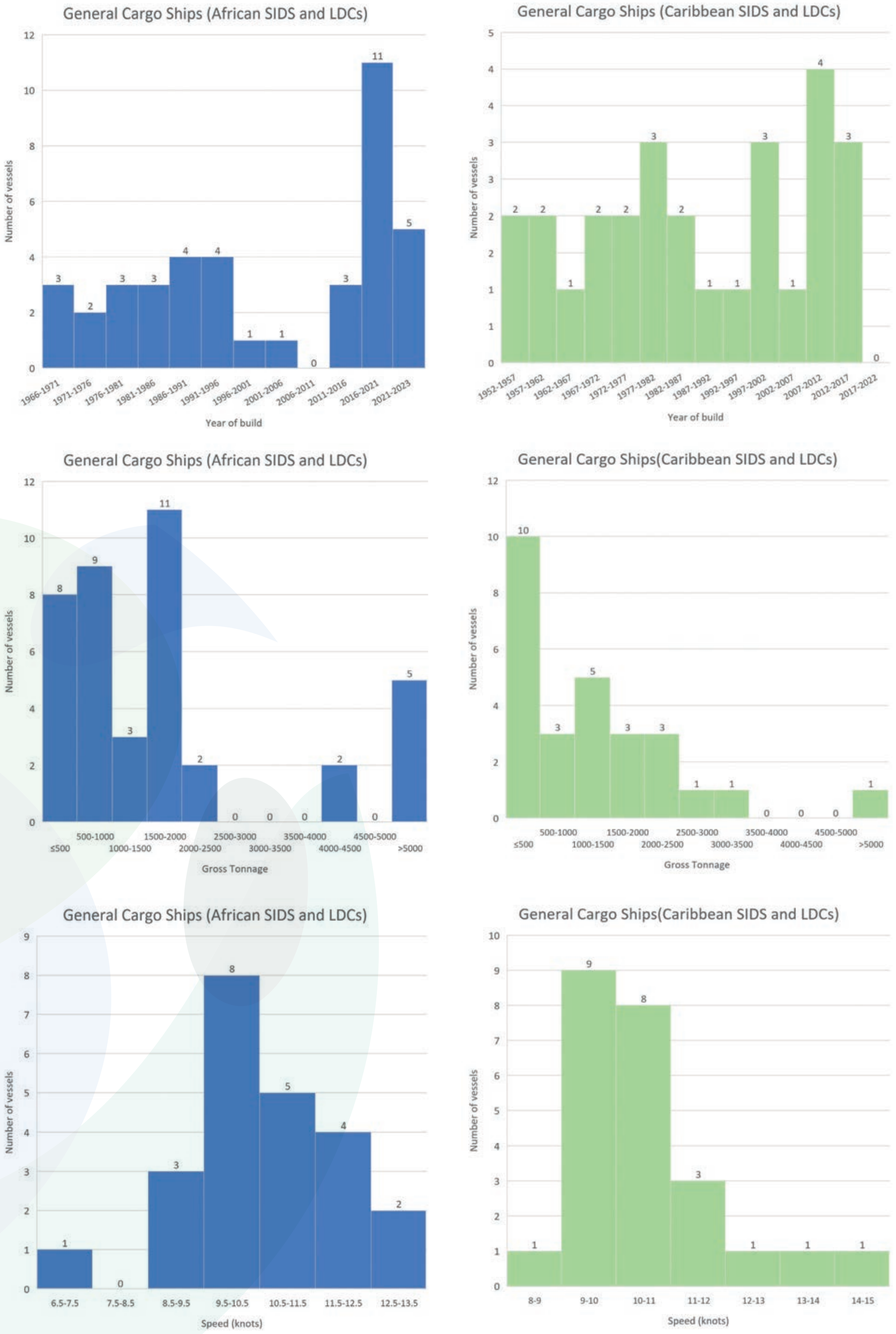


FIG 13: *Age, gross tonnage and speed distribution of general cargo ships in domestic shipping*

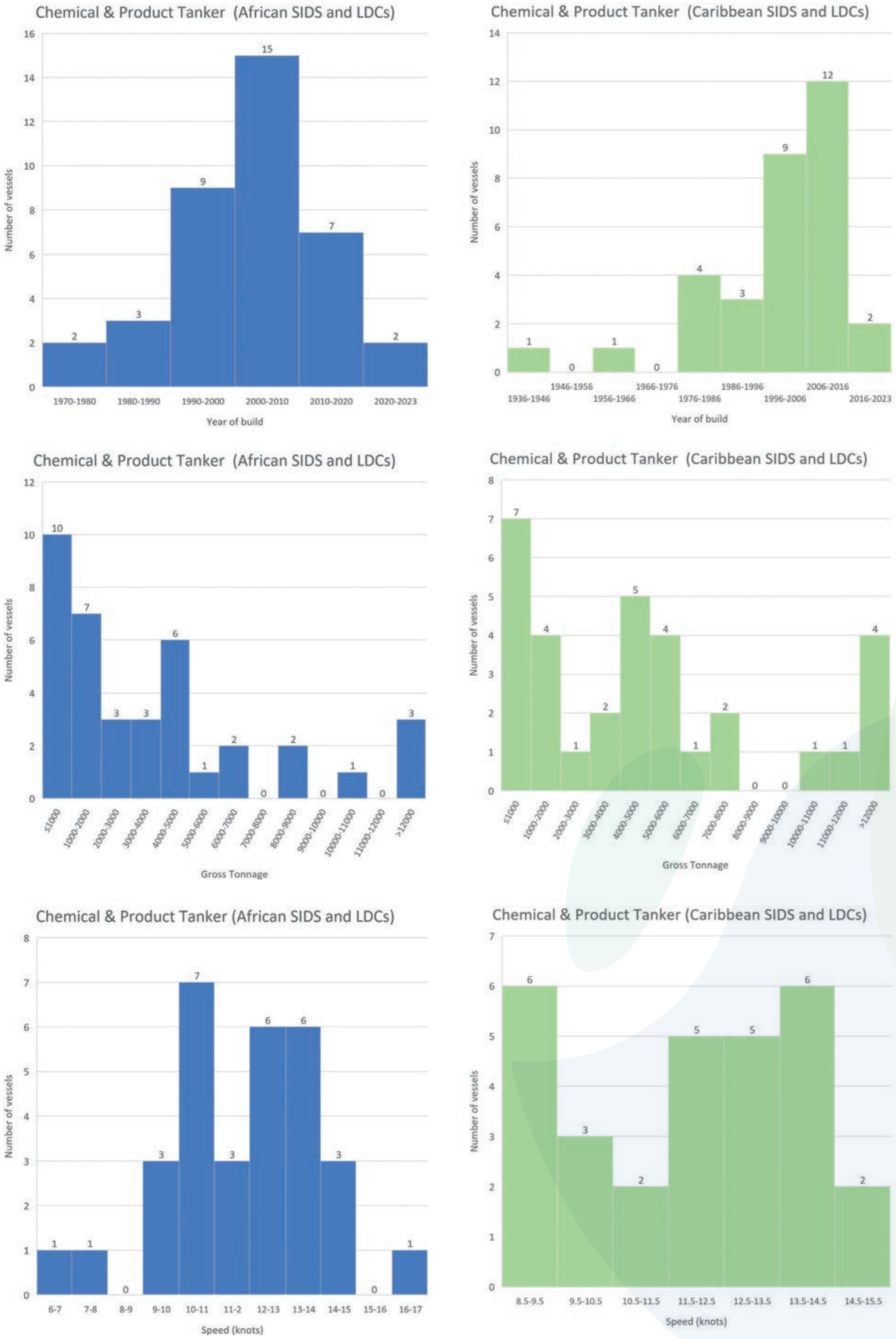


FIG 14: *Age, gross tonnage and speed distribution of chemical/product tankers in domestic shipping*

FIG 15: *Examples of general cargo ships in Africa*

FIG 16: *Examples of general cargo ships in the Caribbean*

FIG 17: *Examples of ro-ro ships in the Caribbean*

FIG 18: *Examples of chemical/product tankers in Africa*

FIG 19: *Examples of chemical/product tankers in the Caribbean*

4.1.3 FERRIES

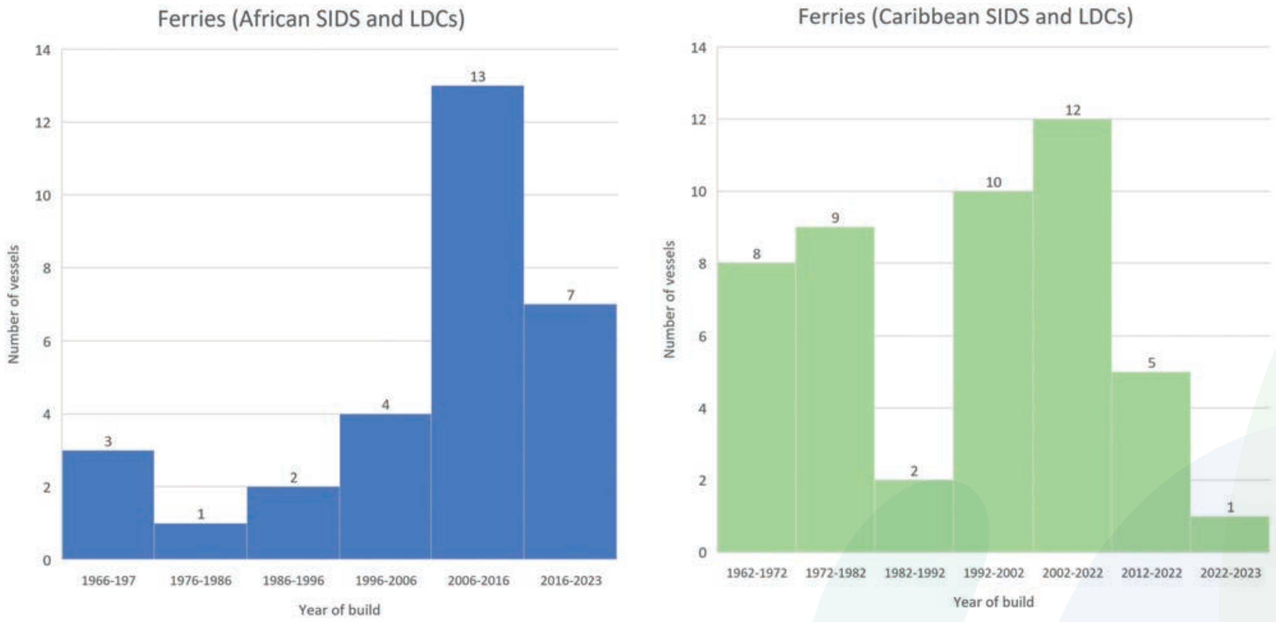


FIG 20: *Age distribution of ferries in domestic shipping*

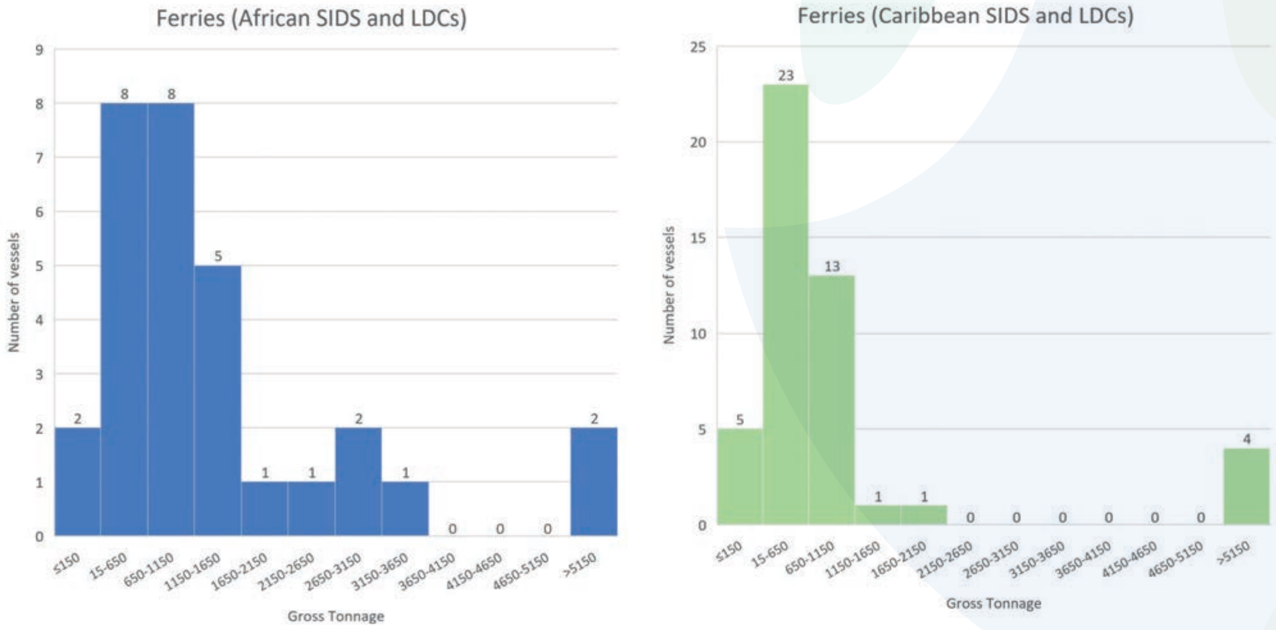


FIG 21: *Gross tonnage distribution of ferries in domestic shipping*

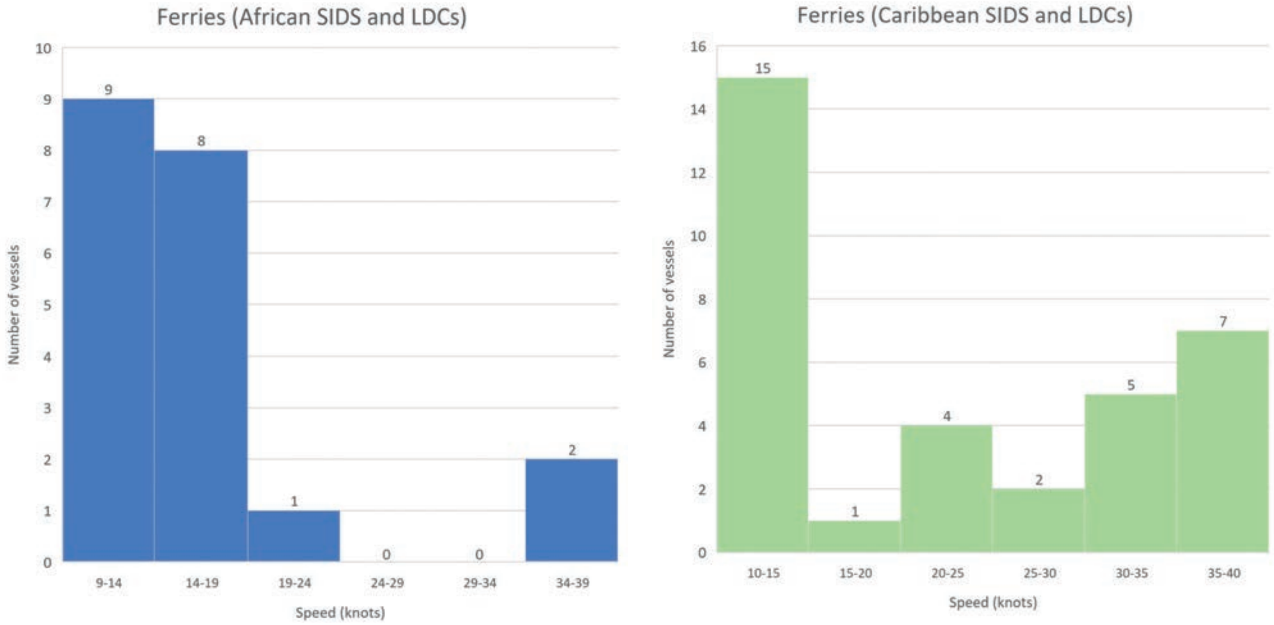


FIG 22: *Speed distribution of ferries in domestic shipping*

FIG 23: *Examples of ferries in Africa*

FIG 24: *Examples of ferries in the Caribbean*

4.1.4 FISHING VESSELS

The global fishing fleet was estimated to be 4.1 million vessels in 2020 (FAO 2022). Asia hosts the largest fleet at about 2.6 million vessels, accounting for two thirds of the global fleet. The African fleet is about 23.5% of the world's fishing vessels, while the Americas, including the Caribbean, is 9%. There are a wide variety of fishing vessels, from small non-motorized personal fishing vessels to large commercial craft including fish factory ships. To estimate the effect of decarbonization efforts, they should be categorized according to their size and propulsion system. About 5% of the global fishing fleet is over 24 metres in size, and about 15% is 12–24 metres. In terms of propulsion, 2.5 million vessels (about 62% of the global fishing fleet) are equipped with engines (FAO 2022).

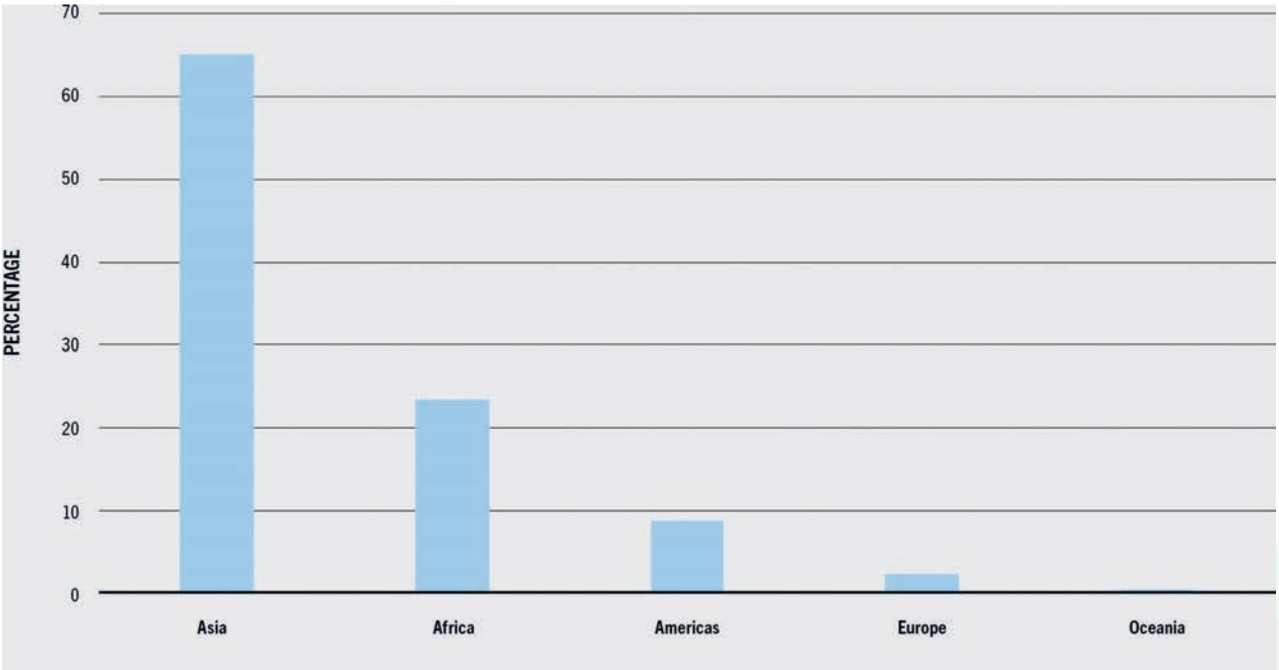


FIG 25: *Global fishing fleet distribution across continents*

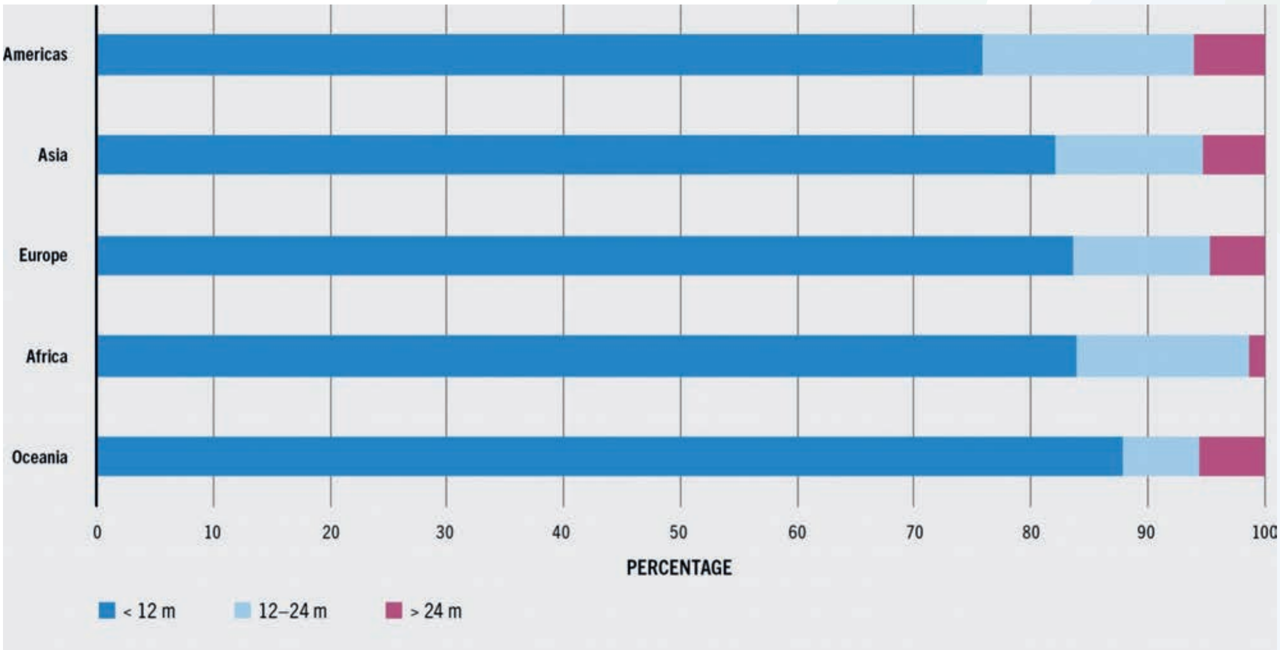


FIG 26: *Size distribution of global fishing fleet*

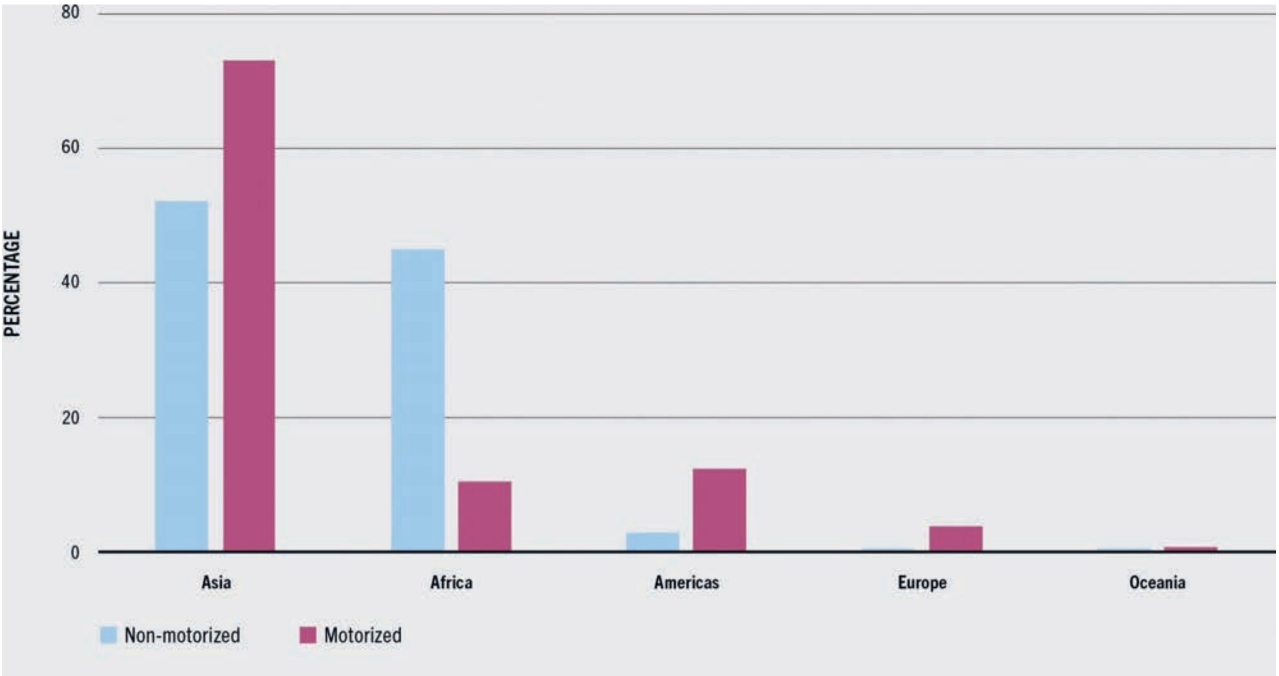


***FIG 27:* Motorization of the global fishing fleet**

Fishing is typically an energy-intensive operation due to the fossil fuel-powered engines of the fleet. Global fishing fleet fuel consumption was estimated to be 50 billion litres in 2000 (Tyedmers et al., 2005) for 80 million tonnes of marine fish, resulting in an average of 625 litres of fuel consumed per tonne of marine fish caught.

Databases on fishing vessels and their characteristics are not comprehensive enough to cover fishing fleets in the current context. As cabotage regulations are not applied in either the Caribbean or Africa, the fishing vessel fleet in the regions cannot be fully distinguished by the use of flag registers either. The Food and Agriculture Organization of the United Nations (FAO) Fishing Vessels Finder (https://www.fao.org/figis/vrmf/finder/search/) and Global Fishing Watch databases (globalfishingwatch.org) were investigated but it was not possible to derive the fishing fleets of the African and Caribbean SIDS and LDCs. Some data were found in the open literature and these were utilized. Most of the fishing boats in SIDS and LDCs were constructed from wood. A trend to move to fibre-reinforced plastic is increasing due to the higher cost and reduced availability of suitable wood for fishing vessel construction, which results in lighter boat displacement and hence less fuel consumption in turn.

Caribbean Region

The average fishing boat length for artisanal, semi-industrial and industrial fisheries are found to be 8.9 metres, 13.5 metres and 20.4 metres, respectively (Dunn et al., 2010). In the Caribbean islands, 94.7% of the fishing vessels are artisanal fishing vessels and only 5.3% are semi-industrial or industrial fishing vessels; the share of artisanal fishing vessels is smaller in Caribbean mainland countries. The number of fish landed in the Caribbean was 132,877 tonnes meat weight, 147,870 tonnes live weight and 216,608 tonnes at high seas by fleets from Belize, St Vincent and the Grenadines in 2020 (CRFM 2021). The total number of fishing vessels in the Caribbean in 2020 was estimated to be 32,128 vessels according to the Caribbean Regional Fisheries Mechanism Report 2020. The size distribution of 17,197 vessels could be obtained, and 88% were less than 18 metres in overall length (CRFM 2021).

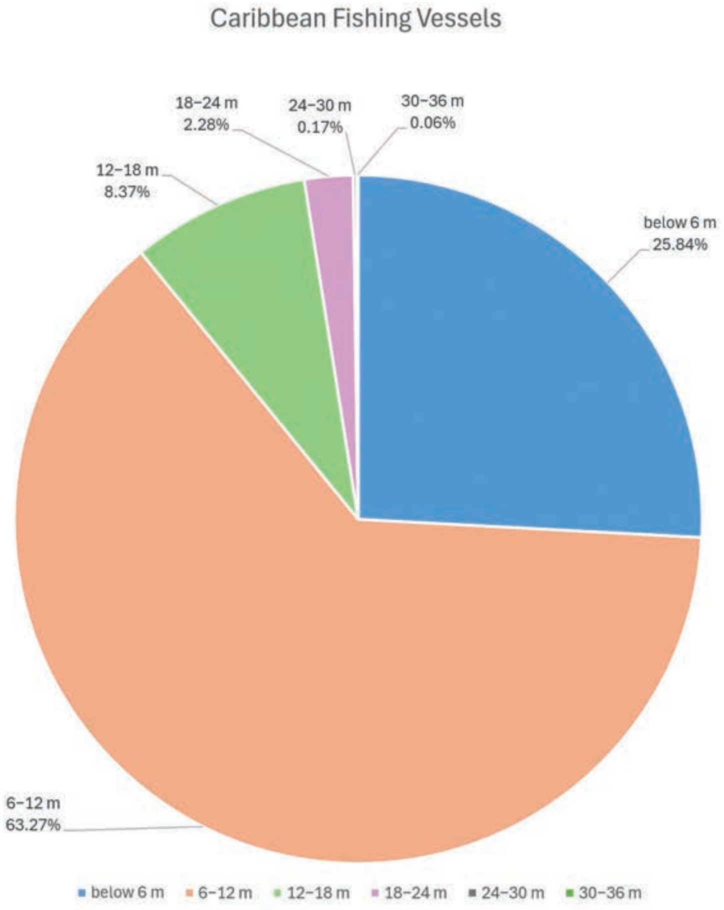


***FIG 28:** Fishing fleet size distribution in the Caribbean*

African Region

According to FAO statistics 23.3% of the global fishing fleet is in Africa, resulting in 955,300 fishing vessels, among which 801,497 are less than 12 metres in length, 141,384 are between 12 and 24 metres, and 12,419 are more than 24 metres long (FAO 2022). Motorization of the African fishing fleet stands at 18.8% (FAO 2022), which corresponds to 180,000 motorized fishing vessels.

***FIG 29:** Artisanal fishing boats from Africa and the Caribbean*

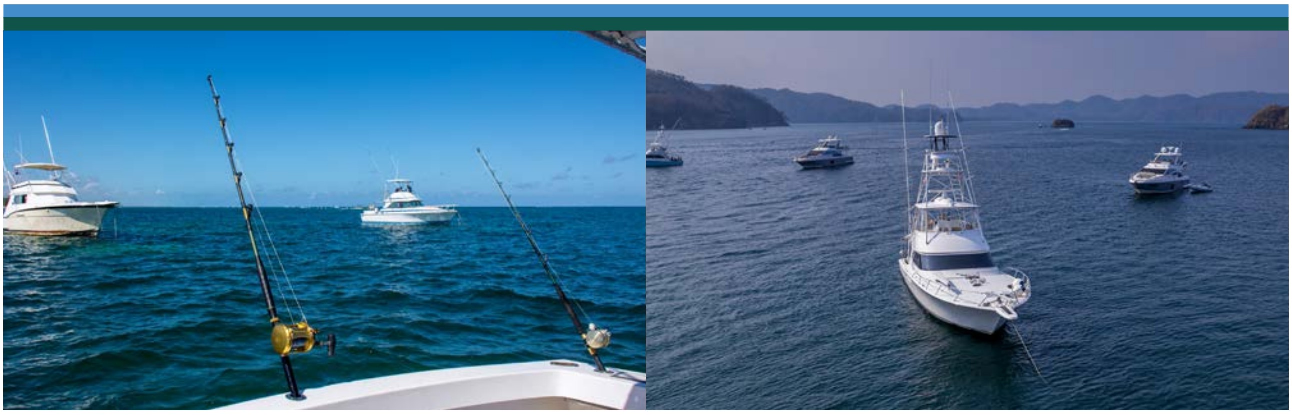


FIG 30: *Sport fishing boats from the Caribbean*

4.1.5 LEISURE VESSELS

Various leisure vessels exist both in Africa and especially in the Caribbean, but these ships were not included in this study.

4.1.6 OTHER

Other types of ships, including non-cargo carrier vessels, reefers, bulkers, anti-pollution vessels, multipurpose vessels, workboats, tenders, dredgers, liquid petroleum gas (LPG) and liquid natural gas (LNG) carriers or storage vessels and electricity generation vessels are recorded in the domestic ship fleet. Most of these ships are small, at less than 5,000 gross tonnage, with the exceptions of LNG/regasification and electricity generation vessels as shown below. These ships cannot be counted as domestic ships as they are stationary and serve as floating storage or floating platforms only (Figure 31). There are two electricity generation ships in the Caribbean and three in Africa. Although these ships stay within the boundaries of a single country for more than one year, these vessels were excluded from the report.

FIG 31: *LNG ships*

Tugs are the most common domestic ship type in the African and Caribbean regions, accounting for 55% and 44% of fleets respectively. In Africa, 18% of tugs are over 20 years old, while in the Caribbean, 47% are over 20 years old. The most common size of tugs is 250–300 gross tonnage for both regions.

5.0

GHG EMISSIONS FROM DOMESTIC SHIPPING

The IMO Fourth Greenhouse Gas Study (2020) separates ship voyages into international, domestic and fishing voyages, it also presents estimations based on ships involved only in domestic shipping. The estimation of total fuel consumption in domestic shipping during 2018 was 31.25 million tonnes, in which 93.3% was estimated to use marine diesel oil (MDO) or marine gas oil (MGO) and 3.6% heavy fuel oil (HFO). If the ships involved in both domestic and international shipping are examined, the estimation of total fuel consumption is increased to 88.79 million tonnes and the share of HFO rises to 38.9%. The share of MDO/MGO utilized was increased due to low sulphur regulations starting in 2020.

The GHG emission estimations from the domestic fleet in this report were conducted using a bottom-up approach as bunkering fuel or fuel consumption data on domestic shipping could not be obtained. A multistage procedure was adopted from the fourth IMO study and detailed methodology is shared in Appendix IV.

5.1 GHG EMISSIONS FROM DOMESTIC SHIPS IN AFRICAN SIDS AND LDCS

The fuel consumption of the African domestic ship fleet in SIDS and LDCs is found to be 41,044 tonnes of HFO/ intermediate fuel oil (IFO) and 113,389 tonnes of MDO/MGO, resulting in 513,669 tonnes of CO_{2e} (metric tonnes of CO_2 emissions) per year.

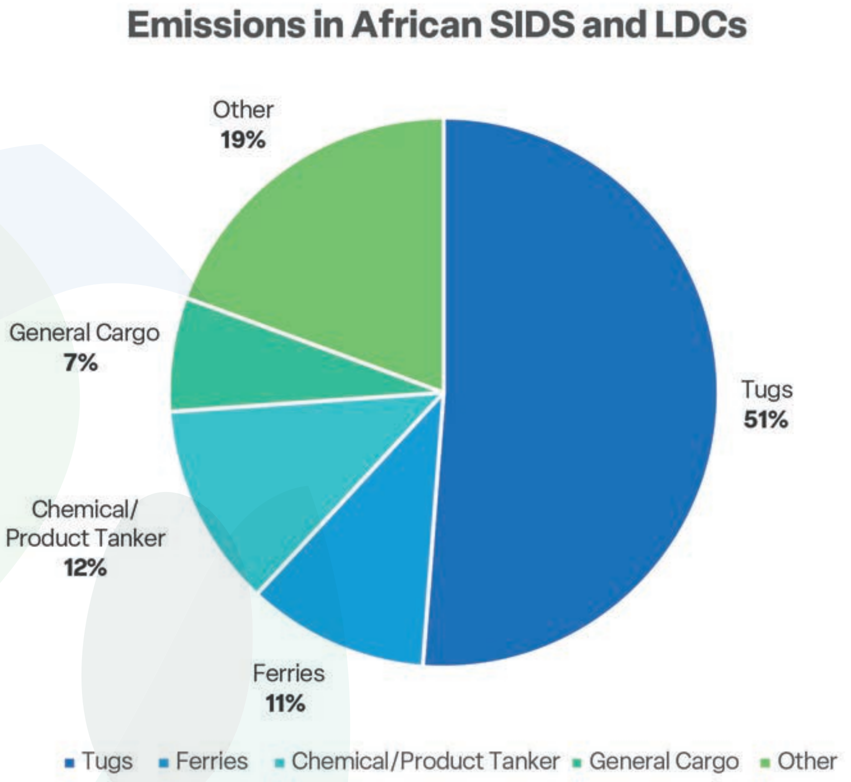


FIG 32: Emission estimation from African SIDS and LDCs for domestic shipping

5.2 GHG EMISSIONS FROM DOMESTIC SHIPS AND INTRA-REGIONAL SHIPS IN CARIBBEAN SIDS AND LDCS

The fuel consumption of the Caribbean ship fleet involved in domestic and intra-regional shipping in SIDS and LDCs is found to be 127,529 tonnes of HFO/IFO and 181,059 tonnes of MDO/MGO, resulting in 1,007,700 tonnes of CO_{2e} per year.

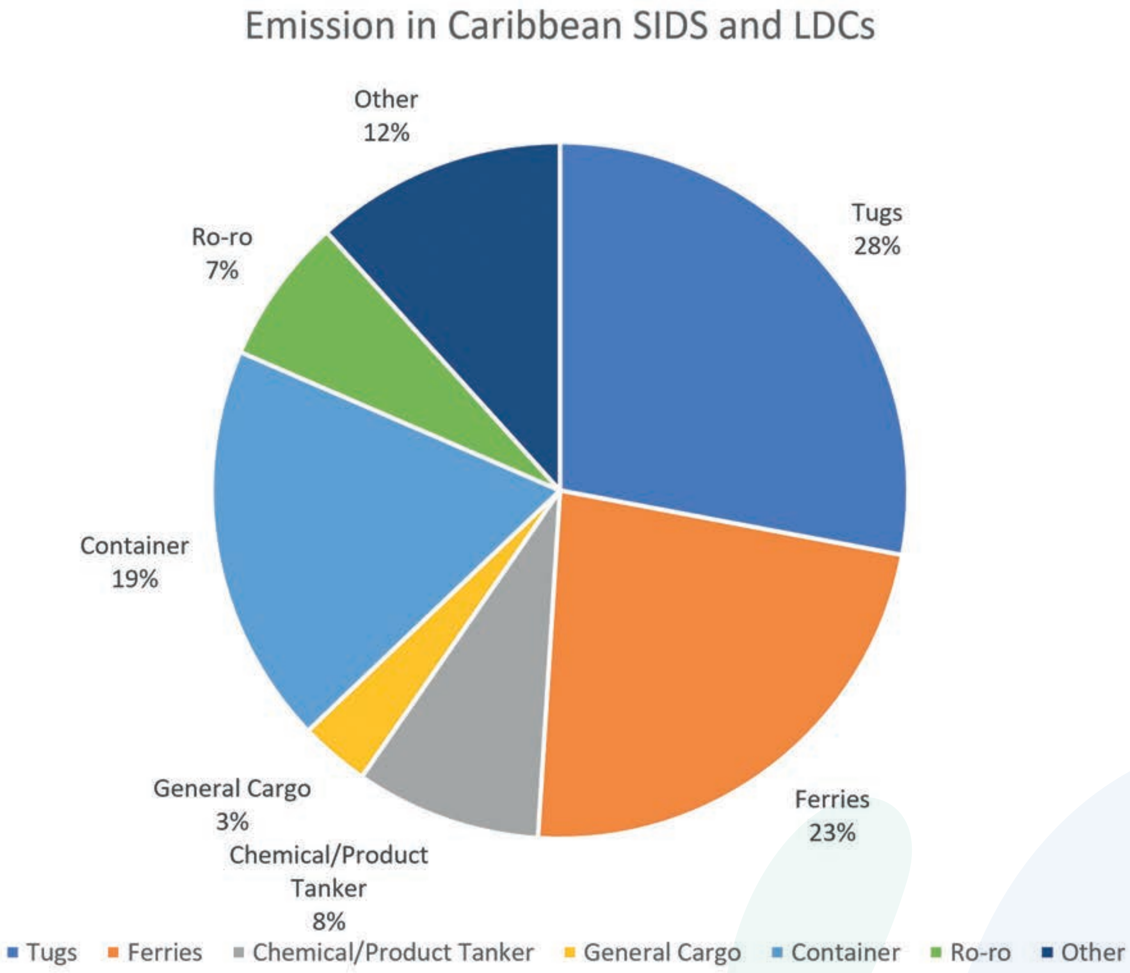


***FIG 33:** Emission estimation from Caribbean SIDS and LDCs for domestic and intra-regional shipping*

6.0

OVERVIEW OF ENERGY-EFFICIENCY TECHNOLOGY UPTAKE FOR DOMESTIC SHIPPING

The global uptake of energy-efficient measures in the domestic shipping fleet, such as alternative fuels, LNG, and electric or battery power, stands at just 2.19%, compared to 8.75% in the worldwide shipping fleet. The current domestic ship fleet list was also checked from Clarksons World Fleet Register for energy-efficiency technology utilization. In the global domestic fleet, 304 ships use some kind of energy-efficiency technology: 115 ships are using LNG, 46 alternative fuels and 222 are using electric/battery power.

Although tugs make up 35% of the domestic fleet, only three have implemented energy-efficient technology. 15 tugs use LNG, 13 tugs use alternative fuel (including biofuel) and 21 use electric/battery power. Meanwhile in the second largest ship type, ferry/passenger ships, 49 are using energy-efficiency technology: 37 LNG, 24 alternative fuel and 144 are using electric/battery power.

The current uptake of energy-efficiency measures for domestic ships is higher than the global fleet only for electric/battery-powered ships. Uptake of alternative fuels, including LNG, is about half that of international shipping, while energy-efficiency technology utilization is only one tenth that of international shipping.

TABLE 1. Current uptake of energy efficiency technologies and alternative fuels for domestic and international shipping

FLEET	DOMESTIC		INTERNATIONAL		GLOBAL	
	Number of ships	%	Number of ships	%	Number of ships	%
Total fleet	28,627	100	73,469	100	102,096	100
Energy-effficient technology	304	1.06	7,468	10.16	7,772	7.61
LNG	115	0.40	925	1.26	1,040	1.02
Alternative fuel	46	0.16	239	0.33	285	0.28
Electric/battery	222	0.78	277	0.38	499	0.49
Total Energy-Efficiency Measures Uptake	**626**	**2.19**	**8,303**	**11.3**	**8,929**	**8.75**

In the African fleet, two tanker ships are fitted with wake-equalizing ducts. In the Caribbean fleet, two container ships feature stator pre-swirling fins and rudder bulbs, one container ship has a rudder bulb, and one general cargo ship is also equipped with a rudder bulb.

Out of 649 total ships in African and Caribbean SIDS and LDCs, use of alternative fuels or electricity/batteries could not be observed. Hence the current uptake of energy-efficiency technology is limited to less than 1% of the domestic ship fleet.

6.1 DECARBONIZATION POTENTIAL IN DOMESTIC SHIPPING OF SIDS AND LDCS

Electrification

Ferries and tugs can be propelled by electric/battery power. Although this technology is mature and used in Europe, Asia and North America, utilization of electrification was not apparent in Caribbean and African SIDS and LDCs. A test case for decarbonization was made to observe the emission reduction by use of electric ferries and tugs. Battery-powered ships need to charge from shore connections, and electric sources are critical for decarbonization of shipping. A review of electric sources was made for selected countries among African and Caribbean SIDS and LDCs from the International Energy Agency website to derive electric grid sources (Table 2).

TABLE 2: *Electricity generation mix for selected African and Caribbean SIDS and LDCs*

AFRICA	Coal (%)	Oil (%)	Natural gas (%)	Hydro (%)	Biofuels (%)	Wind (%)	Solar (%)
Angola		14.8	9.9	75.3			
Benin		19.4	79.1				1.4
Botswana	96	3.8					0.2
Democratic Republic of the Congo		0.1		99.6	0.1		0.2
Eritrea		96.6				0.5	2.9
Ethiopia		0.1		96.1		3.6	0.2
Madagascar	18.6	48.6		30.5	0.9		1.4
Mauritius	42	36.6		3.5	12.3	0.5	5.1
Mozambique		0.9	16.1	82	0.6		0.4
Niger	26.6	63	7.1				3.3
Rwanda	4.3	15.3	22.5	55.9	0.2		1.7
Senegal	6.3	76.5	0.4		1.6	6.3	8.4
South Sudan		97.2					2.8
Sudan		37.7		62.3			
Togo		7.9	65.7	19.3	0.4		6.7
Uganda		1		89.5	7.1		2.4
Zambia	7.3	0.8		91.1			0.8

CARIBBEAN	Coal (%)	Oil (%)	Natural gas (%)	Hydro (%)	Biofuels (%)	Wind (%)	Solar (%)
Cuba		86.6	8.8	0.7	2.4	0.2	1.3
Curaçao		73.6				23.2	3.2
Dominican Republic	27	19.5	36.2	8.7	1.1	5.8	1.7
Haiti		86.8		12.9			0.3
Jamaica		28.4	58.8	3.2	0.4	6.1	3.1
Suriname		51.5		48			0.5
Trinidad &Tobago		0.4	99.6				0.1

Some African states have access to hydroelectric power in large sections of their electric grids, such as the Democratic Republic of the Congo, Ethiopia and Uganda. However, others are using either oil or natural gas for electricity generation and the share of renewable sources is very limited. The average fossil fuel content is 59% for the energy mix. Electrification of ships in states with hydroelectric sources of electricity can be beneficial.

The electricity grid is mainly dependent on oil and natural gas in the Caribbean. A small share of renewable energy is derived from renewable sources and hydroelectricity. Fossil fuel content in the energy mix is 82% on average.

Application of electrification would result in very small reductions in GHG emissions. Converting all ferries and tugs into electric propulsion could reduce emissions by 9.2% in the Caribbean and 25.4% in Africa, and would affect 144 tugs and 47 ferries in the Caribbean, and 174 tugs and 30 ferries in Africa.

Renewable energy investment combined with electrification

One possibility is utilizing solar power at the home ports of domestic ships, enabling charging through locally produced energy. Ferries and tugboats could either be retrofitted or newly constructed with electric propulsion systems. Assuming a fully renewable energy supply for these vessels, emissions could be reduced by as much as 51.1% in the Caribbean and 62% in Africa.

Use of propulsion-improvement devices

Utilization of propulsion-improvement devices, such as Mevis or Schneekluth ducts and fins, improves the propulsion efficiency of tankers, bulk carriers, general cargo ships and container ships. The literature on these devices indicates that thrust deduction factors increase by 0.01 to 0.03, while wake fractions increase by 0.03 to 0.08. The emission effectiveness test was conducted by adopting these changes to the fleet. Such modification affects 94 ships in Africa and 80 ships in the Caribbean and results in emission reductions of 1.6% and 1.4% respectively.

Wind-assisted ship propulsion utilization

Use of Flettner rotors or suction sails can be beneficial for large deck area ships such as bulk carriers and tankers, and has relatively smaller effects on ro-ro ships and ferries. Ship types such as tugs cannot benefit from such devices. The emission reductions by use of such devices were 3.9% in Africa and 5.1% in the Caribbean domestic fleet. Wind energy, similar to solar power, can be utilized to increase clean energy in the port energy mix.

Appendix II provides an overview of the technologies capable of enhancing energy efficiency and mitigating emissions across the industry. Additionally, it delineates the potential savings associated with, and the applicability of, these technologies concerning vessel type and size. Furthermore, it sheds light on the availability of these technologies in the context of domestic scenarios in Africa and the Caribbean.

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7.0

ENERGY-EFFICIENT TECHNOLOGY AND CHALLENGES OF DOMESTIC SHIPS

While domestic shipping serves as a vital component in safeguarding food and energy security, fostering job opportunities and strengthening state connectivity, especially for SIDS and LDCs, it is responsible for 26.2% of shipping emissions when considering domestic voyage-based calculations and 9.2% when assessed on ships involved in domestic shipping only. Even though the 17% of global shipping emissions from domestic voyages of the IMO-regulated international ship fleet will be reduced by the trends in decarbonizing international shipping – facilitated by implementing measures such as EEDI, EEXI, SEEMP, CII, MBM and GFS – indirectly influencing emission reductions in domestic shipping, the remaining 9.2% will not be affected by the IMO regulatory system.[2] Unfortunately, domestic shipping has garnered limited attention from both academia and policy-makers, particularly concerning GHG emission mitigation. If domestic shipping is not decarbonized, its contribution to global GHG emissions could rise further, especially considering the ongoing transition to zero-emission shipping in the international sector.

Achieving zero-emission shipping in the domestic sector requires significant political backing from regional governments in both areas. The establishment of a NAP for the domestic maritime sector represents a crucial initiative in facilitating this transition. However, substantial resources must be allocated to implement such a plan effectively. Nonetheless, if the plan contributes to accelerating progress toward meeting the commitments outlined in NDCs, government intervention and broad political support become more justified. Considering these factors, adopting measures such as domesticating IMO's EEDI, EEXI, SEEMP, CII and DCS, along with implementing levies on fuel or emissions akin to the European Union's Emissions Trading System for domestic shipping, can assist countries in fulfilling their obligations under the Paris Agreement. This presents an opportunity to enhance accountability and mitigate air pollution at the national level (Vakili and Ölçer, 2023).

Recognizing the absence of a universal solution for decarbonizing the maritime sector, a diverse array of strategies – whether individually or in combination – holds significant potential for reducing emissions. Collaboration among all stakeholders, including ports, is crucial for expediting the transition to zero-emission shipping.

Implementing operational and technological measures in domestic shipping may pose unique challenges compared with deep-sea shipping. Each measure's suitability should be evaluated independently. However, due to the shorter distances travelled in domestic shipping routes, this sector provides an ideal testing ground for innovative zero-emission technologies.

To expedite the transition to zero-emission shipping in both regions, investment in new and more efficient vessels and deploying energy efficiency technologies is crucial. However, this transition requires a holistic, systematic and transdisciplinary approach considering the value chain within the sector (Vakili et al., 2022). Evidence indicates that, akin to international shipping, the adoption of carbon-neutral fuels and energy sources is paramount for decarbonizing domestic shipping. Moreover, the selection of alternative fuels for this sector must consider the life cycle potential, specifically in terms of reducing carbon emissions from well to tank. Additionally, formulating a roadmap for future alternative fuels in the domestic sector requires careful consideration of government energy policies. This underscores the importance of viewing the alternative fuel roadmap within the broader context of energy transition, including future energy policies related to production, storage and supply streams, which are crucial in determining the feasibility and longevity of investments. This approach allows for an assessment of the availability and economic viability of alternative fuels for the domestic sector in respective regions.

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[2] There are two models for calculating domestic emissions:

1. **Vessel-based allocation: This model considers ships exclusively dedicated to domestic sectors, contributing 9.2% to global shipping emissions.**
2. **Voyage-based allocation: This model, based on individual voyages, accounts for approximately 26.2% of emissions. It includes ships solely navigating between internal ports (9.2%), as well as international ships making occasional visits between two ports within the same country, treating the voyage and associated emissions as domestic. The contribution of international ships engaged in domestic voyages is calculated as (26.2% - 9.2% = 17%). Considering the trends in international shipping towards reducing GHG emissions through measures such as EEDI, EEXI, SEEMP, CII, MBM and GFS, it is expected that emissions from international ships (17%) within the voyage-based scenario will decrease, indirectly reducing domestic shipping emissions in this scenario.**

While the integration of alternative carbon-neutral fuels and energy options is essential, it is also critical to address challenges such as production uncertainties, inadequate infrastructure, financial constraints and regulatory gaps. Therefore, prioritising energy efficiency enhancements through measures like speed reduction and zero-emission technologies becomes imperative (Vakili et al., 2023).

Optimising hull design, propellers and propulsion

Optimising hull design, propellers and propulsion systems can lead to efficiency gains of up to 25% (Grzelakowski et al., 2022). Weight and volume are two main challenges; however, in the domestic sector, innovative design initiatives and technologies, such as enhancements in hull construction using materials like carbon fibre or adopting multihull designs (Zhu et al., 2023), can effectively address some of these issues. Nonetheless, the high costs and ageing fleets pose significant challenges. Renewing fleets with more efficient vessels may not be applicable due to financial constraints and limited access to funds in these regions, and replacing old, less efficient vessels with second-hand, more efficient ones requires appropriate financial support from governments. Additionally, considering economic scalability can improve efficiency by up to 30% (Lindstad et al., 2012), but this transition requires substantial financial investment and faces challenges due to economic constraints and limitations in port infrastructure (Johnson, 2022). Moreover, deploying such measures across all routes may not be advantageous, as routes with high cargo and passenger volumes are likely to benefit the most from these initiatives.

Deploying new energy-efficient technologies can face challenges such as limited funding, insufficient trained personnel, weak regulatory frameworks, and immature technology. However, straightforward measures like applying hull and propeller coatings and ensuring proper machinery maintenance present significant potential to enhance energy efficiency in domestic fleets.

Wind-assisted propulsion systems

Wind-assisted propulsion systems have the potential to reduce fuel consumption by up to 30%, reaching up to 70% when combined with other measures like hull and propeller optimization and weather routing, depending on vessel characteristics and trade routes. However, deploying these technologies requires investment in capacity building and personnel training, focusing on locally producible technologies.

Renewable energy potential

Given the substantial renewable energy potential in both regions, they could emerge as pivotal energy hubs for the industry in the future. Considering the role of carbon-neutral fuel in decarbonization of the sector, investigation into energy – including production, supply, storage and use – is imperative to understand the future energy strategy of states. This helps to evaluate the feasibility of any proposed energy transition solutions for domestic ships, including the development of pilot projects such as green corridors.

Biofuels

To address the carbon footprint of regional domestic ferry fleets in the short term, it is recommended to continue using the existing fleet and engine technologies currently in operation. Subsequently, efforts should focus on acquiring and implementing biofuels for all domestic ferries, particularly biodiesel, which is already widely utilized in road transport. Sustainable biofuels have emerged as a short-term solution for decarbonizing shipping and are considered a viable alternative fuel compared with options like those derived from renewable electricity or LNG, as well as carbon capture and storage (DNV, 2023). The deployment of biofuels requires minimal retrofitting of current ship engine technology and bunkering infrastructure, thus avoiding significant capital expenditure in the domestic sector. Moreover, it offers vessels the opportunity to transition to e-fuels in the future (OGCI, 2023). Encouraging the cultivation, processing, and production of biofuels and their sources in both regions can contribute to reducing GHG emissions in domestic shipping. Furthermore, given the ample renewable energy capacity in both areas, there is significant potential to produce and utilize green methanol as a maritime fuel in the long term. However, similar to other carbon-neutral alternatives, obstacles such as fleet age, high retrofitting costs, lack of sustainable port infrastructure and limitations in production scale need to be addressed.

Electric propulsion systems

Electric propulsion systems also show promise in reducing GHG emissions by up to 100% in regions with access to renewable energy sources. However, deploying these technologies requires careful consideration of factors such as high capital costs, the availability of sustainable port infrastructure like shore power systems and the capacity of national grids (Vakili and Ölçer, 2023). Battery technology and hybridization offer significant potential for decarbonizing the shipping industry, particularly within the short-sea and domestic sectors. There is a notable shift in technology and investment towards deploying these advancements in the sector. However, it is imperative to support these technologies by establishing sustainable infrastructure, such as shore power systems at ports, and considering their life cycle perspective in terms of decarbonization. This involves ensuring that the energy provided to shore power systems is cleaner than the energy source used by the vessels (Vakili and Ölçer, 2023a).

Fuel cell technology

Furthermore, the rapid advancements in fuel cell technology present an innovative alternative to conventional marine propulsion. Hydrogen, in conjunction with fuel cell technology, could emerge as a pivotal energy source for domestic shipping, offering zero-emission propulsion for fleets.

LNG and ammonia

LNG and ammonia cannot be considered as appropriate alternative fuels for domestic shipping in the African and Caribbean regions. While LNG has been proposed as a transitional fuel for certain segments of international shipping, particularly larger vessels, its viability for domestic shipping is dubious due to the smaller size of domestic vessels and the considerable capital expenditure involved in LNG deployment. Nonetheless, several shipping companies in northern Europe are embracing LNG as an alternative fuel for container, cruise and ferry ships. These companies, bolstered by significant economic resources, are investing in LNG-powered vessels to generate returns over decades, thereby mitigating the elevated construction costs. Furthermore, they are collaborating with LNG suppliers to develop bunkering infrastructure. However, similar conditions are not present for shipping companies in other regions. Moreover, safety concerns associated with ammonia, including toxicity risks and potential hazards to seafarers, as well as environmental threats from potential leakage, render its use in domestic shipping, which often operates in inhabited areas, impractical and risky.

Ports

Ports serve as critical nodes connecting cities and facilitating international commerce. Approximately 5% of total shipping CO_2 emissions occur in ports (Merk et al., 2018), with a higher percentage attributed to domestic vessels due to longer port stays compared with international shipping. Similar to international shipping, ports play a crucial role in expediting the transition to zero-emission shipping, as highlighted in the IMO's resolution. This underscores the importance of implementing shore power systems, providing secure and efficient bunkering infrastructure for alternative fuels, establishing incentive programmes, and enhancing just-in-time policies to promote sustainability and carbon-free shipping practices.

Decarbonizing ports can be divided into two key areas: the port–ship interface and port operations. Attaining zero-emission operations in ports requires establishing comprehensive databases and inventories that outline air emissions and their sources. Although there are initiatives in a few countries for such measures, unfortunately, there is a notable lack of such initiatives in the majority of states in both regions concerning domestic shipping. Meanwhile, the transition to zero emissions at ports can be significantly advanced through automation, electrification, digitalization and hybridization, coupled with the adoption of cleaner and more sustainable alternative fuels.

Regarding the port–ship interface, the regions could accelerate the transition to zero-emission domestic shipping by investing in alternative carbon-neutral fuel and energy infrastructure. It is crucial that ports' decision-makers change their stance and look at the ports as energy hubs rather than only as hubs for receiving cargo. While battery-powered vessels hold promise, especially in regions where the majority of energy comes from renewable sources, the lack of sustainable infrastructure, such as shore power systems, remains a significant challenge in both Africa and the Caribbean. Despite a few ports offering such technology, its use primarily supports the auxiliary engines of small vessels. Barriers to wider adoption include high costs, limited access to funding, and insufficient production and capacity of the national grid.

Using electric pilot boats and electric or hydro tugs in aligning with the use of renewable energy for providing the required electricity for buildings and lighting, as well as leveraging the significant renewable energy potential and integrating it with smart grid technology, can enhance the sustainability of ports and overcome limitations in national grid capacity.

Energy efficiency gap

The development and reduction of GHG emissions from the maritime sector features prominently on the legislative agendas of many African and Caribbean states. However, the development and reduction of GHG emissions from the maritime sector feature prominently on the legislative agendas of many African and Caribbean states. Nonetheless, despite this attention, a notable gap persists in the adoption of the most energy-efficient and cost-effective technologies currently available and actually used in these regions, commonly referred to as the 'energy efficiency gap.' Bridging this energy efficiency gap and advancing decarbonization efforts in these regions necessitates cooperation among stakeholders, both horizontally and vertically. Bridging this gap and advancing decarbonization efforts in these regions necessitates cooperation among stakeholders, both horizontally and vertically.

Energy efficiency barriers have created a gap in both regions, preventing the adoption of the most cost-effective energy-saving measures and technologies in the domestic shipping sector. 'Limited access to capital', 'Lack of trained manpower', 'Immaturity of technologies', 'Weak legislation and enforcement', 'Lack of funding', 'Split incentives', 'Technical risks', 'Lack of incentives' and 'Reluctant to invest due to high risk' were identified as the main barriers to decarbonization of domestic shipping in Africa *(Appendix 3)*. Meanwhile, 'Immaturity of technology', 'Limited access to capital', 'Split incentives', 'Lack of information on profitability of energy-saving measures', 'Lack of incentives', 'Inappropriate technology at site' and 'Inertia' were identified as the main barriers to improving energy efficiency and meeting zero-emission targets for domestic and regional shipping in the Caribbean.

The findings revealed that some barriers were common across both regions, but their impact differed based on the unique characteristics and importance of domestic shipping in each region. Additionally (avoid saying However), due to the broad scope of the research covering African and Caribbean territories, states prioritize energy efficiency and decarbonization in domestic shipping differently. This variation leads to a diverse range of barriers, each with varying levels of importance.

For instance, obstacles such as 'Limited access to capital', 'Immaturity of technology', 'Split incentives' and 'Lack of incentives' were prevalent in both regions. Nevertheless, their relative importances differed. 'Limited access to capital' emerged as the primary concern for Africa, while ranking second for the Caribbean. Conversely, 'Immaturity of technology' held the top spot for the Caribbean but was second in priority for Africa. 'Split incentives' also featured prominently in both regions, being the second-highest barrier for the Caribbean and the third for Africa. Lastly, 'Lack of incentives' ranked third in importance for the Caribbean but fourth for Africa.

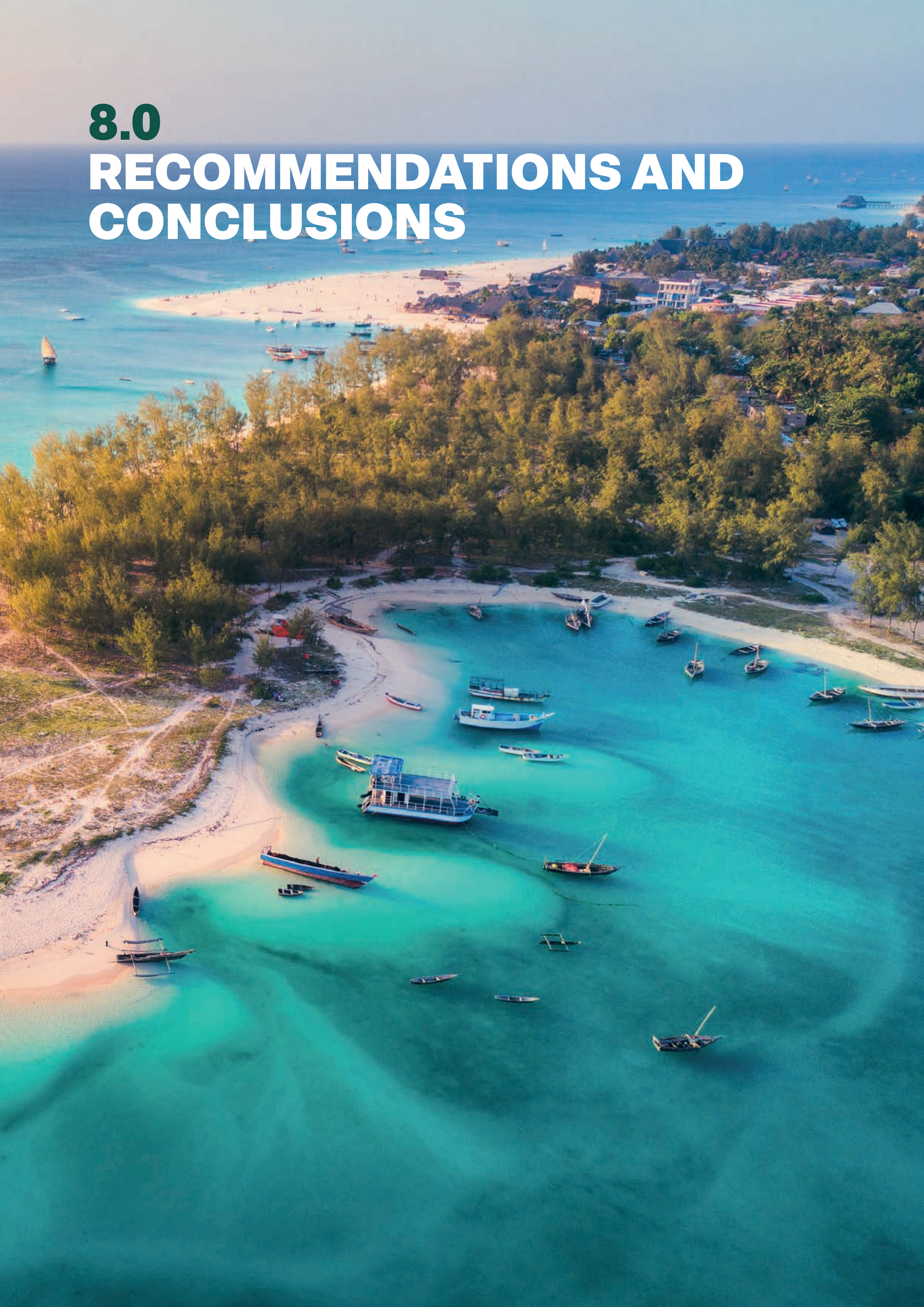
Transdisciplinary framework

It is important to note that the identified barriers are interconnected and mutually influence each other. To overcome the barriers, foster cooperation among stakeholders and achieve mutual benefits at every stage of the value chain, designing, developing and implementing a comprehensive, systematic and transdisciplinary framework is crucial (Vakili et al., 2022) (see Appendix II). This framework should facilitate the seamless integration, adoption and utilization of necessary technologies. Key components of such a framework include investments in industry, organizations, infrastructure and the socio-economic environment. Additionally, capacity building is essential to fully leverage the benefits of newly adopted technologies.

As emphasized in both regions, 'economic' discipline serves as the primary driver for stakeholders' engagement with energy-efficiency measures. For instance, interviewees in the Caribbean region identified 'Reduction of energy cost', 'Access to financial support' and 'Reduction of production cost' as the key motivators for implementing energy efficiency measures. Similarly, African participants cited 'Reduction of energy cost' and 'Access to financial support' as the primary drivers. Moreover, they also recognized 'Long-term energy policy' and 'Environmental commitment' as significant factors influencing the adoption of energy-efficiency measures.

8.0

RECOMMENDATIONS AND CONCLUSIONS



8.1 RECOMMENDATIONS

Technical and operational measures, individually and in combination, play a significant role in the decarbonization of the domestic fleet in both Africa and the Caribbean. Additionally, any new measures must explore the potential synergies with existing ones, especially in relation to incentives for energy efficiency, the adoption of improved operational practices in the shipping value chain and other technologies aimed at reducing ship emissions. However, before an administration adopts and implements such measures, it is essential to conduct a comprehensive impact assessment with relevant stakeholders involved and consider the implications as appropriate. Impact assessment of such measure(s) must consider factors such as the state's geographical remoteness, connectivity, transport dependency, transport costs, food and energy security, and socio-economic progress and development as highlighted in the 2023 IMO Strategy on Reduction of GHG Emissions from Ships.

Developing countries, particularly the LDCs and SIDS, face unique challenges related to capacity building and technical cooperation. These nations have distinct requirements for enhancing their capabilities to implement new measures effectively. One specific barrier they encounter is the availability of safe new energy sources for ships, which can complicate the adoption of proposed initiatives. Collaboration among stakeholders is paramount for addressing these issues and crucial to ensuring that LDCs and SIDS can participate fully in global efforts to improve energy efficiency and reduce emissions in the shipping industry.

At the forefront of this collaboration, technology providers play a crucial role by introducing innovative green solutions that support the shift to zero-emission shipping. Concurrently, governments play a pivotal role in the landscape by implementing appropriate policies, such as embracing the principles of a 'green economy', thereby contributing to the acceleration of this transition. Governments can catalyse progress by revising existing policies, regulations, taxes and subsidies. This may involve offering low-interest loans to facilitate the replacement of older, less efficient vessels with environmentally friendly ones, subsidizing the production of zero-emission alternative fuels to reduce costs, and phasing out subsidies linked to fossil fuel production and use. Simultaneously, ports, as crucial stakeholders, can facilitate the seamless flow of cargo and passengers while providing sustainable infrastructure. By implementing appropriate regulations within their jurisdiction, ports can actively assist in the transition to zero-emission domestic shipping.

The role of governments – development of National Action Plans

By developing National Action Plans (NAPs), outlining respective policies and actions, governments can initiate early actions at the national level to facilitate the reduction of GHG emissions from ships. Efforts to improve domestic institutional and legislative arrangements for the effective implementation of existing IMO instruments are crucial. Additionally, developing activities to further enhance the energy efficiency of ships and initiating research to advance the uptake of alternative low-carbon and zero-carbon fuels are essential steps. These initiatives collectively aim to strengthen the maritime sector's response to environmental challenges, promoting sustainability and reducing emissions. The development of a NAP could mobilize a broad range of national stakeholders to become involved in ship emission reduction efforts, including those in shipping-related sectors that may not necessarily be covered by IMO conventions, and thereby bring in innovative ideas, experience, capabilities and resources.

Opportunities amidst challenges

The advanced age of domestic fleets in LDCs and SIDS is a significant concern, as older domestic fleets tend to incur higher operating and maintenance costs. Poor connectivity due to these ageing fleets has important implications for infrastructure investment in LDCs and SIDS, and the demand for alternative fuel and technology is limited by the infrequent use of main fleet vessels. Unfortunately, the inability to borrow at affordable rates for investment in new shipping, coupled with the inability to insure these assets at reasonable prices, keeps LDCs and SIDS in a cycle in which old ships are replaced by other old ships. However, the ageing fleet also presents an opportunity for new investments and the feasible adoption of technological options suitable for small-scale shipping. The transition to decarbonization also creates opportunities to enhance the renewable energy mix within ports, aligning with the broader national decarbonization trends.

Raising finance for decarbonization of domestic shipping

Overcoming the barriers to affordable financing requires concerted efforts to de-risk the investments, enhance the creditworthiness of shipping projects, and ensure that funding mechanisms are accessible and tailored to the specific needs of the domestic shipping industry. Raising finance for the decarbonization of domestic shipping is crucial for achieving sustainable maritime operations. To address this, innovative financing mechanisms, such as green bonds and climate funds, can be leveraged to attract investment in cleaner technologies and infrastructure upgrades. Public–private partnerships in LDCs and SIDS can also play a pivotal role, combining government support with private sector expertise and capital. Additionally, international financial institutions and development banks can offer concessional loans and grants to support decarbonization initiatives.

Capacity building and research and development

Capacity building and research and development (R&D) are essential for the decarbonization of domestic shipping. Enhancing capacity involves training personnel and developing expertise in innovative technologies and best practices for sustainable shipping. These initiatives encompass training programmes covering various aspects such as developing NAPs for maritime decarbonization, mobilizing financing for decarbonization projects, formulating national roadmaps aligned with IMO goals, and enhancing understanding of emission reduction strategies and solutions. By fostering knowledge sharing and collaboration through workshops and seminars, SIDS and LDCs can tailor robust policies and regulations to suit their specific maritime transport requirements. This can be achieved through specialized workshops, certification programmes and partnerships with academic institutions. Concurrently, investing in R&D is crucial to drive innovation in cleaner fuels, energy-efficient technologies and alternative propulsion systems. Supporting collaborative research projects and pilot programmes can accelerate the development and adoption of these solutions. The unique characteristics of domestic shipping in the African and Caribbean regions, such as short-sea shipping and the prevalence of small vessels, has the potential to serve as a testing ground for zero-emission technologies and alternative fuels, which can then be scaled up for deployment in deep-sea and international shipping. Realizing this potential necessitates significant investments in both vessels and port infrastructure. By fostering a skilled workforce and advancing technological breakthroughs, domestic shipping can make significant strides toward reducing its carbon footprint and achieving long-term sustainability.

Developing ports as energy hubs

Ports play a pivotal role in the domestic maritime industry, serving as critical hubs for cargo handling, logistics and transportation. Beyond their operational functions, ports are increasingly becoming focal points for implementing sustainability initiatives, such as reducing emissions, improving energy efficiency and adopting green technologies. Tugs are the most common domestic ship type in the African and Caribbean regions, accounting for 55% and 44% of fleets, respectively. By supporting their energy transition, ports can support the domestic maritime industry's overall efficiency and environmental performance. Furthermore, they can introduce local regulations to reduce emissions from domestic shipping. Implementing speed limitations within their jurisdiction and introducing environmental incentive schemes are effective measures to curb emissions from domestic shipping.

Green corridors

Green corridors are designated routes designed to promote the use of low-emission technologies and alternative fuels, enhancing environmental performance and reducing carbon footprints. Taking advantage of repetitive port calls by domestic ships in LDCs and SIDS, green corridors can be established. Domestic shipping plying across such corridors can benefit from the incentives encouraging the adoption of green technologies and operational efficiencies. Additionally, green corridors can serve as testing grounds for tailored innovative solutions, providing valuable data and insights for scaling up sustainable practices across the LDCs and SIDS.

8.2 CONCLUSIONS

Domestic shipping plays a pivotal role in ensuring food and energy security and fostering connectivity among states, particularly SIDS and LDCs. However, it also contributes significantly to global shipping emissions, accounting for 26.2% based on domestic voyage calculations and 9.2% evaluated using ships involved in domestic shipping only.

Domestic shipping's proximity to coasts and ports with high population densities amplifies its potential to impact air quality and public health, leading to significant societal implications. As the transition to zero-emission shipping accelerates, much of the focus has been on international shipping, leaving the domestic sector relatively under addressed. However, the importance of decarbonizing domestic shipping will grow as it plays a critical role in coastal and port operations, especially in LDCs and SIDS. Addressing its environmental footprint is essential not only for protecting societal well-being but also for advancing the broader objective of sustainable maritime transport.

The unique characteristics of domestic shipping in the African and Caribbean regions, such as short-sea shipping and the prevalence of small vessels, mean it has the potential to serve as a testing ground for zero-emission technologies and alternative fuels, which can then be scaled up for deployment in deep-sea and international shipping. Realizing this potential necessitates significant investments in both vessels and port infrastructure.

A combination of technological and operational measures holds significant potential for decarbonizing domestic shipping, but the nature and type of short-sea shipping and the small size of vessels in the domestic shipping sector may pose restrictions on certain operational measures such as speed reduction, just-in-time practices, weather routing and waste heat recovery. Even so, there exist other operational strategies, such as hull and propeller cleaning management, and machinery maintenance, which represent low-hanging fruit and can effectively reduce fuel consumption and emissions.

Additionally, investing in vessel design improvements and replacing older vessels with more efficient ones – or renewing the fleet altogether – can significantly reduce emissions from the domestic fleet. It is important to note that such transitions require substantial investment and support from governments and international organizations. Governments can collaborate with financial institutions and banks to support sectoral decarbonization through initiatives such as providing low-interest rate loans. Furthermore, developing and integrating decarbonization efforts into NAPs is a key step toward achieving zero-emission domestic shipping. Besides, ports can offer incentives for domestic shipping aimed at encouraging environmentally friendly practices.

In conclusion, decarbonizing domestic shipping in SIDS and LDCs is both a formidable challenge and an opportunity for sustainable development. The transition to greener shipping practices requires a multifaceted approach, including investment in innovative technologies, enhanced infrastructure and innovative financing mechanisms. Capacity building and targeted R&D will be essential to overcoming existing barriers and fostering the adoption of low-emission solutions. Addressing challenges such as fleet age, financing and infrastructure limitations requires a coordinated approach involving stakeholders across the industry and public sectors. Additionally, the broader transition to decarbonization presents unique opportunities for SIDS and LDCs, particularly in the African and Caribbean regions, to leverage their advancements in renewable energy production to further enhance the sustainability of their maritime sectors and strengthen energy resilience within ports. By leveraging international support, fostering public–private partnerships and exploring green corridors, SIDS and LDCs can advance their maritime industries toward greater environmental sustainability. Investing in domestic shipping proactively will not only contribute to global climate goals but also enhance the resilience and economic viability of domestic shipping in these vulnerable regions.

APPENDICES

APPENDIX I – LIST OF LDCS AND SIDS

List of LDCs (Source: UN, 2024)

LDCS AT A GLANCE

LDC list

List of all LDCs in PDF format (updated December 2023)

Consolidated LDC fact sheets

2021 LDC Snapsnots (PDF format) ***NEW***

Individual LDC fact sheets

Afghanistan
Angola
Bangladesh
Benin
Burkina Faso
Burundi
Cambodia
Central African Republic
Chad
Comoros
Democratic Republic of the Congo
Djibouti
Eritrea
Ethiopia
Gambia
Guinea
Guinea-Bassau
Haiti
Kiribati
Lao People's Dem. Republic
Lesotho
Liberia
Madagascar
Malawi
Mali
Mauritania
Mozambique
Myanmar
Nepal
Niger
Rwanda
Sao Tome and Principe
Senegal
Sierra Leone
Solomon Islands
Somalia
South Sudan
Sudan
Timor-Liste
Togo
Tuvalu
Uganda
Unite Republic of Tanzania
Yemen
Zambia

Graduated country fact sheets

Bhutan
Botswana
Cabo Verde
Equatorial Guinea
Maldives
Samoa
Vanuatu

List of SIDS (Source: UN, 2024)

Small Island Developing States

1. Antigua and Barbuda
2. Bahamas
3. Barbados
4. Belize
5. Cabo Verde
6. Comoros*
7. Cook Islands
8. Cuba
9. Dominica
10. Dominican Republic
11. Fiji
12. Grenada
13. Guinea-Bissau*
14. Guyana
15. Haiti*
16. Jamaica
17. Kiribati*
18. Maldives
19. Marshall Islands
20. Micronesia (Federated States of)
21. Mauritius
22. Nauru
23. Niue
24. Palau
25. Papua New Guinea
26. Samoa
27. Sao Tome and Principe*
28. Singapore
29. St. Kitts and Nevis
30. St. Lucia
31. St. Vincent and the Grenadines
32. Seychelles
33. Solomon Islands*
34. Suriname
35. Timor-Liste
36. Tonga
37. Trinidad and Tobago
38. Tuvalu
39. Vanuatu

*Also Least Developed Country

Associate Members of the United Nations Regional Commissions

1. American Samoa
2. Anguilla
3. Aruba
4. Bermuda
5. British Virgin Islands
6. Cayman Islands
7. Commonwealth of Northern Marianas
8. Curacao
9. French Polynesia
10. Guadeloupe
11. Guam
12. Martinique
13. Montserrat
14. New Caledonia
15. Puerto Rico
16. Sint Maarten
17. Turks and Caicos Islands
18. U.S. Virgin Islands

APPENDIX II – TABLES OF MEASURES TO IMPROVE ENERGY EFFICIENCY AND DECARBONIZATION OF DOMESTIC VESSELS

The following table offers an overview of the technologies capable of enhancing energy efficiency and mitigating emissions across the industry. Additionally, it delineates the potential savings and applicability of these technologies concerning vessel type and size. Furthermore, it sheds light on the availability of these technologies in the context of domestic scenarios in Africa and the Caribbean region.

ABATEMENT MEASURE		SAVING POTENTIAL	APPLICABILITY (TYPE/SIZE OF VESSELS)	AVAILABILITY TO AFRICAN AND CARIBBEAN DOMESTIC SCENARIOS
Wind propulsion	*Soft sail*	The technology has been deployed in numerous cargo and ferry operations, demonstrating an average fuel savings of around 25% (Held, 2017).	Many designs, concepts and models exist for vessels of various types and sizes.	Throughout historical timelines, sailing vessels have maintained significant importance in various geographic regions, particularly concerning small domestic crafts like fishing boats. Soft sail rigs showcase a diverse range of technological advancements, ranging from intricate and costly setups seen in luxury yachts to simpler, cost-effective configurations commonly found in traditional fishing vessels. In both regions, future advancements are anticipated to prioritize innovation within less advanced technology spheres. This underscores the need for investment in capacity building and personnel training, emphasizing the development and adoption of locally producible technologies.
	Fixed sail	Depending on scale can improve efficiency by up to 30% (Atkinson et al., 2018).	Applicable to vessels of various sizes and types, but particularly suited for larger vessels without obstructions on deck, such as bulk carriers and tankers (Atkinson et al., 2018).	Given the characteristics of domestic vessels in both regions, they have not yet been utilized or studied for domestic deployment. However, there is potential for deployment within certain domestic vessels in both regions.
	Rotor (e.g. Flettner rotors)	The efficiency can be enhanced by up to 30%, depending on the scale and number of rotors (Hanses, 2018). Advanced designs and modelling for various vessel types are available, with projected savings of up to 50% for new builds that integrate advanced hull and other component designs.	There is potential to deploy this technology in various sizes and types of domestic vessels, including ferry passenger vessels. The fuel-saving potential is heightened by reducing vessel size. The capital cost ranges from \$300–800k per rotor, yet it can yield energy savings of up to \$200k annually (Maersk, 2019), contingent upon the vessel's type and size, and the scale and number of rotors. Given the maturity of the market, there is potential for a reduction in associated costs.	Given the characteristics of the vessels in both regions, there is potential for the utilization of this technology in certain types of vessels, such as ferries and roll-on/roll-off (ro-ro) vessels. However, it requires importing the technology and training staff accordingly.
	Kite (e.g. Beluga sails; sky sails)	The extent of fuel efficiency improvement depends on the route and can range from 5% to 15%.	More suitable for larger vessels operating on long routes.	The applicability to domestic vessels in both the Caribbean region and Africa is very low. It may be practical for only a very limited number of domestic routes. Moreover, due to the high associated costs and safety concerns, personnel would require training.

ABATEMENT MEASURE		SAVING POTENTIAL	APPLICABILITY (TYPE/SIZE OF VESSELS)	AVAILABILITY TO AFRICAN AND CARIBBEAN DOMESTIC SCENARIOS
Wind propulsion (Continued)	*Suction wings*	There is a potential for 10–30% improvement in fuel efficiency. Depending on the design and scale, each wing has the capability to reduce carbon emissions by 2,000 tonnes per year.	It is applicable in larger vessels, and there has been an increased focus on installing such technology. However, retrofitting may not be cost-effective given the age of vessels. It is more practical to incorporate this technology into new vessel designs.	Given the sizes of the vessels, there is limited availability for deployment within domestic shipping in Africa. However, for larger vessels operating within the Caribbean region, the technology holds potential for deployment. The main barrier is the capital cost, and personnel training is also required.
Solar	*Auxiliary power supply*	Varies from 1–3% depending on type and size of vessels and scale of deploying the technology (DNV, 2022).	Deploying this technology holds significant potential in addressing auxiliary power needs across various transport demand scenarios, given its scalability and adaptability. Retrofitting can be applied to both large and small vessels. Given that the majority of domestic shipping in Africa and the Caribbean region experiences prolonged port stays, resulting in higher-than-average auxiliary fuel consumption, this technology can contribute to reducing fuel consumption during port stays.	The technology is accessible in both Africa and the Caribbean region, but it requires support from additional components such as battery storage and controllers. In addition to capital costs, limitations on deck space and the impact of equipment on cost-effectiveness hinder the deployment of the technology on board vessels, particularly for retrofitting purposes. Moreover, building capacity and training personnel are necessary.
Biofuels *First generation (crop based)* *Second generation (waste based)* *Third generation (specially engineered crops such as algae)*		An overall emissions reduction of 25–100% is feasible (Bouman et al., 2017). However, there is criticism regarding the sustainable production of the fuel, particularly concerning land use. Additionally, competition exists from other sectors such as aviation transportation for the use of this fuel. One key advantage of biofuels is the lower investment required to modify existing bunkering facilities compared with other options.	The fuel can be utilized in vessels of various types and sizes. Retrofitting vessels incurs lower costs compared with other alternative fuels. Investing in biofuels (in the short term) also opens up the possibility for the same ships to utilize 'e-fuels' produced by capturing CO_2 from biogenic sources.	The utilization of biofuels presents a notable advantage for domestic vessels. Only minor retrofits are necessary for current ship engine technology and bunkering infrastructure, thus circumventing major capital expenditures. The study identifies "access to funding and capital" as a significant barrier to the adoption of measures for achieving "zero-emission" shipping in the domestic sector. The potential expansion of biofuel production in Africa and the Caribbean is widely seen as offering significant opportunities for growth and development within the regions. However, it necessitates trials and research to establish scaled, cost-effective production for domestic shipping. The applicability will be more favourable in high, wet islands and states. In the Caribbean region, states may require imported fuel stocks or imported refined products. Nevertheless, there exists enormous resource and sustainability potential for liquid biofuels in Africa. Currently, no successful, cost-effective large-scale production solution has been established, and there is a lack of detailed research on its application to the regions' maritime domestic use. Considering the potential of biofuels in reducing GHG emissions, cultivation, processing, and production of biofuels and their sources need to be encouraged in both regions for use in domestic shipping.

ABATEMENT MEASURE		SAVING POTENTIAL	APPLICABILITY (TYPE/SIZE OF VESSELS)	AVAILABILITY TO AFRICAN AND CARIBBEAN DOMESTIC SCENARIOS
Electric/ hybrid propulsion		The technology has the potential to achieve up to a 100% reduction in GHG emissions. However, careful consideration must be given to the energy sources used for charging these batteries, as the life cycle of battery-powered vessels may lead to higher air emissions compared with diesel-powered vessels (Vakili and Ölçer, 2023a). While electric motors are generally perceived as cheaper than traditional engines, the cost of batteries per unit of energy and their integration into ships render them a costly choice. Various scenarios suggest that electric vessels often exhibit lower cost-effectiveness compared with alternative fuel options such as hydrogen, ammonia and biofuels (Bouman et al., 2017).	There is considerable potential for implementing this technology within the domestic shipping sector, especially for short-sea shipping. Improvements in hull construction, such as employing multi-hull designs constructed from carbon fibre, can help mitigate the issue of increased weight associated with integrating this technology into vessels. Moreover, with the rapid advancements in fuel cell technologies for ferries and small-sized vessels, these innovations may present viable solutions in the short to medium term.	There is significant potential for harnessing this technology in both the African and Caribbean regions. However, its widespread adoption is currently constrained, except for specific targeted applications where the potential is moderate to high. Factors such as the high capital costs associated with deploying the technology on board vessels, the availability of sustainable infrastructure at ports (such as shore power systems) and the capacity of national grids require careful consideration. Additionally, the life cycle implications of adopting this technology in domestic shipping and access to low-carbon electricity should be thoroughly assessed to ensure its overall benefits. States with a majority of electricity from renewable sources can significantly reduce emissions from their domestic shipping from a life cycle perspective by implementing this technology. The field is expected to rapidly evolve, with international advancements in technology enhancing accessibility for both regions in the near future. Apart from high capital expenditure, challenges related to technology transfer requirements and the training of personnel pose additional barriers that must be addressed.
Fuel cells		Depending on the type of technology and fuel used, there is potential to reduce emissions by up to 90% (DNV, 2023a; Madsen et al., 2020; Mekhilef et al., 2012). Various fuels, including methanol, LNG and ammonia, can be utilized, but hydrogen is more prevalent than other options. Hydrogen can be conventionally produced through methane steam reforming, fossil fuel or biomass gasification, or water electrolysis.	The technology can be deployed on both large and small vessels. High-temperature fuel cells may become suitable for onboard energy on larger vessels. However, current technology is better suited for smaller vessels engaged in short-sea shipping, where the storage of compressed hydrogen is feasible (Nuttall et al., 2021). The integration of hydrogen and battery technologies can create an advanced propulsion system for larger vessels, aligning with the need for zero-emission propulsion systems.	There is significant potential to utilize this technology in both regions for domestic shipping. While research at a small scale is ongoing, the technology has not yet been implemented, and its future availability depends on international advancements in technology and fuel supply storage solutions in both regions.

ABATEMENT MEASURE	SAVING POTENTIAL	APPLICABILITY (TYPE/SIZE OF VESSELS)	AVAILABILITY TO AFRICAN AND CARIBBEAN DOMESTIC SCENARIOS
LNG/compressed natural gas	While LNG contains carbon and isn't a complete decarbonization solution, its significant production capacity and ability to meet over 90% of sulphur oxide (SOx) and nitrogen oxide (NOx) emission requirements, coupled with a 20–30% reduction in CO_2 emissions, position it as a transitional fuel for shipping decarbonization (Sharples, 2019). However, concerns have arisen about its effectiveness in reducing CO_2 emissions due to methane slips during operations (Le Fevre, 2018). Considering the 'well-to-wake' approach, the climate benefits of LNG are deemed limited (McKinsey & Company, 2023).	Not applicable for very small vessels, LNG may be suitable for larger vessels. However, considering the size of domestic vessels, particularly small ships, and the high capital expenditure associated with deploying LNG, driven by additional costs of retrofitting ships, constructing engines and tanks, and necessary onshore investments, it does not appear to be an appropriate solution for domestic shipping.	Not widely available, LNG has primarily been used for large vessels such as cruise ships in the Caribbean region. Additionally, some states in Africa have invested in deploying this fuel for the maritime industry. As previously highlighted, LNG is not considered an appropriate alternative fuel for the decarbonization of domestic shipping in either region.
Hydrogen	Hydrogen emits no CO_2, particulate matter or SOx during combustion, although NOx emissions may occur when combustion temperatures exceed 1,700 K (Mallouppas and Yfantis, 2021; Andrews and Shabani, 2012).	Hydrogen holds promise as a marine fuel. However, before its deployment in the maritime sector, careful consideration of the technical, safety and economic aspects associated with this fuel is essential. While hydrogen fuel cells show potential for use in small vessels, additional development is necessary to address technical challenges for their application in larger vessels. Moreover, exploring innovative operational solutions such as supplying hydrogen in containers and loading it on deck offers flexibility for using the fuel in small vessels engaged in short-sea routes swiftly, as it can be replaced as needed without disrupting the vessel's schedule.	Currently not readily accessible, the regions boast abundant renewable energy sources, presenting a substantial opportunity for green hydrogen production. Several countries in these areas have considered green hydrogen production in their long-term plans. Presently, many studies and feasibility assessments are ongoing. However, challenges such as limited capital investment and funding, restricted availability of technology and insufficient infrastructure have been identified as significant barriers to fuel production.

ABATEMENT MEASURE	SAVING POTENTIAL	APPLICABILITY (TYPE/SIZE OF VESSELS)	AVAILABILITY TO AFRICAN AND CARIBBEAN DOMESTIC SCENARIOS
Methanol	Methanol emerges as a promising medium for hydrogen transport (Liu, 2022). Although most methanol is currently derived from natural gas, it has the potential to reduce CO_2 emissions by 25% compared with HFO (Yadav et al., 2020). Furthermore, its production from renewable energy sources holds the capability to eliminate GHG emissions entirely, offering a sustainable alternative.	The fleet of methanol-powered vessels continues to grow, spanning various vessel categories such as container ships, bulk carriers, tankers, cruise liners and passenger ships, both in deep-sea and short-sea shipping. Considering factors such as availability, compatibility with existing infrastructure, affordability, engine design simplicity, ship technology, and its capacity to mitigate SOx and NOx emissions, methanol emerges as a promising frontrunner for future marine fuel (Andersson and Salazar, 2015; ITF, 2018). Furthermore, the presence of a well-established supply infrastructure and logistical network for bunkering methanol vessels sets it apart from other alternative fuels (Svanberg et al., 2018).	With the substantial capacity of renewable energy in both regions, there is significant potential to produce and utilize green methanol as maritime fuel. Currently, several studies and feasibility assessments are underway. However, the age of the fleet in both regions, along with the absence of sustainable infrastructure at ports and limitations in production scale, pose significant barriers. The primary obstacle to transitioning domestic fleets in both regions to utilize this fuel is the associated high cost of retrofitting.
Ammonia	Recognized as a zero-carbon tank-to-wake fuel, ammonia holds promise for expediting progress toward meeting the IMO's 2050 targets. However, as it is mainly derived from the combination of nitrogen and hydrogen, it is crucial to consider emissions from both hydrogen production and ammonia synthesis when evaluating the fuel's life cycle emissions (ABS, 2020).	Due to challenges related to auto-ignition and a notably slow flame speed, ammonia is better suited for slow-speed engines, especially those commonly found in large vessels.	Both regions rank among the top producers of ammonia. Given the abundant renewable energy sources in both areas, there is potential to produce green ammonia for the shipping industry. However, safety concerns, including risks of toxicity and hazards to seafarers, as well as environmental threats from potential leakage, render its use in domestic shipping impractical and risky. This is particularly significant considering the proximity of domestic shipping routes to populated areas and the frequent access to ports, many of which are situated near urban centres.

ABATEMENT MEASURE		SAVING POTENTIAL	APPLICABILITY (TYPE/SIZE OF VESSELS)	AVAILABILITY TO AFRICAN AND CARIBBEAN DOMESTIC SCENARIOS
Optimized hull, propeller and propulsion design	*Including changes in the hull shape, lightweight construction materials, etc.*	Efficiency enhancements in vessel design, along with the integration of new propellers and lightweight materials, have the potential to boost efficiency by up to 25% (with lightweight materials contributing approximately 10% and slender hull designs offering up to 15% savings) (Grzelakowski et al., 2022). The extent of this efficiency improvement varies depending on factors such as size, type, operational profile and route (Faber et al., 2016). Furthermore, the integration of artificial intelligence and deep learning algorithms into ship design processes is expected to yield even greater efficiency gains in the next generation of the shipping industry.	There is significant potential to enhance the efficiency of domestic shipping by improving the design of associated vessels. However, much of the research focuses on larger vessels, with less attention paid to smaller sizes and domestic operations.	There is considerable potential to create employment opportunities and stimulate economic growth by promoting local shipyards in both regions to manufacture domestic vessels and replace ageing fleets with newer, more efficient ones (Vakili et al., 2022). With the capacity for small-scale ship construction in both regions, there is ample opportunity to build new and more efficient vessels for domestic use. Additionally, replacing old and less efficient domestic vessels with second-hand, more efficient ones is a feasible option. However, the main barrier to implementing a fleet replacement policy in both regions is the lack of funding and access to capital.
Frictional resistance reduction	*Air bubble*	The data indicate that the technology is utilized in vessels of various types and sizes, operating at different speeds, with resulting net savings ranging from 4% to 15% (Silverstream, 2023; Vakili et al., 2023).	It is more suitable for larger vessels rather than smaller ones. Retrofitting existing vessels is possible; however, it is associated with a high capital cost.	Given the age and size of the fleet, as well as the associated costs of retrofitting vessels, there is limited potential for developing this technology in domestic shipping in both regions. However, there is potential to consider it for certain types of new ship designs, such as ferries, roll-on/roll-off (ro-ro) cargo ships, and introduction into new fleets.
Wake flow improvement	*Propulsion-improving devices (PIDs) & Energy-saving devices (ESDs)*	The technologies have showcased energy efficiency improvements ranging from 1.5% to an impressive 21% (Heinke and Hellwig-Rieck, 2011; Heinke and Lübke, 2014; Wärtsilä, 2022). Typically, these technologies offer a short payback period, rendering them a financially prudent option for vessel operators striving to enhance efficiency and mitigate emissions of underwater radiated noise (Vakili et al., 2023).	There is considerable potential through the appropriate selection of measures based on ship size, type and operational profile. However, the majority of research has been conducted on larger vessels rather than smaller ones.	The required technologies are readily available in both regions. Given the short payback period associated with these advancements, they represent viable options for deployment in the domestic fleets of both areas. These technologies can be implemented either through retrofitting during routine drydock maintenance of vessels or through integration into newly introduced vessels in the fleet. However, to fully optimize the efficiency benefits of these technologies, it is crucial to carefully consider and tailor deployment measures – selecting the best-fit technology – to the specific size, type and operational profile of each vessel.

ABATEMENT MEASURE	SAVING POTENTIAL	APPLICABILITY (TYPE/SIZE OF VESSELS)	AVAILABILITY TO AFRICAN AND CARIBBEAN DOMESTIC SCENARIOS
Waste heat recovery (WHR)	WHR has been identified as having a fuel reduction potential of up to 12%, depending on the ship type (Tillig et al., 2015). Additionally, derating the engine, especially when combined with permanent slow steaming and wind hybrids, can provide an additional 1–3% in savings (Faber et al., 2012).	In the domain of domestic shipping, WHR systems are particularly recognized for emission reduction and enhancing overall energy efficiency, primarily in larger vessels rather than smaller ones. Studies highlight the potential to recover waste heat from exhaust gases and other sources in passenger ferry diesel engines (Gürgen and Altin, 2022). Additionally, WHR systems can utilize waste heat from fuel cells for fuel conversion processes in fuel cell systems (Lin et al., 2021).	The technology exists in both regions; however, further research is required to adopt it within their domestic fleets. Due to the high capital costs and the age and size of the fleet in both areas, the technology is not suitable for retrofitting in the current fleets. Nevertheless, it holds potential for consideration in the new generation of vessels.
Appropriate passage planning, power demand and weather routing	Weather routing emerges as a highly effective technique for enhancing onboard energy efficiency, offering potential efficiency gains of up to 5%, contingent upon vessel type, size and typical routes. This measure is expected to increase in importance with the deployment of wind energy technologies.	Given the nature of domestic shipping, which typically operates over short distances, the applicability of these measures ranges from low to medium for both large and small vessels. It varies depending on the area and distance of trade.	It can be applied in both regions with a medium to high level of applicability. In the domestic segment, where passages often follow fixed schedules, masters can consider local currents, tides and eddies, particularly in restricted areas and along straight routes, to maximize the benefits of improving vessel energy efficiency.
Speed reduction	The power required to propel a vessel is directly proportional to the cube of its speed (Kristensen and Lützen, 2012). A mere 10% reduction in vessel speed can result in a notable 27% decrease in fuel consumption (Psaraftis and Kontovas, 2010), along with a reduction in emissions of 10–15% (Faber et al., 2012). Considering that fuel constitutes a significant 60% of operating costs (Golias et al., 2010), optimizing speed can yield both economic and environmental benefits (Beşikçi et al., 2015). However, the effectiveness of this strategy may vary across different market segments (Hämäläinen, 2014).	This measure can be implemented on both large and small vessels. However, reducing speed in short-sea and domestic shipping operations may not offer the same level of feasibility and effectiveness as it does in deep-sea shipping (Vakili et al., 2023). The appropriateness of this approach should be evaluated on a case-by-case basis.	Medium to low applicability. Some domestic ships already utilize voluntary slow steaming during periods of high fuel costs. Faster passage times are typically demanded by passenger vessels. Individual governments have the option to introduce local regulations on ship speed within port jurisdictions and may consider implementing carbon pricing for domestic shipping, potentially resulting in a notable decrease in air emissions from the domestic shipping sector. However, due to the unique characteristics of domestic shipping, the implementation of speed reduction in this segment requires further assessment of its overall impact on safe navigation and food and energy security, as well as the economic and environmental development of the shipping industry.

ABATEMENT MEASURE	SAVING POTENTIAL	APPLICABILITY (TYPE/SIZE OF VESSELS)	AVAILABILITY TO AFRICAN AND CARIBBEAN DOMESTIC SCENARIOS
Just-in-time (JIT) arrival	Implementing JIT practices that involve reducing vessel speed offers economic and environmental benefits by reducing air emissions and underwater noise pollution. Additionally, it can alleviate port and anchor congestion, streamlining the logistics supply chain (Yang et al., 2021). Deploying these measures has the potential to reduce fuel consumption and GHG emissions by 14–23%, depending on the scenario.	In the domestic shipping sector, implementing JIT practices enables the adjustment of arrival times at ports, facilitating smoother logistics and decreasing port stays, thereby enhancing efficiency (Hansen et al., 2021). However, it requires collaboration among shipping lines, ports and terminals to exchange the data and information necessary for ships to optimize their voyages.	The deployment of this measure is feasible in both regions, with applicability ranging from low to medium. JIT efficiencies rely on synergies within the port and shoreside logistics chain components.
Optimized ship handling *(including ballast water & cargo handling)*	Optimizing the placement of pumps in AFRAMAX-class (Average Freight Rate Assessment) tankers holds promise for substantial efficiency enhancements, with reported improvements ranging from 5% to 15% (Plessas et al., 2016). Effective trim management further complements these gains, potentially reducing engine power requirements by approximately 5–10%, thereby diminishing fuel consumption and lowering air emissions (Hochkirch and Bertram, 2010; Mewis and Hollenbach, 2007).	High applicability and potential savings are more pronounced for larger vessels than smaller ones. Utilizing computerized cargo data and deploying sensors can enhance ships' handling and operational efficiency.	The potential exists for deploying the measure, with low to medium applicability, particularly for larger domestic vessels in the two regions as opposed to smaller and older vessels.
Hull and propeller coating and cleaning	Implementing suitable coatings and conducting routine maintenance and cleaning of a vessel's hull and propeller are vital for enhancing overall efficiency. This practice is estimated to reduce fuel consumption and air emissions by approximately 7–10% (IMO, 2011).	There is significant potential to implement these measures for both large and smaller vessels. The practice can be carried out either in dry dock or through cleaning by dive teams.	The potential to deploy this measure is high in both regions. However, further research is needed to identify and designate ports with appropriate facilities to conduct the operation.
Hull and machinery maintenance	The measure offers a potential emissions reduction of 2–8% (Nuttall et al., 2021). Maintenance is not only about optimizing operational efficiency but also plays a crucial role in mitigating risks and ensuring safety in maritime operations.	The measure has potential applicability for both large and small vessels. Some aspects of the measure can be managed by the crew during routine operations, while other maintenance tasks may require dry dock facilities. Implementing well-designed planned maintenance systems can enhance vessel maintenance and improve energy efficiency.	There is significant potential to deploy this measure in both regions, although the extent of implementation may vary depending on the specific circumstances. Given the high average age of the fleets in both regions, implementing these measures could be seen as a relatively straightforward way to improve energy efficiency in domestic shipping. Moreover, there is strong potential to train both onboard and offshore staff of shipping companies in implementing these measures.

ABATEMENT MEASURE	SAVING POTENTIAL	APPLICABILITY (TYPE/SIZE OF VESSELS)	AVAILABILITY TO AFRICAN AND CARIBBEAN DOMESTIC SCENARIOS
Economies of scale *(construction of larger vessels)*	The efficiency potential can reach up to 30% (Lindstad et al., 2012). However, transitioning to this level of efficiency demands significant financial investment, compounded by economic constraints (Vakili et al., 2022) and limitations in port infrastructure (Johnson, 2022).	The measure is applicable to smaller vessels, but its practicality and benefits are more pronounced in high-volume routes.	The potential for deploying this measure is considered low to medium in both regions. Implementing such measures across all routes may not yield significant advantages. Routes with high cargo and passenger volumes are expected to derive the greatest benefits from these initiatives. Moreover, the implementation of these policies necessitates substantial capital investment, with funding shortages identified as a major barrier to decarbonizing domestic shipping in both regions. Additionally, domestic ports and terminals must enhance their potential and capacity to accommodate larger vessels and handle higher cargo volumes and passenger numbers.
Shore power (cold ironing)	Implemented as an innovative measure to mitigate air emissions within ports, this technology proves effective when the source of electricity in the grid is environmentally cleaner than onboard ship sources (Vakili & Ölçer, 2023a). Additionally, the technology has the potential to reduce both air and underwater noise pollution (Vakili et al., 2020; 2020a; 2021a). However, the feasibility of implementation depends on regional air policies and the emissions intensity of ports' electricity supplies (Innes and Monios, 2018). Installation of the required infrastructure is expensive, costing approximately $10 million per installation, primarily related to extending the grid into the port (Merk et al., 2018). Deploying such technology for smaller vessels is comparatively cheaper, however.	Applicable to both small and large vessels, although larger vessels such as cruise ships are particularly energy-intensive even in ports, making the utilization of this technology challenging within the regions due to a lack of sustainable national grid infrastructure and production. It is more practical to use the technology for domestic and small vessels due to the smaller capital cost and the reduced additional demand it places on the national grid.	The technology is available and applied for domestic vessels in a few ports in both regions. However, for a larger-scale application of the technology, further investment in infrastructure and an increased contribution of renewable energy to national grids are required. Lack of funding, sustainable infrastructure at ports and trained personnel are the main barriers to implementing the technology in both regions.

APPENDIX III – BARRIERS TO IMPROVING ENERGY EFFICIENCY AND DECARBONIZATION OF DOMESTIC SHIPPING IN AFRICA AND THE CARIBBEAN

Introduction

Considering the substantial impact of fuel costs on fleets' operational expenses (constituting approximately 60% of the total), coupled with increasingly stringent international environmental regulations, operators and shipowners are eager to enhance the energy efficiency of their operations. However, despite this motivation, there exists a persistent gap between the potential for energy efficiency improvements and the actual implementation of measures due to various barriers (Dewan et al., 2018). These barriers act as deterrents to investing in technologies that are both energy and economically efficient (Sorrell et al., 2000), hindering the adoption of cost-effective energy-saving measures and causing a misalignment between optimal and real-time implementation, often referred to as the 'energy efficiency gap' (Thollander and Ottosson, 2008). Therefore, identifying and addressing energy efficiency challenges within the industry can not only bridge this gap but also yield significant economic benefits while expediting the decarbonization of the shipping sector (Vakili et al., 2021).

In light of the aforementioned issues, Vakili et al. (2021b; 2022a) propose a comprehensive framework for identifying and overcoming barriers to energy efficiency in the maritime industry, adopting a life cycle perspective of maritime clusters. This framework is characterized by its holistic, systematic and transdisciplinary approach, which acknowledges the interconnectedness and mutual influence of various barrier types. The framework categorizes barriers into five primary domains: human factors, technology and innovation, policy and regulation, operations and economics.

Background

In light of the above, a questionnaire was designed, developed and distributed to different stakeholders, namely ship owners, ports' operators, administrators and policy-makers, technology providers and seafarers. The survey was conducted among both African and Caribbean relative stakeholders from different backgrounds and management levels.

The questionnaire was designed in three different sections:

- Section A: 38 barriers to energy efficiency have been categorised under five different disciplines, namely human factors, operations, technology and innovation, policy and regulation, and economics. They were asked to identify the importance of each barrier for their organization.
- Section B: 12 drivers of energy efficiency improvement have been enumerated. Interviewees were asked to identify the most important drivers for them to improve energy efficiency.
- Section C: Identification of the key disciplines that can improve energy efficiency in their organization.

In total 18 responses were received from Africa and 16 responses from the Caribbean region. After identifying the barriers, key drivers and key disciplines for improving energy efficiency and reducing air emissions within each discipline, the aggregated results were also considered to provide a more holistic perspective to overcoming the barriers to energy efficiency and motivating and supporting the drivers within the key disciplines to improve energy efficiency and decarbonization in the domestic sector in both regions.

Results

Identification of barriers, drivers, and disciplines to improve energy efficiency in LDCs and SIDS

AFRICA

In total 18 responses were received from Africa. As Figure 1 shows the majority of participants, at 44.4% (eight people) were from administration and policy-maker stakeholders. Port operators, seafarers and technology providers represented 11.1% (two people) and the remaining 22.2% (four people) were other stakeholders such as non-governmental organizations (NGOs). Unfortunately, there were no replies from ship owners or operators. The majority of the participants were at a senior level in their careers (39.3%), 24.1% of the participants were at the moderate-to-mid level or junior level, and 12.5% of the participants did not highlight their level of occupation (Figure 2).

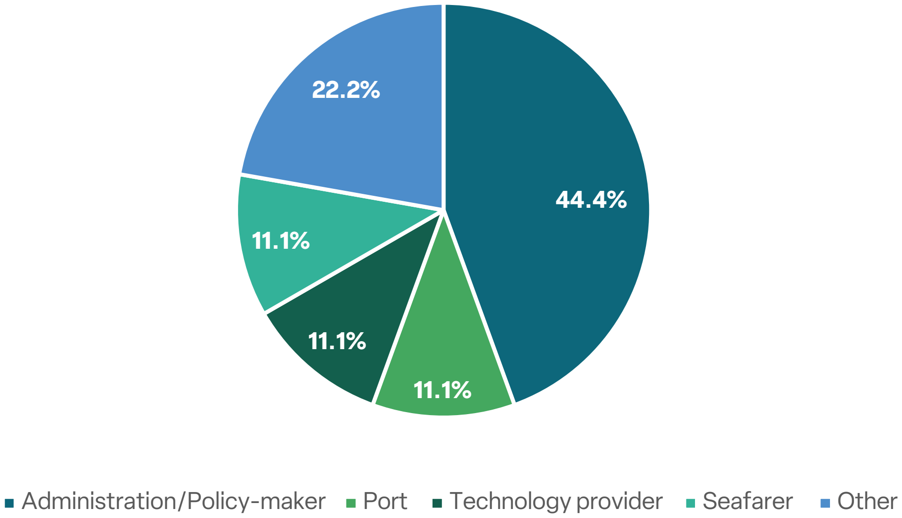


FIG A1: *Distribution of participants in questionnaire responses from Africa*

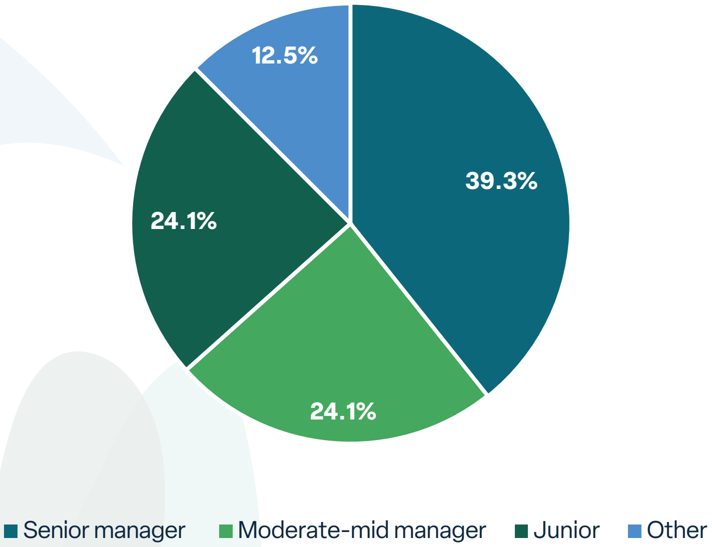


FIG A2: *Levels of seniority among respondents to the questionnaire from Africa*

Energy efficiency barriers in Africa

The graphical representation in Figure 3 illustrates the primary barriers hindering efforts to enhance energy efficiency within Africa's maritime industry, as perceived by stakeholders at various levels. An analysis of survey data revealed that 'Limited access to capital' and 'Lack of trained manpower' were identified as the most significant obstacles, both scoring 0.86 points, impeding progress in domestic shipping energy efficiency across the continent. These findings were consistently echoed during interviews with multiple stakeholders.

Following closely, 'Weak legislation and enforcement' and 'Immaturity of technologies' were ranked as the second most pressing barriers, each garnering a score of 0.81 points, posing significant challenges for stakeholders striving to improve energy efficiency. Additionally, factors such as 'Lack of funding', 'Split incentives' and 'Technical risks' received 0.78 points, collectively standing as the third most formidable barriers to decarbonizing domestic shipping operations in Africa. Furthermore, 'Lack of incentives' and 'Reluctance to invest due to perceived high risk' emerged as the fourth most significant hurdles in the quest to enhance energy efficiency and decarbonization within the region's domestic shipping sector.

Moreover, as depicted in Figures 4 and 5, disciplines such as 'Economics' and 'Technology and innovation' were identified as pivotal areas, each scoring 0.89 points, signifying their paramount importance in addressing energy efficiency challenges. Concurrently, the primary drivers for reducing CO_2 emissions from Africa's domestic fleet included imperatives such as 'Reducing energy costs' (0.83 points), 'Access to financial support', 'Commitment to environmental sustainability' and the incorporation of 'Long-term energy policies', each registering a score of 0.78 points.

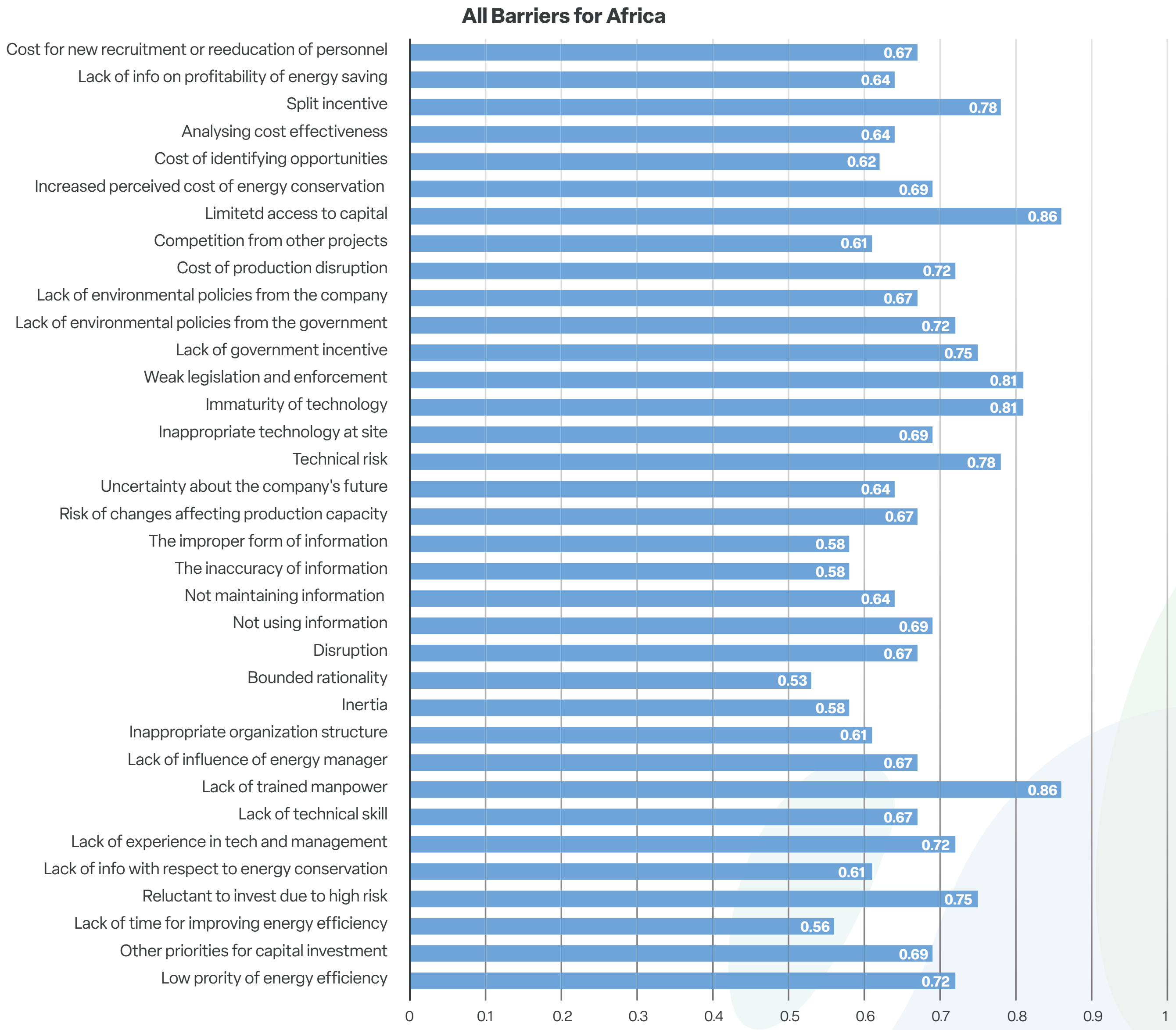


***FIG A3:** List and ranking of energy efficiency barriers in Africa*

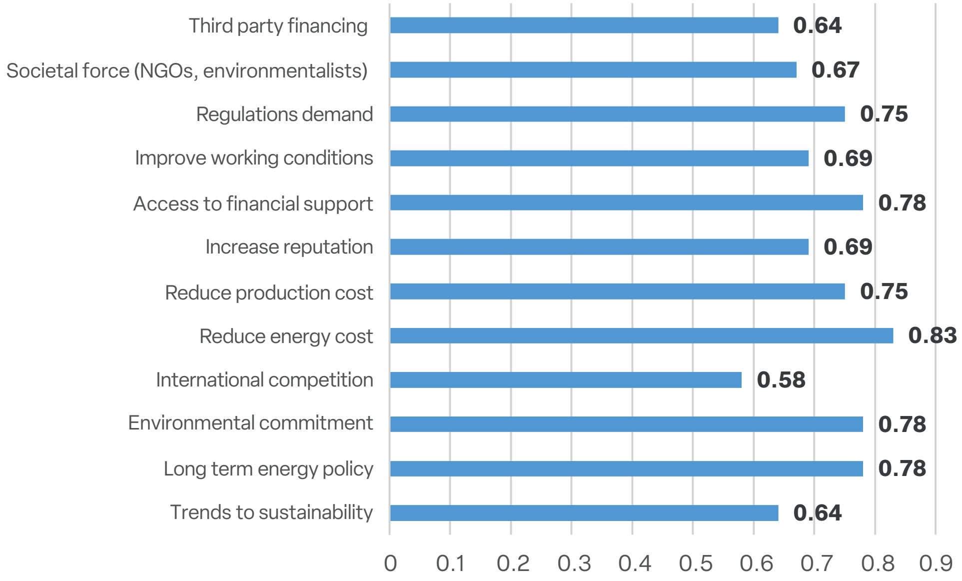


***FIG A4:** List and ranking of drivers for improvement of energy efficiency in Africa*

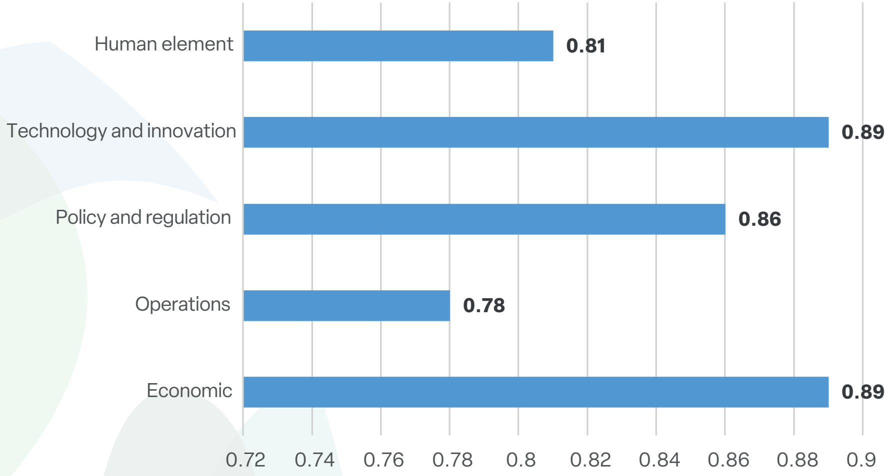


***FIG A5:** List and ranking of disciplines to improve energy efficiency in Africa*

THE CARIBBEAN

A total of 16 responses were gathered from the Caribbean region. As illustrated in Figure 6 the plurality of participants, comprising 31.3% (six individuals), represented various stakeholders not specifically categorized, such as NGOs and investors. Following this, administration and policy-makers, and ship owners, constituted the second largest groups of participants, each comprising 25% (four individuals) of the respondents to the questionnaire. Port stakeholders accounted for 12.5% (two responses) of the total, while only one seafarer (6.25%) participated in the survey. Regarding career levels, the majority of participants, comprising 58.2%, occupied mid-level positions. Senior-level professionals constituted 33.4% of the participants, while junior-level participants comprised 8.4% of the total respondents (Figure 7).

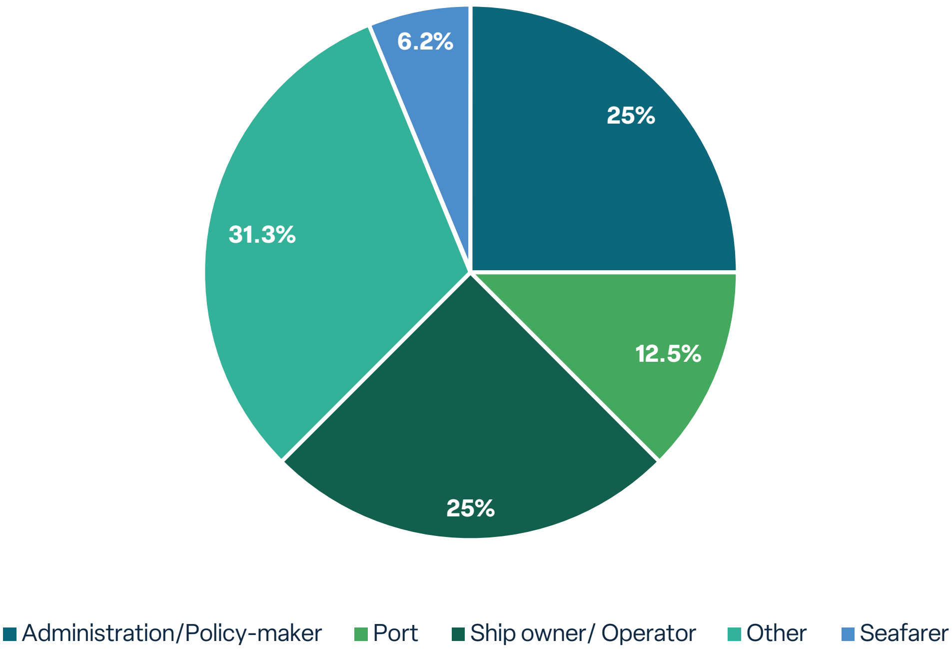


FIG A6: *Distribution of participants in questionnaire responses from the Caribbean*

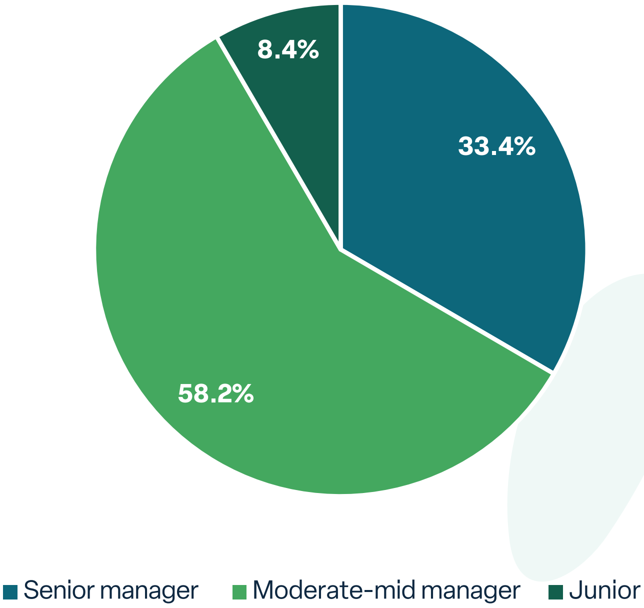


FIG A7: *Levels of seniority among respondents to the questionnaire from the Caribbean*

Energy efficiency barriers in the Caribbean

Figure 8 provides insights into the primary barriers hindering energy-efficiency improvement within the Caribbean shipping industry, as perceived by stakeholders across different levels. Analysis of the questionnaire data revealed that the most significant barrier, scoring 0.78 points, was the ‘Immaturity of technology’. Following closely were ‘Split incentives’ and ‘Limited access to capital’, each scoring 0.75 points, identifying them as the second most critical obstacles to energy-efficiency and decarbonization efforts in domestic shipping. Additionally, ‘Lack of information on the profitability of energy-saving devices’ and ‘Lack of government incentives’ scored 0.72 points, positioning them as the third most important barriers to decarbonization within the Caribbean’s domestic shipping sector. Furthermore, ‘Inappropriate technology implementation’ and ‘Inertia’ were identified as the fourth most significant barriers to improving energy efficiency and decarbonization in the region.

During interviews, similar barriers were consistently raised by participants regarding energy-efficiency improvement within the region. Notably, some interviewees emphasized that decision-makers often prioritize initiatives other than energy-efficiency improvements due to considerations surrounding capital allocation.

As depicted in Figures 9 and 10, the disciplines perceived as most crucial for overcoming these barriers were 'Policy and regulations' and 'Technology and innovation', scoring 0.78 and 0.75, respectively. Meanwhile, the primary drivers identified for enhancing energy efficiency and reducing GHG emissions in the Caribbean's domestic shipping sector were 'Reduction of energy costs' and 'Access to financial support', scoring 0.83 and 0.73 points, respectively.

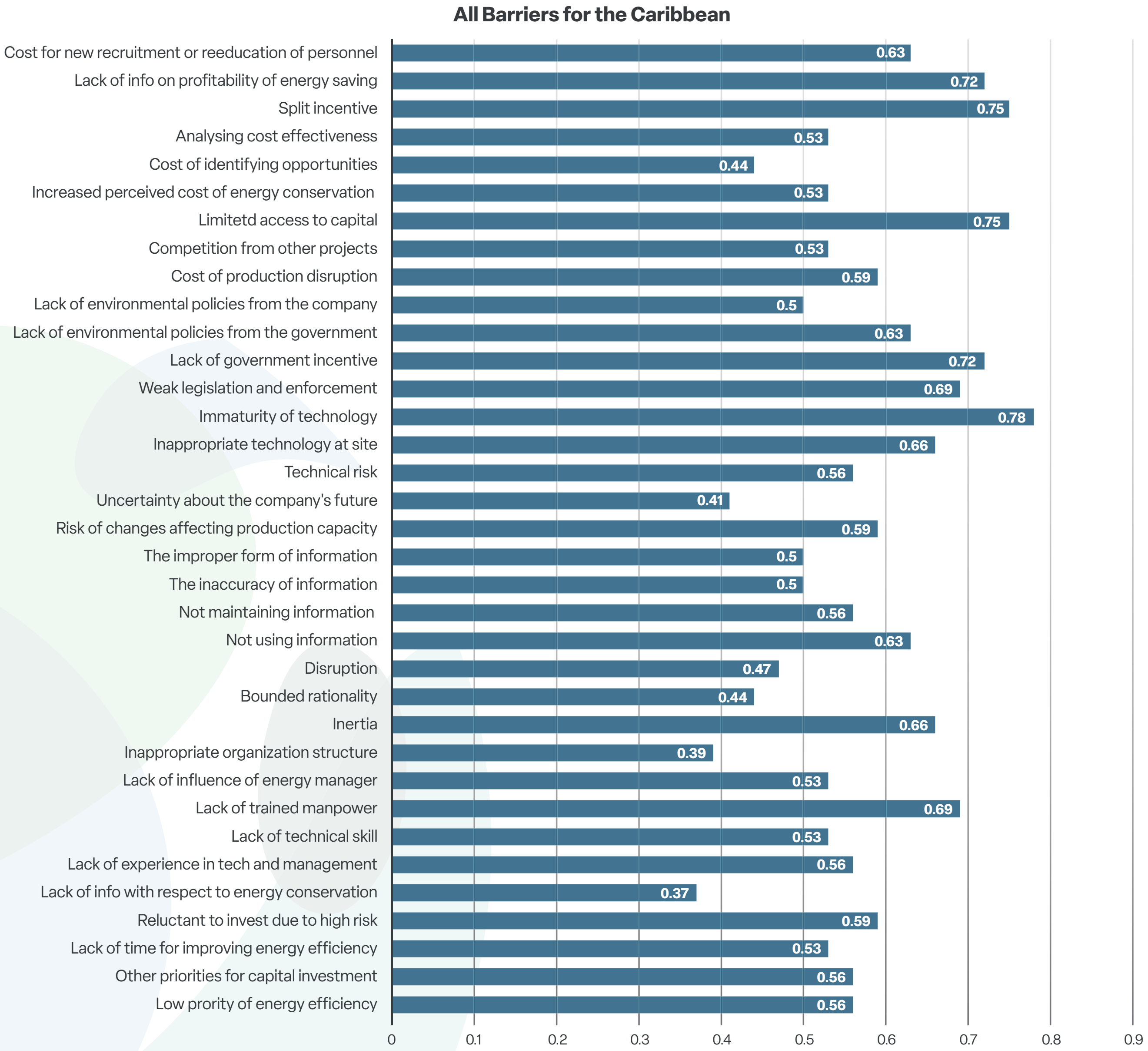


***FIG A8:** List and ranking of energy efficiency barriers in the Caribbean*

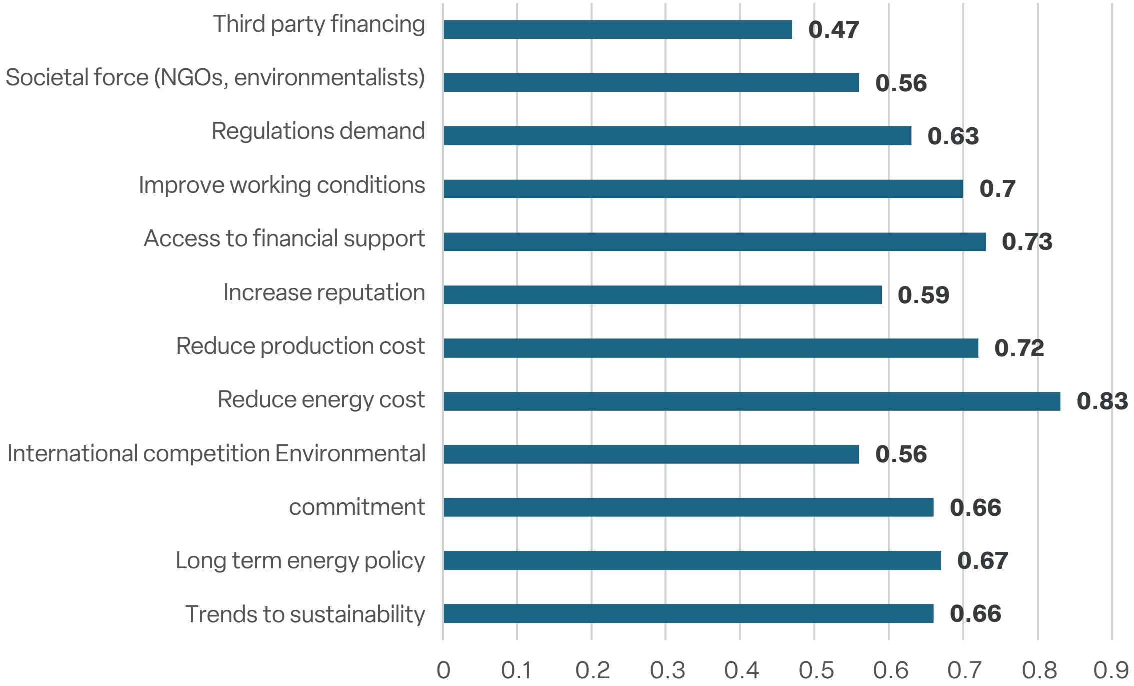


***FIG A9:** List and ranking of drivers for improvement of energy efficiency in the Caribbean*

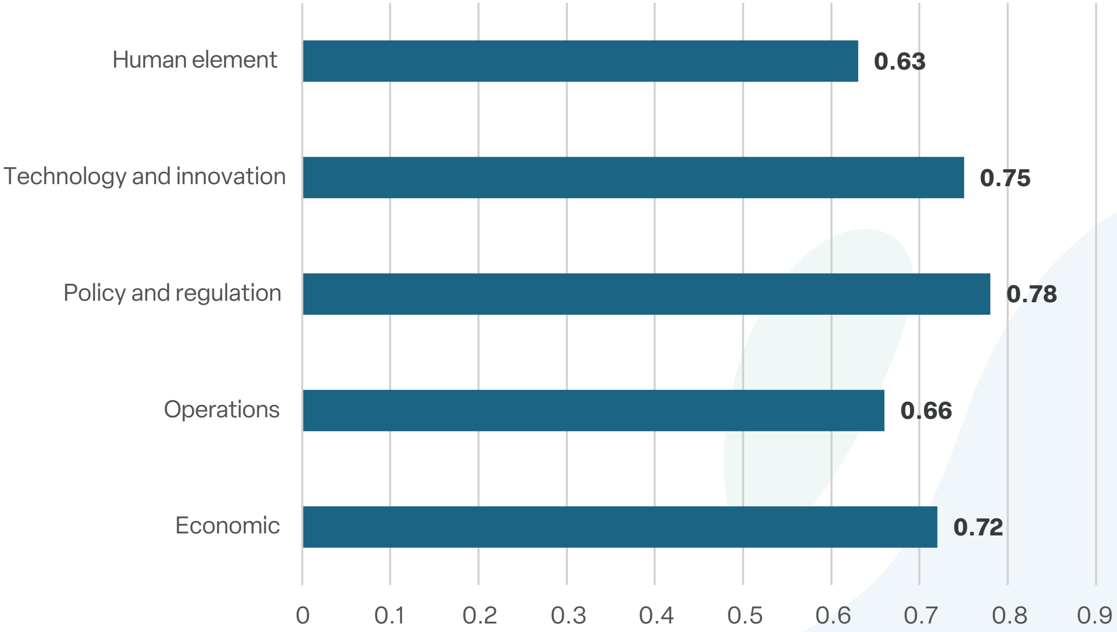


***FIG A10:** List and ranking of disciplines to improve energy efficiency in the Caribbean*

Discussion

The section highlighted energy gaps in energy efficiency and pinpointed existing barriers to achieving zero-emission domestic shipping in the African and Caribbean regions. Addressing these barriers will require careful consideration and targeted policy interventions.

In Africa, primary barriers to decarbonizing domestic shipping include ‘Limited access to capital’, ‘Lack of trained manpower’, ‘Technological immaturity’, ‘Weak legislation and enforcement’, ‘Lack of funding’, ‘Split incentives’, ‘Technical uncertainties’, ‘Lack of incentives’ and ‘Investment reluctance due to perceived high risks’. Meanwhile, in the Caribbean region, major impediments to enhancing energy efficiency and achieving zero emissions in domestic shipping are ‘Technological immaturity’, ‘Restricted access to capital’, ‘Split incentives’, ‘Lack of information regarding the profitability of energy-saving measures’, ‘Lack of incentives’, ‘Inappropriate technology deployment’ and ‘Inertia’.

Significantly, many of these barriers are common to both regions and predominantly stem from economic disciplines. Recognizing their interconnectedness and mutual influence, it is crucial to overcome them and bridge the associated energy efficiency gap, promoting decarbonization efforts through cooperation among stakeholders, both horizontally and vertically.

To promote such collaboration and achieve mutual benefits across all stages of the value chain, the development and implementation of a comprehensive, systematic and transdisciplinary framework are paramount. This framework should facilitate the seamless integration, adoption and utilization of essential technologies, with investments in industry, organizations, infrastructure and the socio-economic environment serving as fundamental components. Furthermore, capacity building is indispensable for maximizing the advantages of newly adopted technologies.

APPENDIX IV – METHODOLOGY FOR GHG EMISSION ESTIMATIONS FROM DOMESTIC FLEETS IN AFRICA AND THE CARIBBEAN

The GHG emission estimations from the domestic fleet in this report were conducted using a bottom-up approach, as bunkering fuel or fuel consumption data on domestic shipping in Africa and the Caribbean could not be obtained. A multistage procedure was adopted from the IMO Fourth GHG Study as follows:

1. Ships operating solely in West and East America and Africa were subtracted from Clarksons World Fleet Register using deployment data. Clarksons deployment data is based on AIS data for ships over 100 gross tonnage. IMO number, and Maritime Mobile Service Identity (MMSI) if IMO number is not available, for the ship was used as means of identification. The main characteristics of the ship and energy-efficiency measures adopted for the ship were also subtracted from Clarksons World Fleet Register.
2. Each ship in the list was checked as to whether it had operated solely in African SIDS and LDCs, or in and between Caribbean SIDS and LDCs, during the past 12 months using a commercial AIS data provider. Ships meeting these criteria were used in further studies in this report. The data related to duration underway in operations during the past 12 months and average speed were also checked individually to determine whether the ship was laid up or operational during this period.
3. The data cleaning and gap filling were conducted. Ship type, gross tonnage, main dimensions, speed and engine power were taken as a minimum set of parameters. If such data were not available for an individual ship they were filled with at least an equate fit estimation from existing data for that ship type considering the gross tonnage or other characteristics. IMO Fourth GHG Study gap filling was based on deadweight, while gross tonnage was used as the main parameter for gap filling in this work as the majority of ships involved in domestic shipping may not have a sensible deadweight value.

Ship type classifications used in this work are:

- Passenger ship – ferry
- Tanker
- General cargo ship
- Ro-ro ship
- Container
- Tug
- Bulk carrier
- Other

4. The emission model was established with a number of steps:
   a) Design Froude number was estimated from ship design speed, i.e. the speed given in the ship's specifications, and ship length
   b) Ship geometric coefficients such as block coefficient, midship section coefficient and prismatic coefficients were estimated from the design Froude number and ship dimensions using empirical equations. The ship wetted surface area was estimated using the Holtrop–Mennen method.
   c) Ship form factor was estimated with the Holtrop–Mennen method, and ship viscous resistance at design speed was estimated. Using engine power and estimated ship propulsion efficiency, the ship wave resistance coefficient was estimated for the design speed.
   d) Ship operational speed was determined from AIS data
   e) Ship wave resistance was estimated for the operational speed using the difference between operational and design speed
   f) Ship resistance components were determined as well as ship propulsion coefficients
   g) Ship power requirement, fuel consumption and emissions were estimated including the weather effects, engine loading effects etc.

All ships were assumed to consume MDO/MGO. Even though there are some ships which may consume HFO/LFO (light fuel oil) in the database, the majority of ships involved in domestic shipping currently use MDO/MGO as their main fuel. The emission factor differences between HFO/LFO between MDO/MGO were ignored.

Although this approach is not fully correct, due to assumptions made during the calculation, it is used only for comparative calculations to estimate the magnitude of emission savings for a given energy efficiency measure for domestic shipping.

It should be mentioned that the domestic shipping approach in this report is different to that in the IMO Fourth GHG Study. In the IMO study, each voyage was classified as domestic or international according to AIS data, and the fuel consumption and emission predictions used a voyage-based model. Only ships involved exclusively in domestic voyages over the past 12 months were evaluated in the current study, i.e. domestic voyages conducted by ships that also undergo international voyages have not been included.

Although the IMO Fourth GHG Study approach is more indicative with regard to the emissions of domestic shipping, the efforts to decarbonize ships involved in both domestic and international shipping can be dealt with via international shipping decarbonization studies. These ships have to comply with the IMO set of decarbonization measures such as EEDI, EEXI, CII and SEEMP, and so they will not be affected by national efforts, which are the main scope of this study.

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