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Study for Mapping Innovation Needs, Risks and Barriers for Decarbonizing Maritime Transport

- Final Report -

By

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Abbreviations and Acronyms

ADB	Asian Development Bank
AER	Annual Efficiency Ratio
AIS	Automated Identification System
APEC	Asia Pacific Economic Cooperation
ATP	Ability to Pay
CAPEX	Capital Expenditures
CBA	Cost Benefit Analysis
CBI	Climate Bonds Initiative
CCS	Carbon Capture and Storage
CEA	Cost Effectiveness Analysis
CI	Carbon Intensity
CII	Carbon Intensity Indicator
CoC	Confirmation of Compliance
CSC	Clean Shipping Coalition
CTCN	Climate Technology and Centre Network Technology
DCS	Data Collection System
DWT	Dead Weight Tonnage
ECLAC	Economic Commission for Latin America and the Caribbean
EEDI	Energy Efficiency Design Index
EEDI	Energy Efficiency Design Index (for Ships)
EEXI	Energy Efficiency Existing Ships Index
EIB	European Investment Bank
EPL	Engine Power Limit
ESG	Environmental, Social and Governance
ESI	Environmental Ship Index
EU	European Union
FIN-SMART	Financing Sustainable Maritime Transport platform
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse Gas
GIS	Geographical Information Systems
GKGP	Green Knowledge Growth Platform
GloMEEP	Global Maritime Energy Efficiency Partnerships
GSIP	Green Shipping Investment Platform
GSP	Norway's Green Shipping
GT	Gross Tonnage
GZC	Getting Zero Coalition
IAP	International Advisory Panel
IAPH	International Association of Ports and Harbours
IAPP	International Air Pollution Prevention
ICS	International Chamber of Shipping
ICT	Information and Communication Technology

IFC	International Finance Corporation
IFI	International Financial Institution
ILO	International Labour Organization
IMLI	International Maritime Law Institute
IMO	International Maritime Organisation
IMRF	International Maritime Research Fund
IOT	Internet of Things
IPCC	Inter-Governmental Panel of Climate Change
IT	Information Technology
KPI	Key Performance Indicators
LDCs	Least Developed Countries
LNG	Liquified Natural Gas
LPI	Logistics Performance Index
LSCI	Liner Shipping Connectivity Index
MACC	Marginal Abatement Cost Curve
Mar-RI UK	UK Maritime and Research Innovation
MARPOL	International Convention for the Prevention of Pollution from Ships MEPC Marine Environment Protection Committee (of IMO)
MDBs	Multilateral Development Banks
MEPC	Maritime Environmental Protection Committee
MINT	Maritime Innovation and Technology (Fund) of Singapore
MPA	Maritime and Port Authority of Singapore
MRV	Monitoring, Reporting and Verification of CO2 emissions
MSW	Maritime Single Windows
MTCC	Maritime Technology Cooperation Centres
MTF	Maritime Technologies Forum
nm	nautical mile(s)
NoGAPS	Nordic Green Ammonia-Powered Ship
OECD	Organisation for Economic Cooperation and Development
OPEX	Operating Expenditures
PBSP	Pacific Blue Shipping Partnership
RFID	Frequency Identification Systems
ROPAX	Roll on Roll off and Passenger
RORO	Roll on / Roll off
SAYS	Save As You Sail
SCP	Sustainable Clean Port Programme
SEEMP	Ship Energy Efficiency Management Plan
SFAP	UK-Norway Sustainable Finance Action Platform
SHA	Stakeholder Analysis
SIDS	Small Island Developing States
SNG	Synthetic Natural Gas
SoC	State of Compliance
SPC	Smart Port Challenge
SSI	Sustainable Shipping Initiative

SSS	Short-Sea Shipping
UK	United Kingdom
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
US	United States of America
VT(MI)S	Vessel Traffic (Monitoring and Information) System
WB	World Bank
WMU	World Maritime University
WTO	World Trade Organization

Disclaimer

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1. Introduction and Background

In line with the global efforts to preserve the environment and tackle climate change, maritime transport decarbonisation has been on the agenda of science, technology, industry and policy making for some time, yet has gained impetus with the adoption of the IMO Initial Strategy on reduction of Greenhouse Gas (GHG) emissions from ships (Initial Strategy) in 2018, aimed at reducing sector-wide emissions by at least 50% by 2050.

Regulation directly affects the innovation process, while innovation and technical change have significant impact on regulation and help accelerate the process and pathways to regulatory compliance. IMO, as the UN specialised agency regulating the international maritime industry, is using its regulatory mandate to further improve the energy efficiency of international shipping through concrete measures such as the improvement of ships' design, the installation of energy saving devices, and the development of plans for ships' energy efficiency management and reporting.

In addition to these measures, significant innovation and technological leaps will be needed if maritime decarbonisation targets are to be achieved in scope and scale within the desired timeframe. Innovative solutions will be required in several areas spanning ship design and operations, voyage planning and optimisation, energy and fuel technology, bunkering and port infrastructure, investment and financing mechanisms, business models, and supporting services. Similarly, appropriate innovation models, processes and networks will need to be organised and managed in an efficient, coordinated and inclusive way among various stakeholders and network partners.

Understanding the full scope and extent of innovation needs, risks and barriers associated with maritime decarbonisation is a key prerequisite towards developing appropriate strategies and policies aimed at accelerating the energy transition and achieving decarbonisation targets.

For developing countries, particularly Small Island Developing States (SIDS) and Least Developing Countries (LDCs), the risks and barriers to designing, testing and deploying innovation may be further compounded by additional challenges posed by the structure of their maritime markets, the scarcity of their economic and financial resources, and the limited technical capacity of their innovation networks and institutional structures.

As we take on the global challenge to transform the industry towards zero carbon shipping, there is a need for a better understanding of the innovation models, frameworks and processes of knowledge diffusion and sharing in order to fill structural holes and differential gaps and ensure an inclusive innovation process without leaving anyone behind.

The objective of this study is to carry out a mapping exercise of innovation projects, models and networks for maritime decarbonisation and outline the risks and barriers to decarbonising maritime transport particularly in developing countries, SIDS and LDCs. Another emphasis of the study is to showcase successful models and best practices for fostering innovation models and networks that promote collaboration, inclusion and knowledge sharing.

Using a combination of a desktop review and a stakeholders' survey, the report maps innovative technologies, financing mechanisms, business and operating systems for maritime decarbonisation, outlines the main risks and barriers to innovation deployment and diffusion, and reviews the network models, structures and typologies of current innovation and Research and Development (R&D) programmes. In so doing, the paper examines the gap between existing innovation efforts and the requirements for achieving decarbonization targets for developing countries, particularly SIDS and LDCs. The report also highlights innovation models, projects and networks that have proven to be most successful both within and outside the maritime industry.

2. Transforming Maritime Transport Systems towards Decarbonisation

The international maritime community has embarked through the 2018 IMO Initial Strategy on a shared roadmap towards decarbonisation. The Initial Strategy sets clear GHG emissions targets, provides indicative timelines, and envisages the deployment of multiple tools and technologies. The transition towards maritime decarbonisation will likely require a combination of new technologies and operating systems, alternative fuels and infrastructures, innovative business models, and novel financing and funding schemes.

New business models converging circular and sharing economy, additive manufacturing and servitisation, big data and analytics, and digitisation of logistics and supply chain systems can also make a significant impact on energy efficiency and emissions reduction. Similarly, innovation in contractual and commercial structures, including for chartering contracts, bunkering arrangements and service level agreements, will help overcome split-incentive and interface risks and accelerate the transition towards maritime decarbonisation.

Developing and deploying zero carbon ships and associated infrastructure will also require innovative funding schemes and financing mechanisms. Traditional maritime financing products may not be suitable or readily supportive of new asset type, technology and risk profile. New and innovative instruments are being introduced and explored for financing green maritime assets, infrastructure and services.

A successful deployment of any of the above measures, technologies, models or mechanisms is contingent on close coordination and collaboration among various stakeholders. At the same time, the transition will provide major opportunities for countries and operators to upscale green and renewable energy production, storage and distribution; thereby expanding capacity and usage while reducing costs and gaining competitive advantage.

The diversity and complexity of the maritime industry means that decarbonisation of the sector will be achieved through a combination of technologies, operating processes, business models and other supporting measures. The success and delivery of each pathway will depend on several factors and uncertainties around technology's availability and scalability, level of demand, infrastructure and technical challenges, costs and prices, and skills development and transition, as well availability of effective innovation solutions and use of suitable innovation models and networks addressing the needs of developing countries, especially LDCs and SIDS.

2.1. Operating Systems and Technologies

2.1.1. Ship design, operational improvements and energy efficiency solutions

Energy efficiency has for long been a key concern of the shipping industry given that fuel costs represent as much as 50% of total ship operating costs, depending on the type of ship and service. Various ship's design and technology solutions were already in place as part of the drive to improve fuel savings and reduce operating costs.

In 2011, IMO agreed to include a new chapter on "energy efficiency" in MARPOL Annex VI and adopted mandatory energy efficiency regulations for ships under MARPOL Annex VI – Energy Efficiency Design Index (EEDI) for new ships, Ship Energy Efficiency Management Plan (SEEMP) for all ships. The EEDI has subsequently been strengthened through further amendments.

In addition, in 2016 IMO adopted mandatory IMO Data Collection System (DCS) for ships to collect and report fuel oil consumption data from ships over 5,000 GT - first calendar year data collection completed in 2019.

IMO's Marine Environment Protection Committee (MEPC 76), adopted further amendments to MARPOL Annex VI that will require ships to reduce their GHG emissions. These amendments combine technical and operational approaches to improve the energy efficiency of ships, also providing important building blocks for future GHG reduction measures.

The new measures will require all ships to calculate their Energy Efficiency Existing Ship Index (EEXI) following technical means to improve their energy efficiency and to establish their annual operational Carbon Intensity Indicator (CII) and CII rating. Carbon intensity links the GHG emissions to the ship's transport capacity over distance travelled.

Ships will get a rating of their energy efficiency (A, B, C, D, E - where A is the best). Administrations, port authorities and other stakeholders as appropriate, are encouraged to provide incentives to ships rated as A or B also sending out a strong signal to the market and financial sector.

A ship rated D for three consecutive years, or E, is required to submit a corrective action plan for verification by its Administration, to show how the required index (C or above) would be achieved.

The amendments to MARPOL Annex VI (adopted in a consolidated revised Annex VI) are expected to enter into force on 1 November 2022, with the requirements for EEXI and CII certification coming into effect from 1 January 2023. This means that the first annual reporting will be completed in 2023, with the first rating given in 2024.

2.1.2. Energy and propulsion technology options

Many believe that propulsion technologies represent the frontier game changer as they have the potential to offer a direct route to maritime decarbonisation. Alternative fuels such as Hydrogen, Ammonia and Methanol, renewable energy sources such as Solar and Wind and other propulsion technology options such as Fuel Cells, Batteries and Nuclear can all play a role in powering zero or near zero carbon ships. Many of these options can be used as hybrid combinations while others can be employed in a dual fuel engine with cleaner fuels readily available such as Liquified Natural Gas (LNG), Biofuels and Methanol.

***Table 1**: Energy and Fuel Technology Options (Elaborated by Consultant from various sources)*

Option/ Solution	Function / Objective	Impact on GHG reduction	Technology & Operational Risk	Availability & Scalability Risk	Investment & Financing Risk
LNG	Mature, available and scalable technology for use as a step towards the energy transition	Medium	Low	Low	Medium
Methanol	Low cost and proven use. Can be employed in a dual-fuel engine and make use of existing bunkering facilities	Very High	Medium	Medium	Medium
Biofuels	Blending potential with fossil fuels. Lacks global infrastructure and bunkering facilities but can be distributed through existing HFO/MGO systems.	Medium	Medium	Medium	Medium
Ammonia	Large-scale potential for use in ocean shipping; has challenges with supply and mass transport of ammonia. Those can be avoided with the development of liquefied ammonia gas carriers.	Very High	High	Medium	High
Hydrogen	Large potential with adaptations to marine engines at an early development stage. Liquification needed to achieve a comparable energy density to ammonia and fuel. CCS & land-side investment would also be required.	Very High	High	Medium	High
Wind and Solar renewables	Can contribute to auxiliary power requirements, but neither technology currently offer sufficient energy density to reliably propel a ship.	Medium			High

Alternative fuels seem to be promising and some are in advanced stages of testing and piloting, with Ammonia and Methanol currently taking the lead over Hydrogen and Hybrids. In order to be truly carbon-neutral, the process of manufacturing or producing these fuels must itself use green energy such as renewable or nuclear energy. Furthermore, if the combustion of carbon-neutral fuels is associated with Carbon Capture and Storage (CCS), this can result into net-negative emissions which, along other forms of remediation such as forestation and ocean fertilisation, further contribute to decarbonisation and GHG reduction.

Nonetheless, each alternative fuel option has its own challenges and requires further research and innovation, experimentation and testing prior to deployment and implementation.

For instance, Methanol's innovation needs lie in its green production, scalability and the requirement of an extensive network of terminals, while Ammonia's innovation challenges include hull engine technology, fuel supply system, safety navigation methods, storage tank space and other supply chain and infrastructure challenges. On the other hand, hydrogen once produced to a high purity level becomes a promising technology, but it still requires overcoming innovation challenges in areas such as liquification/gasification process and cost, CCS and land-side investment.

Non-fuel propulsion technologies such as batteries and renewables can also contribute to auxiliary power requirements, but neither technology is currently able to offer sufficient energy to cover long-distance ship journeys. Innovation needs of non-fuel technologies lie in the energy density and technical scalability and reliability of renewable energy. However, renewables can be indirectly exploited by using renewable land-based technology for cold ironing and for charging battery-powered ships. Drawing from the improvements in battery technology in sectors such as the automotive industry, this can be feasible for small operations such as Short-Sea Shipping (SSS), ferries and supply vessels. Some electric ferry vessels are already in operations on short domestic journeys.

The technology options outlined above face similar type yet different levels of challenges related to their resource availability, green production processes, readiness, scalability and reliability as well as the requirement of extensive networks of storage, distribution and bunkering. Some technologies such as Batteries have currently low energy density which restricts their use to short-distance sailing. Other technologies such as LNG are mature and readily available and can be a viable step towards the energy transition as LNG itself cannot meet the 2050 targets of 50% reduction of GHG emissions; but carbon neutral bio-LNG or Synthetic Natural Gas (SNG) can become a credible fuel alternative.

Notwithstanding the above, the choice of which alternative fuel or energy to use may not be a binary decision after all. The technology for proofing future ship build to accommodate more than one fuel type is already in place and gaining traction, with newbuild orders with alternative fuel systems doubled to 12% of total orders in 2020 compared to 2019 orders. As a result, the main challenge will likely shift to the required supply, storage and landside infrastructure for fuel alternatives as they become readily scalable and cost effective over time.

As technology and operating risks for alternative fuel and energy options are being addressed, other risks and barriers require equal consideration. These include investment, financing, economic, market and coordination risks which may hinder or delay the development and widespread deployment of alternative fuel and energy technologies. Some of these risks and barriers may be global in nature, while others are more region or country specific.

For developing countries, particularly SIDS and LDCs, access to green financing and new ESG financial products to fund and support maritime decarbonisation is limited. Other enabling factors such as R&D, digitalisation, technical and human and skills are also in short supply in many developing countries, SIDS and LDCs.

2.1.3. International projects lead by IMO to support implementation of Initial GHG Strategy in developing countries, LDCs and SIDS

In addition to regulatory developments, a range of IMO-led global projects initiated since 2012 support developing countries in ratifying MARPOL Annex VI and to implement the MARPOL energy efficiency measures and to support and encourage pilot projects, innovation and R&D.

GHG SMART Training Programme

To support specific needs of Least Developed Countries (LDCs) and Small Island Developing States (SIDS), IMO together (and with the financial support) of the Republic of Korea started in 2020 a Sustainable Maritime Transport Training Programme to Support the Implementation of the GHG Strategy (GHG Smart Programme). The Programme, which will hold its first capacity building training at the end of the year, is a long-term training Programme to support the implementation of the Initial IMO GHG Strategy by building sufficient capacity, especially among the LDCs and SIDS, to prepare for implementation of the Strategy.

Global Maritime Technology Cooperation Centres Network (GMN)

In 2017, IMO has set up five Maritime Technology Cooperation Centres (MTCCs) in Latin America, the Caribbean, Pacific, Asia and Africa, with financial assistance from the European Union. These five MTCCs constitute the Global MTCC Network (GMN), which is implementing the IMO project titled "Capacity Building for Climate Mitigation in the Maritime Shipping Industry". This Network promotes the uptake of low-carbon technologies and operations in maritime transport in developing countries with a view to limiting GHG emissions from their shipping sectors through technical assistance and capacity building. The role of MTCCs is specifically mentioned in the Initial Strategy.

The Network has completed a range of pilot projects over the past years. Tangible results include port energy audits and retrofitting of domestic ships for better energy efficiency. The MTCCs engaged with over 100 participating countries, resulting in more than 3,000 participants across 70 maritime energy efficiency workshops to date. Furthermore, the MTCCs have been working with over 2,000 participating ships to deliver sets of fuel oil consumption data which can help inform and support energy efficiency improvement.

GreenVoyage2050

The IMO-Norway GreenVoyage2050 project (https://www.greenvoyage2050.imo.org) is building on the earlier GEF-UNDP-IMO GloMEEP project's most successful activities and supports countries in the implementation of concrete measures that are identified in a country's National Ship Emissions Reduction Strategy (NSERS)/National Action Plan, while mirroring earlier activities of GloMEEP in new partner countries. The project is initiating and promoting global efforts to demonstrate and test technical solutions for reducing GHG emissions, as well as enhancing knowledge and information sharing to support the Initial Strategy. Several developing countries, including LDCs and SIDS, are participating in the project, including strategic partners from the private sector, who contribute expertise and experience through the project's Global Industry Alliance to Support Low Carbon Shipping.

GloFouling

IMO, through the Global Environment Facility/UNDP funded GloFouling Partnerships Project (https://www.glofouling.imo.org) seeks to increase the level of implementation of IMO's Biofouling Guidelines and the use of best practices for other maritime sectors, through a wide range of activities including assistance for policy definition and implementation, delivery of training courses for technical capacity building, catalysing investment in technology R&D, spurring information sharing and awareness raising on the issue and its solutions.

The work of GloFouling Partnerships has also showcased close interlinkages between the maritime GHG reduction potential and the protection of marine biodiversity by implementing the IMO Biofouling Guidelines as a state-of-the-art management of biofouling resulting in significant fuel efficiency gains, in addition to minimizing the transfer of invasive aquatic species to local marine environments. The project is currently undertaking a study to quantify fuel consumption savings resulting from biofouling management measures that are readily available and highlight their role in the overall reduction of GHG emissions in the short term.

Blue Solutions

IMO has partnered with the Partnerships in Environmental Management for the Seas of East Asia (PEMSEA) to undertake the preparatory project and to develop a full project proposal to reduce maritime transport emissions in East and Southeast Asian countries with the support of the International Climate Initiative (IKI) of Germany.

This partnership is the first step towards an ambitious Asia Maritime Transport Emissions project (known as the Blue Solutions Project), which will aim to support East and Southeast Asian countries in identifying opportunities to prevent and reduce transport emissions. The full-size project, once approved, will target reduction of GHG and other pollutant emissions from ships within ports, and from hinterland transport through energy efficiency improvements, optimized processes and innovative technologies (blue solutions), with the aimed start of the project by early 2022.

FIN-SMART

The IMO-EBRD-World Bank co-led Financing Sustainable Maritime Transport (FIN-SMART) Roundtable is a platform for regular dialogue among key maritime stakeholders, especially the financial institutions, on addressing the financial challenges related to the transition of shipping to a more sustainable and resilient future, with a focus on maritime decarbonization financing.

The Roundtable and its various workstreams, launched in 2020, have been providing a platform between Member State representatives, International Financial Institutions (IFIs), representatives of private banks, other key maritime stakeholders to identify maritime decarbonization investment risks, opportunities and potential financial solutions, with a special emphasis on financing needs and options in developing countries, particularly LDCs and SIDS.

NextGEN

IMO and the Government of Singapore have launched in 2020 the Green and Efficient Navigation (NextGEN) initiative, which aims at facilitating information sharing and collaboration on maritime decarbonization initiatives and projects, presenting an opportunity to provide an online platform of collaboration across the maritime value chain. The online Portal aims seek to facilitate information sharing among stakeholders, identify opportunities for and gaps in maritime decarbonisation, and build networks and platforms for collaboration.

2.2. Funding and Financing Mechanisms

The innovative solutions and technologies required to decarbonise the maritime industry require investment and financing to advance and implement them. Both the private and public sector will need to play a significant role in supporting this, but the uncertainties associated with novel technologies and innovative systems and processes are a barrier that everyone needs to help overcome.

2.2.1. Traditional maritime lending and financing instruments

Financing maritime assets is usually split into two main areas of asset financing: ship finance versus port and infrastructure finance. While both share the features of a capital intensive and long-lived asset life cycle, they differ in almost everything else from their financial structures and financing instruments to their sources of finance and funding.

Ship finance is quite unique and has some distinctive features that are hardly found in other market segments. Not only the ships are mobile and their owners free to choose their own jurisdiction, but shipping markets are fragmented, cyclical and volatile and complemented by second hand and chartering markets, making the ship itself a highly speculative asset.

As a result, much of shipping finance is geared towards small companies, usually in terms of a combination of lease, equity and debt finance, the latter is often structured as a mortgaged-backed loan. Corporate loans and capital market financing are mostly geared towards large shipping companies, but Initial Public Offering (IPO) financing remains still a very minor player in ship finance. Most recently, special structures such as Project/Receivables financing and Limited Partnerships have become popular, but they are geared towards operating or leasing ships rather than investing in them.

Unlike ship finance, port and energy supply finance sits comfortably within the broad setup of infrastructure asset finance. However, a distinction is often made between basic infrastructure versus operational infrastructure with the former usually falling under public ownership while the latter operating under some form of private sector ownership. Such a structure has given rise to mixed financing instruments with Public-Private Partnership (PPP) and Project Finance instruments becoming the most dominant route over in port and energy infrastructure finance. Where private financing is used, IFIs and national infrastructure banks have been the traditional providers of debt financing, but there has been a surge of institutional and infrastructure investor financing for ports and energy supply over the past two decades or so.

2.2.2. Green financing in shipping and ports

Investment in green and decarbonisation technologies represents an upfront expense and a new type of investment which may not be readily supported by traditional maritime financing instruments. To overcome this, specialist green financing instruments have been set-up including sustainability bonds, social bonds, green loans, and ESG (Environmental, Social and Governance) linked loans.

In shipping and ports, several multilateral initiatives have been set up over recent years, for instance the EIB Green Shipping Financing and the IFC-GEF joint Green Shipping Investment Platform. Other multilateral development banks are also building up support for special financing programmes for low carbon and sustainable shipping but have so far focused on project-specific financing. Other proposals that have been put forward include the $5 billion International Maritime Research Fund (IMRF) to support research and development for low and zero carbon fuels and the Pacific Blue Shipping Partnership (PBSP) aimed at raising $500m to make all shipping in the Pacific Ocean carbon neutral by 2050 [See Box 1].

At national levels, many Governments have set up specific financing programmes with the objective of reducing the environmental impact of shipping and maritime-related activities. Examples include Singapore's Maritime Green Initiative, South Korea's 2030 Green Ship-K, and the EU's Green Shipping Fund. From the supply side, the industry has also stepped up its efforts to align its financing with the global targets of maritime decarbonisation. Initiatives such as the Poseidon Principles while representing a welcome step towards integrating shipping in green and ESG financing criteria, are actually more restrictive and place additional burden particularly to small operators and those from developing countries.

2.2.3. Innovative finance and maritime decarbonisation

Despite the above efforts, the financing of maritime decarbonisation is still markedly small and lagging other sectors and industries such as EV car financing. Most importantly, it is yet to capture the far-reaching impacts of the decarbonisation agenda, which challenges traditional assumptions about maritime asset valuation and requires a deep understanding of the technologies and business models that underpin future maritime green assets. Specifically, the need for alternative energy sources, new ship design and operation, and new business models and supply chain structures will transform maritime finance towards high upfront capital costs (CAPEX) asset financing against lower costs of operations (OPEX). This naturally moves the maritime system into the domain of long-term, ESG and responsible financing.

Successful experience in PPP financing of ports can provide a good benchmark for green ship finance. For instance, risk, profit and revenue sharing agreements in PPPs can be replicated in low-carbon shipping and ship chartering as was recently demonstrated by initiatives such as the Sustainable Shipping Initiative (SSI) and the 'Save As You Sail' (SAYS) scheme [See Box 2]. Additional targeted finance innovations will be required to support maritime decarbonisation, for instance through blended finance and gap funding [See Box 3]. Innovative solutions should also enable public and private finance to come together, for instance by supporting diversified portfolios where public finance can provide a risk buffer to attract institutional and private investors.

Contingently recoverable grant resources also reduce the risks and upfront costs associated with the exploratory phase of capital-intensive projects. These have been particularly used in developing commercial extractive-type resources. This instrument has been used to incentivise geothermal projects in the Organisation of Eastern Caribbean States (OECS) and offers some useful concepts to other emerging sectors, including the blue economy [Box 4].

Box 1:

Enhancing NDCs with ocean-based climate action mitigation by financing by reducing greenhouse gas emissions from marine transport and increasing well-sited, environmentally responsible ocean based renewable energy.

Eight Pacific SIDS, Fiji, the Marshall Islands, Kiribati, Samoa, Solomon Islands, Tonga, Tuvalu, and Vanuatu announced the Pacific Blue Shipping Partnership1 that is committed to reducing the use of fossil fuels in domestic shipping by 40 percent by 2030 with a view to a 100 percent carbon-free marine transport sector by 2050. This ambition will be achieved through a 10-year program of large-scale investment in retrofitting and vessel replacement.

The sector currently faces a range of challenges including the prevalence of old, inefficient, and under maintained vessels, and a lack of supporting modern infrastructure including ports and facilities for bunkering, shipbuilding, maintenance, and repair. This will also impact the transport cost as fuel cost represents 40 to 60% of a ship's operating costs. Transportation and mobility are cross-cutting issues central to the sustainable development of the Pacific.

In consultation with multi-lateral and bilateral development partners, the PBSP is developing a blended finance package exceeding US$500 million to enable a 10-year initial work programme (2020–2030) focused on three key priorities. This partnership involves the following:

- Large-scale infrastructure transformation, inclusive of both short-term ferry upgrades and high-ambition projects to increase port/jetty access for underserved populations around the region.
- Small-to-medium scale enterprise development to ensure the private sector is provided with appropriate finance to meet regional maritime transport needs.
- Capacity building, analysis, and Research & Development efforts to deliver long-term success of the Partnership for the region.

[1] https://mcst-rmiusp.org/index.php/projects/current-projects/pacific-blue-shipping-partnership#:~:text=Summary,a%2040%25%20reduction%20by%202030.

Box 2:

Innovative financing Solutions to Overcome Split Incentive Risks

Split incentive risks are a major barrier against long-term decarbonisation investments. A large proportion of international shipping runs on tramp and ship chartering be it on a voyage, time, or bareboat (demise) basis. Under traditional charter arrangements, ship voyage and operating costs (OPEX) including the cost of bunker fuel are often borne by charterers, therefore providing little incentives for owners to invest in CAPEX energy-efficiency and other technical improvements that do not accrue long-term profits or savings.

To overcome split-incentive barriers, innovative contractual and financing mechanisms can be used to share the risks and benefits among the parties involved. For ship chartering, long-term time or bareboat charters can be used as an incentive for operators/charters to invest in upgrading their chartered fleet knowing that they can save costs on fuel that can recoup the investment outlay before the end of the charter term. This investment model has been used by Maersk Line on its long-term chartered fleet; but can also work for small owners and operators assuming new contractual and legal provisions are included in standard charter parties.

For voyage and short-time charters, an 'owner compensation' or CAPEX clause can be introduced in the charter party whereby the owner is compensated through amortized contributions from the charterer against the cost of investment in energy-efficient upgrades. Another provision is a profit-sharing mechanism where both the owner and the charterer agree on a profit-sharing formula linked to the spread price between conventional and alternative fuels over the course of the charter.

A similar scheme was introduced by the Sustainable Shipping Initiative (SSI). The 'Save As You Sail' (SAYS) scheme is designed to share fuel savings from investment in retrofitted technologies between the lenders, owners, and time-charterers. Under SAYS, the owner takes out a loan with a finance provider and agrees a regular fixed SAYS fee with the time charterer on top of their charter rates. The additional income for owners represents a share of the cost savings that the charterer makes, thereby covering the owner's SAYS loan payments and potentially generating profit to the owners during and after the loan period.

Most recently, some of the world's largest bulk cargo owners and traders have signed up to the Sea Charter, a framework that establishes a common baseline reporting and disclosing methodology to allow their chartering activities to be aligned with global climate goals and the IMO decarbonisation Strategy.

Box 3:

Innovative Financing for Shore-based Electricity Supply

Cold ironing, or the provision of shore-based electricity, allows, ships to turn off their auxiliary engines while berthing in ports and other terminal facilities. However, only a small amount of shore power connections exists in developing countries, and even a smaller amount in SIDS and LDCs. This may be due to a combination of factors most notably the requirement of adequate power supply installations and connections at the port which are not only costly on their own but also constrained by electricity supply and related energy costs.

Several studies and case references point towards the cost of cold ironing installations to be reasonably recouped within a 5-to-8 year pay-back period, making it an attractive investment for many ports and terminal operators. Assuming the power supply is drawn from renewable sources rather than combustible fuels, then the major challenge would be restricted in the supply and cost of the electricity, the latter could be a binding constraint especially for small island developing ports.

In the Pacific, the SIDS countries in the region naturally endowed with cost-competitive renewable energy resources; yet most of these countries are heavily reliant on diesel for power generation. This has resulted into higher emissions and electricity tariffs. Recognising the need to structurally shift power generation from diesel to renewable energy, the Pacific SIDS countries have established aggressive renewable energy targets, sometimes up to 100%. However, the lack of access to adequate funding has limited the uptake of renewable energy.

In order to fill the financing gap, the Asian Development Bank (ADB) has been running since 2017 the Pacific Renewable Energy Investment Facility, a $750 million blended co-financing instrument designed to support a series of renewable energy projects in 11 small Pacific Island Countries (PIC-11) till 2024.

As of late 2020, a total of $200 million investment[2] has been approved for various projects, two of which have the requirements of providing offshore power supply to cold ironing facilities in island ports.

Source: Adapted by Consultant from ADB project's sheet

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2 See the latest Interim Report outlining approved and pipeline projects under this facility: https://www.adb.org/sites/default/files/project-documents/49450/49450-004-dpta-en.pdf

Box 4:

OECS Sustainable Energy Facility

The Sustainable Energy Facility (SEF) for the Eastern Caribbean is a financing package of Inter-American Development Bank (IDB) loan; Global Environment Facility Trust Fund (GEF) grant; and Clean Technology Fund (CTF) contingently recoverable grant or loan resources, provided through the IDB to Caribbean development Bank (CDB) as executing agency. It funds technical assistance and investments in Renewable Energy and Energy Efficiency.

SEF has three components:

1. EE investments,

2. Regulatory framework, institutional strengthening and capacity building, and

3. Renewable Energy - intermittent and base-load.

The US$71.5 million loan and grant package has funded renewable energy and institutional capacity projects in six Eastern Caribbean countries. The goal of the Sustainable Energy Facility3 (SEF)-Expanded for the Eastern Caribbean is to contribute to the diversification of the energy matrix in five Eastern Caribbean Countries: Dominica, Grenada, St. Kitts and Nevis, St. Lucia, and St. Vincent and the Grenadines.

SEF-Expanded is a comprehensive effort to reduce carbon emissions, lessen dependence on fossil fuels, and minimize the cost of power generation and electricity tariffs by promoting geothermal power in the five Eastern Caribbean nations.

Most of the resources under SEF are for supporting geothermal energy (GE) development, mobilised under CDB's GeoSMART Initiative. GeoSMART initiative provides resources to finance pre-investment activities to unlock the investments

[3] https://businessviewcaribbean.com/idb-expand-sustainable-energy-facility-eastern-caribbean/

2.3. Other Supporting Systems and Services

2.3.1. Maritime informatics and digitisation

Over the past decade or so, there has been a huge leap in digitisation technologies and their applications across sectors, including in shipping and ports. Digitisation technologies in the maritime sector include robotics and automation currently mostly applied in ports and sea-shore interfaces, Maritime Single Windows (MSW) to share and integrate standardised maritime information and processes, Artificial Intelligence (AIS) with shipping applications such as the Automated Identification Systems (AIS), Internet of Things (IOT) where Radio-Frequency Identification Systems (RFIDs), sensors and remote device technologies are used to connecting various components of the maritime chain, ledger and blockchain technologies increasingly used in shipping contracts and payment systems, as well as other technologies such clouds logistics, next generation wireless, additive manufacturing and augmented reality.

Many of these technologies are and can be used to accelerate maritime decarbonisation, for instance big data and integrated analytics for improving operational performance and optimising energy use, electronic sensors for tracking and monitoring energy use and GHG emissions, and single window platforms for standardising and sharing data and information on maritime decarbonisation and environmental compliance.

Several maritime digitisation forums and open innovation challenges have been taking place over the past decade, prompted by the emergence of a new type of accelerators and incubators in the maritime digital space. Open innovation models provide a platform for collaborative innovation, networking, acceleration and diffusion, and similar efforts and structures can be used in maritime decarbonisation to help establish a base for collaborative and inclusive innovation and accelerate the transition towards low or zero carbon shipping.

2.3.2. Business models and operations

One of the areas that have not attracted enough attention with regards maritime decarbonisation targets is the economic and business model underpinning maritime operating and related systems. Unlike other fields where the agenda and targets of climate change often include fundamental changes to business models and operations, including developments in circular economy, product standards and servitisation.

The global shipping and port industry has not been at the forefront of these developments but is beginning to respond to the strong signals from markets, investors, lenders, cargo owners and customers. It has since become clear that technology and product innovation alone may not be sufficient to overcome the decarbonisation challenge, and that new business models and innovative solutions are needed to accelerate the path to a sustainable and decarbonised shipping industry.

2.3.3. Government support and policy guidance

In many countries, governments and public sector agencies are the main funding source for R&D and innovation programmes. They can also be a major maritime customer that can accelerate the demand for maritime decarbonisation services through public procurement.

In addition, governments often provide the policy frameworks and regulatory incentives that accelerate and streamline the development and commercialisation of innovation products, technologies and processes. Governments also engage in a parallel regulatory framework that regulates and monitors safety, privacy and liability issues of new products and technologies. Achieving these outcomes will require policy and regulations that enable flexible approaches to research and innovation.

2.3.4. Decarbonisation skills and training

As the global maritime sector transitions to net-zero, there will need to be a corresponding transition in the skills of the workforce, and a supply chain to match. This requires innovation in new skills and training to be in line with new carbon technologies, operating systems and business and supply chain models. If not addressed timely or adequately, the requirement of trained technical and managerial personnel in maritime decarbonisation could be a barrier to its long-term success.

Currently, scant research has been undertaken on the skills' requirements for future fuel technologies, financing mechanisms, business models and management systems that will be needed to transit to and achieve decarbonisation targets. New skillset, technical standards and training programmes will be required to educate and train seafarers, bunker traders, port workers and other workforce specialities across the decarbonised maritime supply chain.

2.3.5. International development and coordination

As international standards and regulations for maritime decarbonisation expand, this opens significant opportunities for international collaboration in innovation projects and activities. Conversely, risks and barriers could arise from restrictions placed on access to and deployment of innovation products and services. Given the global challenge of climate change and the international nature of maritime operations and services, collaborative and knowledge sharing platforms should be put in place to promote innovation collaboration and inclusion.

The process of developing new maritime regulations, standards and guidelines provides a unique platform for starting and diffusing co-innovation work. Recent examples include the development and diffusion of collaborative innovation in the MSW and e-navigation areas.

3. Barriers to Technological Progress and Innovation Diffusion in Maritime Decarbonisation

The above review shows that there exist various pathways for maritime decarbonisation, each with different risk profile. Because innovation is a process, the risks and barriers to innovation may occur at different stages of the innovation process from concept generation and mobilisation to product diffusion and implementation Some risks such as interface risks may be exclusive to or accentuated in a single stage of innovation, while other risks such as financing risks could be spanning across multiple phases of the innovation process.

For developing countries, SIDS and LDCs, the barriers to innovation may take on additional dimensions due to several factors including, but not limited to, insufficient financial resources, inadequate R&D frameworks, and lack of technical and technological capacity.

Several seminal works on innovation and development outcomes have emphasised the role of innovation in bridging the gap between developing and developed countries. This role is centred around the ability to identify, develop, absorb and adapt to new innovations and technologies, which brings to light the need to identify and address the risks and barriers to innovation and flow of knowledge in developing countries, particularly SIDS and LDCs.

In identifying and addressing those risks and barriers for maritime decarbonisation, the focus should be on mitigating if not eliminating them because the transformational process towards zero or low carbon shipping should be inclusive if we are all to achieve the same outcome.

3.1. Categorising Risks to Innovation in Maritime Decarbonisation

3.1.1. Technology risks

New technologies are expected to be deployed in the medium and long term. Those would include the development of technologically uncertain concepts and products, such as hydrogen storage, ammonia mass transportation, or direct air carbon capture and storage, which have not been tested or deployed at scale before. Throughout the innovation process, technology risks may materialise in different ways, for instance in areas such as technological failure, discontinuity, unreliability and interoperability.

To manage technology risk, organisations often carry out experimental trials and pilot projects on a small scale to test the effectiveness of a technology or a product against the above risks. Many of the greatest innovations within and outside the maritime industry started as small-scale research projects, speculative designs, concept tests and/or market experiments that ended up revolutionising the industry and the marketplace.

Technological risks may also be categorised according to the perception and management of the risks inherent in the typology of innovation (incremental, sustained, disruptive or radical)., with the level of risk (and return) intensifying as one moves from incremental to radical innovation.

3.1.2. Economic and market risks

Regardless of the technology adopted, the costs associated with decarbonising the industry remains uncertain and will be influenced by market factors such as fuel prices, costs of new asset and equipment type and the availability of supply, storage and bunkering infrastructure.

At the same time, any innovative low-carbon solution must meet the needs and demands of the marketplace, including for specific and regionally disadvantaged shipping and port markets such as those of SIDS and LDCs. Unless innovation is in line with market and economic forces, it is unlikely to succeed in the marketplace.

Market barriers to maritime decarbonisation also include the risks of carbon leakage, loss of competitiveness and innovation capture given the global but fragmented nature of international shipping and operations. As we move together towards a shared goal of a globally decarbonised maritime sector, policies and safeguards must be put in place to promote technological neutrality and protect against carbon leakage.

3.1.3. Financial and financing risks

Innovation requires financing of technology and product development, testing, demonstration, implementation and diffusion. The interaction between technology risks and market risks creates uncertainties for operators, lenders, investors and other financing or funding organisations.

On their own, many segments and operators within the maritime industry, particularly small shipowners and ports, do not have the financial resources to fund innovation and R&D projects. However, by collaborating and pooling resources they can generate joint funding and secure additional financing from lenders, governments and other funding agencies. In the same way as shipping alliances and consortia have been operated over decades, it is possible to set up purpose-built collaborative structures for maritime decarbonisation where the risks and rewards of innovation are shared among the consortia or alliance members.

Elsewhere, the choice between funding incremental and sustained innovations versus funding disruptive and radical innovations is further complicated by the difficulty to square market and demand risks, especially in relation to investment trade-offs and pay-back periods for various technology and innovation types and structures.

In the short-to-medium term, investment and financing risks materialize through exposure to stranded assets embedding discontinued, redundant or depreciated technologies. Lenders and investors will steer away from exposure to innovations and technologies that are discontinued or not aligned with maritime decarbonisation targets. In the medium to long run, these risks could materialise through exposure to new technologies and products that manifest themselves through uncertainties over operational interoperability or market scalability.

3.1.4. Interface and coordination risks

To achieve a synchronised transition to low and zero carbon shipping, coordination of innovation and research would be required across markets and stakeholders. At the same time, innovation in low carbon shipping solutions may not be possible if it is not supported by interoperable and harmonised investments in bunkering facilities, terminal storage, onshore power, and other port and terminal infrastructures

Coordination risks also include interface, split-incentive, intellectual property rights, privacy and confidentiality risks. Such risks often arise where innovation is developed, tested, managed and commercialised through decentralised and open network structures. Those risks are usually dealt with through appropriate contractual arrangements but also by building trust and transparent collaborative structures between network partners.

Innovation can also benefit from coordination between maritime operators, countries, and supply chain stakeholders to avoid duplication of efforts and maximise positive outcomes. Open innovation and knowledge sharing can also support synergies and scale economies while pooling resources and reducing overall risk and costs.

3.1.5. Research-Policy interface risks

A salient innovation risk in maritime decarbonisation is the potential disconnect between the innovation and R&D community on the one hand and market and policy decision makers on the other hand. Sometimes, the outcome and evidence from innovation and scientific research are not taken on board by policy makers and market operators. Some other times, innovation and R&D projects at universities and other research institutions may not always be aligned with the need of the marketplace or the orientations of policy makers.

To reduce research-policy interface risks, the interaction between scientists and researchers on the one hand and market operators and decision-makers on the other hand must focus on creating knowledge that is applicable and potential ready for use. In practice this means that information is produced in line with end-users' needs with the most robust innovation and technology being promoted to use for decarbonisation policies and implementation strategies.

At the same time, the research and scientific community should be given the freedom and flexibility to examine and develop innovative solutions and technologies even if they are not initially commercially feasible. Innovation is not a one-way knowledge transfer only, but it requires policy and market players to also innovate in new financing mechanisms, business models and policy frameworks that can promote and diffuse new products and technologies.

Recent efforts in the development and delivery of R&D projects show that innovation and research should be incorporated into a participatory process of agenda setting. An integrated approach is therefore required in order to bridge divides within and between knowledge and practice communities in a coordinated and collaborative effort towards achieving maritime decarbonisation targets. As shown further below, such participatory process is not always used in the current innovation and R&D efforts for decarbonising maritime transport.

3.2. Implications for Developing Countries, SIDS and LDCs

While most of the above innovation risks are also applicable to developing countries, some would have higher impacts than others. This is particularly the case of SIDS and LDCs who face harsher environmental challenges while also suffering from distinct challenges in developing, financing and managing R&D projects as well as accessing innovative knowledge and participating in the innovation process and its outcome.

To capture some insight from maritime stakeholders in SIDS and LDCs about their perceived risks and barriers to innovation in maritime decarbonisation, a quick two-stage survey was carried out where 48 respondents[4] out of an initial sample of 102 target participants were asked to rank individual risk issues in the medium-to-long-terms based on a 10-point scale. For each of the 10 barriers or risks identified, the average score reported by all respondents was computed to rank risks from highest to lowest probability for both medium-term (up to 2030) and long-term horizons (up to 2040) to capture changes in the perceived level of risk across horizons.

The barriers identified in the survey denote the risks and uncertainties related to the development, testing and deployment of the innovative tools and technologies necessary for the implementation of maritime decarbonisation targets as set by the IMO Initial Strategy. Those span broad categories of innovation risks such as technology, market, financing, and coordination risks, as well as additional and specific barriers that have been identified and by survey respondents, for instance barriers stemming from the difficulty to access open knowledge and innovation, the lack of technical and management capacity, and the perceived risks and costs of innovation.

***Table 2**: Ranked risks to innovation in maritime decarbonisation in medium-to-long-term horizons (Consultant)*

Innovation Barriers	Perception (2030 rank)	Perception (2040 rank)
Knowledge transfer barriers and access to innovation networks	10	9
Investment, funding and financing barriers	9	8
Technology risks and barriers	8	5
Lack of collaboration and interface coordination	7	3
Lack of technical and management capacity	6	4
Lack of adequate innovation policy, including on patents and licences	5	4
Inadequate assistance from government and private sector	4	6
Market and economic risks	3	4
‘Perceived’ risk of innovation	2	3
Regulatory uncertainties and risks	1	2

[4]: See Appendix 1 for the list and affiliation of survey participants.

The rankings from Table 2 reveal some interesting results provide some interesting insights into the specific innovation barriers faced by developing countries, SIDS and LDCs in the context of maritime decarbonisation.

The most significant barrier is the lack of access to open knowledge and innovation, which supports the above discussion on the dominance of closed and centralised innovation networks for maritime decarbonisation. This was followed by funding and financing barriers reflecting the scarcity of financing schemes and mechanisms in developing countries, SIDS and LDCs for R&D and innovation in maritime decarbonisation and green technology.

The top two barriers are allocated persistent high-ranking scores in both the medium and short runs. Conversely, technology barriers while perceived of high risk in the short and medium term are allocated a medium risk ranking in the long run as they become more mature and reliable to be deployed at large scale.

At the other end of the scale, the least significant barrier to innovation is the regulatory risk implying that respondents do not foresee a major regulatory change or deviation from maritime decarbonisation targets in the medium or long run, but also underlines a wider support of and adherence to the decarbonisation agenda as set in the Initial Strategy.

Also low in the risk ranking is the perceived risk of innovation. This ranking which may be surprising at first breaks the myth that maritime organisations in developing countries, SIDS and LDCs are reluctant to innovate or resistant to innovative change. Instead, it is the barriers to accessing knowledge sharing and participating in innovation networks that makes it difficult for them to intensify their innovative efforts in maritime decarbonisation, particularly if coupled with the lack of sufficient funding and adequate financing.

Other barriers which have been perceived of high risks include the lack of capacity to administer and manage innovation and the inadequacy of existing innovation frameworks, especially around licences and intellectual property rights. Those barriers may be overcome through targeted programmes of technical assistance and institutional development.

3.3. Region Specific Barriers

While the above risks and barriers are presented uniformly, different regions (and even specific countries within the same region) may phase different and additional challenges to support their maritime decarbonization efforts.

To capture some insight from maritime stakeholders in specific SIDS and LDCs, 8 follow-up interviews were carried out with selected survey participants to examine risks and barriers at regional level. Feedback from these interviews shows regional differences both in terms of innovation challenges and priorities:

- Within the Caribbean the main barrier puts forward seems to be that of coordination and cohesion among the region's maritime authorities and market players. The shipping fleet in the region is already too old, but there is an urgent need for further awareness about the maritime decarbonisation strategy and a strong harmonisation of innovation policies at national and regional level.

- In the Pacific Islands Countries (PIC), the awareness of decarbonisation requirements and challenges seem to be on the top of many policy agendas and there seems to be a concerted effort to tackle those challenges including exploring the possibilities of exploring the use of abundant solar energy as an alternative source of renewable and carbon neutral shipping and port operations. For now, policy makers and operators in the region are channelling their efforts into exploring ways to establish funding and financing schemes for maritime decarbonisation.

- In East and Southern Africa, the decarbonisation challenges and investment needs seem to be concentrated more on the shore side rather than the shipping side. However, despite a few pilot projects being currently considered, both the lack of visibility over alternative fuel sources and the fragmentation of the shipping and port industry in the region remain the key challenges in the short-to-medium term. For example, some ports in the region already have shore powered electricity supply, but those are hardly used by ship operators who find the price of electricity supply too exorbitant to shift from diesel-based solutions or whose ships are simply not retrofitted to that effect.

- Additional feedback from interviewees re-emphasised the need for open participation innovation networks and tailored financing instruments to the specific needs of SIDS and LDCs regions.

4. Innovation Models and Processes Fostering Maritime Decarbonisation

To achieve a globally decarbonised maritime network by or before 2050, an intensification of the innovation process must take place over the next few years and decades. To do so, a better understanding of the innovation models and frameworks that underpin maritime decarbonisation is required. Equally, a deeper assessment of the process of innovation inclusion, diffusion and knowledge sharing in the context of current maritime decarbonisation efforts is needed to shed lights on any potential gaps especially for developing countries, SIDS and LDCs.

4.1. Innovation Models and Networks

4.1.1. Evolution of innovation models and typologies in the maritime sector

One of the main difficulties in the study of innovation is the lack of clarity and consensus on what innovation means, the process by which it takes place, and the mechanisms that underpin its deployment and diffusion. The study of innovation also requires an understanding of the different models that underpin the frameworks and processes for conceptualising and advancing innovation.

While innovation may have different views and dimensions, much of the academic and professional literature converges on the need to treat innovation as a process, rather than a simple event or outcome. As the innovation process involves at least four steps or stages: idea generation and mobilisation, advocacy and screening, testing and experimentation, and diffusion and implementation; one of the difficulties of studying innovation in the context of maritime decarbonisation is that the various technologies and pathways are at different stages of the innovation process, while the decarbonisation target requires that all pathways converge towards the same innovation outcome of low or zero carbon emission by 2050.

Historically, innovation and technological progress have been the leap driver in maritime firms' and sector's productivity and competitiveness, such as when shifting from sailing ships to steamships, transiting from conventional to containerised operations, or replacing manual processes with electronic and automated systems. Yet, the maritime industry is perceived to display a lesser propensity to innovate compared to other industries. This may be due to the infrequency of radical and distributive maritime innovations over the past few decades.

Furthermore, disruptive innovation which challenges traditional methods and incumbent businesses in low-end markets or creates new market footholds that did not exist before, has been sporadic in the maritime sector compared to other transport sectors such as railways and aviation. Similarly, radical or breakthrough innovation, which combines a revolutionary technology with a new business model, has been particularly scarce since the advent of containerisation. There is also empirical evidence showing that the industry's productivity growth was mostly found in scale (size) and technical (cost) efficiencies and less by innovation and technological change.

There is also a wide view that innovation in the maritime industry is somewhat conceived and diffused through closed networks. This may be true for past innovation which followed a linear sequence of functional activities, either as technology push from R&D and scientific discovery, a market pull prompted by the needs of the marketplace, or a coupling model combining both push and pull sequences. However, since the 1990s, many maritime innovations were carried out as an interactive or integrated process based on connecting maritime businesses with external research institutions, supply chain partners and the broader marketplace.

The latest generations of innovation models advocate networking and openness. Network innovation emphasises that innovation is shared and accelerated through a distributed network of alliances, cooperation and reciprocal joint ventures beyond the supply chain. The ultimate form of network innovation is open innovation which extends the scope of innovation to a decentralised and open network, including individual users and even the general public. The maritime industry has only recently recognised the importance of network innovation, especially in areas related to electronic processes and digitisation, supply chain risk and security, and latterly environmental management and decarbonisation.

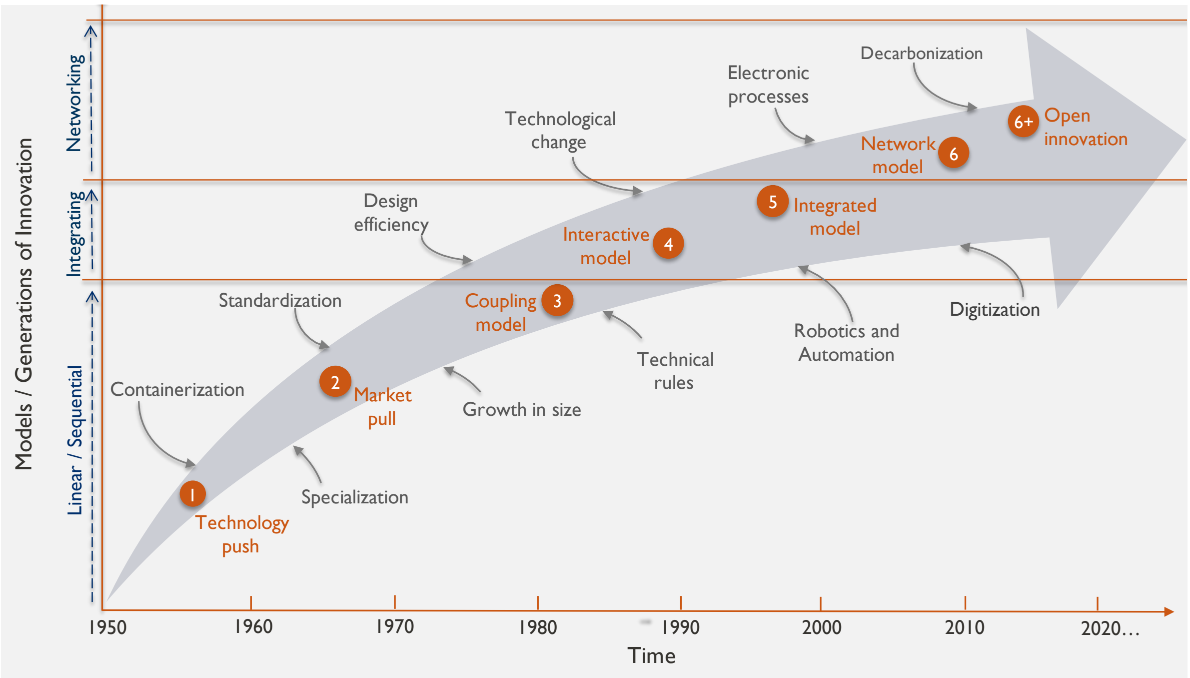

***Figure 1**: Innovation Models and Developments in the Maritime Industry (Consultant)*

4.1.2. Network Innovation and Maritime Decarbonisation

To foster and harness innovation, organisations increasingly collaborate with external partners and other actors. By pooling resources and coordinating innovation efforts, firms can stimulate synergies and generate network effects and externalities. As firms, organisations and even countries realise that links and networking become as important as the actual production and ownership of knowledge, innovation networks have evolved from being just network structures of innovation to becoming innovation models in their own rights. As such, the network structure and linkages between participants in the innovation process provides a novel way for conceptualising and analysing innovation including in the maritime field.

One of the main challenges for decarbonising maritime transport is that different technological options and solutions will be needed to achieve a wider uptake and diffusion. Even where all pathways are considered, maritime decarbonisation cannot be shaped by technology alone but is also dependant on market forces, policy and regulation. Given these challenges, a suitable structure is needed to stimulate tractions, share knowledge and generate the transformational innovation needed to achieve the transition to low or zero carbon shipping.

Innovation networks are vital organisational structures that support knowledge sharing and interaction among network partners. The focus is on structures that form beyond a single R&D project and on interplay synergies that take place outside a single firm or organisation.

Structurally, innovation networks may be organised according to a product, technology, standard, sector, supply chain, or geographical dimension or a combination of some of or all these emphases and dimensions. Institutionally, innovation networks may be organised in opposing ways, for instance centralised vs. decentralised networks, close vs. open networks, and publicly funded vs. privately funded vs. public-private networks.

Product or technology networks aim at sharing knowledge and learning about a new product, process or technology including pilot and demonstration projects. Examples of product or technology innovation networks for maritime decarbonisation include Sea LNG, the Green Maritime Methanol Consortium, the Castor Joint Development Programme for Ammonia-fuelled tanker, and the HyEng Corporation for Marine Hydrogen. Syndicated networks exploring or offering novel financial products may also be classified as technology innovation networks; see for instance the IFC-GEF joint Green Shipping Investment Platform (GSIP) and the EIB's InnovFin Energy for Demonstration Project.

A relevant branch of product and technology networks is the standards' innovation networks, the latter collaborate on exploring and developing standards around new or emerging innovations and technologies. Mandatory standards for maritime decarbonisation include the IMO's EEDI, CII and EEXI for measuring and managing GHG emissions. Additional voluntary standards include the IAPH ESI (Environmental Ship Index) and the ISO's 50001 (Energy Management). Similarly in the financial sector, innovative ESG and green financing products in shipping and ports are being systematised and standardised such as in the case of the Poseidon principles and the shipping criteria of the Climate Bonds Initiative (CBI). Expert forums such as the International Advisory Panel (IAP) on maritime decarbonisation, formed by Singapore's SMF and MPA, also aim to explore standards for innovative decarbonisation products.

Industry and supply chain networks shift the focus away from product or technology features to the broader sector and supply chain dimensions. Industry networks are collaborative structures aimed at supporting innovation within a particular sector or industry, whereas supply chain networks focus on leveraging value chain partnerships where co-innovation and complimentary tooling are diffused across the supply chain. Examples of industry and supply chain innovation networks in maritime decarbonisation include the Maritime Technologies Forum (MTF), Mærsk Centre for Zero Carbon Shipping, UNEP's Sustainable Clean Port Programme (SCP) and KTN's Decarbonising Ports and Harbours Innovation Network.

Regional or geographical innovation networks seek to link spatial and agglomeration clustering with innovation and knowledge sharing. These networks evolve around innovation districts or hubs to provide proximity and access to universities and research organisations, finance and investment institutions, and other support structures such as accelerators and incubators.

Purpose-built green maritime innovation clusters, such as Norway's Maritime CleanTech and North America's Blue Sky Maritime Coalition, are uncommon. Instead, maritime decarbonisation clusters tend to be part of generic spatial clusters set up at national, regional or city levels. Some recently established innovative hubs use a hybrid structure for instance by combining clustering both spatially and technology, such as in the case of the Nordic Green Ammonia-Powered Ship (NoGAPS).

A particular application of spatial innovation clustering is the national R&D programmes for green shipping and maritime decarbonisation. These programmes are established in order to strengthen and leverage a country's maritime position and advance innovation and research in line with the country's strategic and priority needs. Among these, worth noting Singapore's Maritime Innovation and Technology (MINT) Fund, Norway's Green Shipping (GSP), the UK's Maritime and Research Innovation (Mar-RI UK), Japan's Green Innovation Fund, the US Research Projects Agency-Climate (ARPA-C) fund, and the EU's Horizon 2020 and subsequent Horizon Europe, EIT and Innovation Fund and particularly its Zero-Emission Waterborne Transport Partnership.

National R&D programmes are criticised because of their centralised and closed structures particularly where participation in the network is open to national or resident entities only. Even where participation is open to outside entities, co-innovation and access to shared knowledge is only available to network members who actively participate in multiple research calls and work packages. This obviously limits cross-synergies and knowledge sharing and has given rise to alternative public-private partnerships where network partners are able to access knowledge creation and learning even if they are not participating in a research project or programme. Modern R&D programmes are designed as a decentralised network with no dominant partner leading to a better dissemination of knowledge among partners.

Next to national R&D programmes, countries can also establish or be part of collaborative international schemes for R&D in maritime decarbonisation and green shipping. While some programmes involve bilateral collaboration, e.g., the UK-Norway Sustainable Finance Action Platform (SFAP), most schemes are multilateral in scope. Institutionally, these programmes sit either within established regional innovation and R&D structures such as the University of the South Pacific and its Micronesian Centre for Sustainable Transport, or as part of institutionalised international educational networks such as the IMO's World Maritime University (WMU) and its regional networks, the joint EU-IMO GMN Maritime Technology Cooperation Centres (MTCC) and the UNFCCC (United Nations Framework Convention on Climate Change) Climate Technology and Centre Network Technology (CTCN).

A relatively new addition to maritime innovation networks is the open network which has come to prominence over the past decade as more firms and organisations come to embrace the concept of open innovation. Since then, several network platforms and marketplaces for open innovation have been established. Existing open innovation networks have emerged around international partnership and advocacy initiatives such as the Getting Zero Coalition (GZC), Mission Innovation, the Green Knowledge Growth Platform (GKGP), the Financing Sustainable Maritime Transport (FIN-SMART) forum and the Global Industry Alliance to Support Low Carbon Shipping (Low Carbon GIA). The latter is a public-private partnership initiative started under the framework of the GEF-UNDP-IMO Global Maritime Energy Efficiency Partnerships (GloMEEP) project, which aims to collectively identify and develop innovative solutions to address common barriers to the uptake and implementation of energy efficiency technologies, operational best practices and alternative low- and zero-carbon fuels. Since the conclusion of the GloMEEP project, the Low Carbon GIA has been operating under the framework of the GreenVoyage2050 Project.

The IMO-UNEP Maritime Zero-Low Carbon Innovation Forum has a great potential to further expand the participation and reach of open networks for maritime decarbonisation and make innovation more inclusive and accessible to developing countries, LDCs and SIDS. In so doing, the Forum can become an important setting for developing tools and programmes aimed at closing the gap in the global innovation map for maritime decarbonization.

To illustrate the interplay between innovation type and network structure, Figure 2 maps some relevant maritime decarbonisation R&D and innovation schemes and places them in a simple diagram combining the level of innovation intensity with the scope of participation.

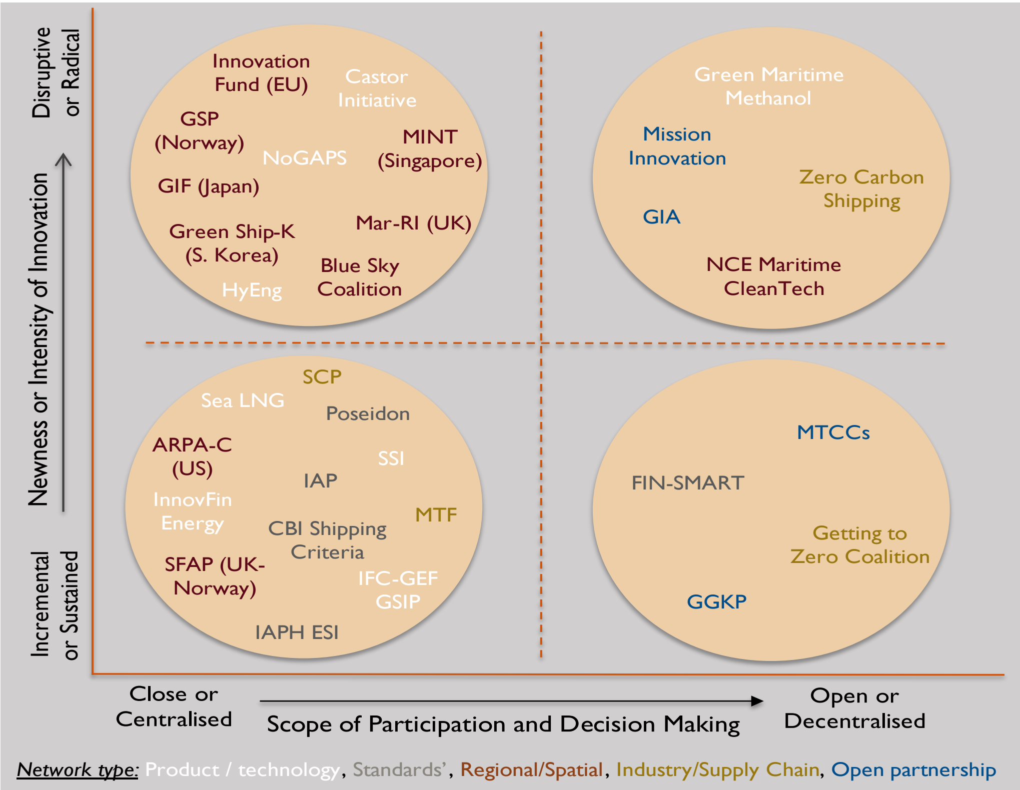

***Figure 2**: Network Structure and typology of Innovation Programmes in Maritime Decarbonisation (Consultant)*

The uptake from the above is that despite the perception of closeness, the international maritime industry is breaking up with its passive and conservative image when it comes to decarbonisation and environmental management. The mapping summarised in Figure 2 shows that the industry is quite active in various innovation networks for maritime decarbonisation, yet there is still a predominance of centralised, closed or semi-closed networks against a few open networks of high innovation intensity.

One of the most striking observations about the mapped innovation networks is the absence of some key stakeholder groups such as regulators, ports, and onshore supply facilities, which could severe or delay innovation diffusion and implementation. Similarly, market collaborative structures such as consortia and alliances that have dominated international shipping for decades do not seem to be replicated in innovation networks, Above all,

Closed and centralised networks may be suitable to innovation tasks featuring a high degree of uncertainty (e.g., radical innovation) or variability (e.g., disruptive innovation), or to the early stages of exploration and development of the innovation process. However, they limit co-innovation, knowledge flow and sharing and may be detrimental to the end user or even fail to progress to the diffusion and deployment phases of the innovation process.

Above all, open network structures for innovation in maritime decarbonisation are very limited despite their wide and successful use in many other settings including for maritime technology [See Box 5]. Through an open and collaborative innovation, an organisation can access and incorporate into its innovative process external ideas and technologies from outside groups and individuals (outside-in process) but can also communicate its internal knowledge and innovation to be diffused and incorporated into others' innovation processes (inside-out process).

Box 5

Collaborative Open Innovation in Ports: The Smart Port Challenge

Open innovation models provide a platform for collaborative innovation, networking, acceleration and diffusion. Many ports are using open innovation competitions to bring together diverse participants in an open and inclusive open innovation challenge with the objective of incubating and accelerate most relevant innovation projects and start-ups.

Open port innovation competition initially started in 2014, and rolled out annually since then, as a PEMA (Port Equipment Manufacturers' Association) student challenge open to university students globally and held at annual TOC events. The Smart Port Challenge (SPC) concept further extends the students' port competition challenge by applying the structured and targeted process used by start-up incubators and accelerators.

As part of its PIER71(Port Innovation Ecosystem Reimagined @ BLOCK71), the Maritime and Port Authority (MPA) of Singapore has first launched the inaugural SPC in 2017 with the participation of 12 from 12 maritime corporates providing 21 challenge statements. The Smart Port Challenge is designed as a 6-month programme from proposal submission through to award of funding support. Since then, the annual programme has supported over 60 start-ups who went on to secure additional funding including through the MPA's mini start-ups grants.

Other ports have also launched their own version of the SPC, most recently the Port of Marseille-Fos in 2018 and the Moroccan National Port Agency in 2020/21. The latter was organised as an SPC online hackathon attracting more than 500 participants from 30 countries, representing universities, SMEs and start-ups, as well as established private and public sector companies, students, and researchers together with private sector companies.

At the end of the virtual open competition, 3 innovation projects were sleeted including a project on carbon-neutral energy production. Eco Wave Power is an onshore wave energy technology company that developed a patented, smart and cost-efficient technology for turning ocean and sea waves into clean electricity. The winning projects were offered an incubation programme transitioning their idea from prototype to proof of concept.

Beyond the winning projects, SPC events enable participants to establish a base for collaborative and inclusive innovation. Similar network innovation platforms and accelerators help not only to drive adoption of the most innovative solutions, providing business opportunities and pay-offs for the participants and winners.

Source: Consultant from various sources

4.2. Innovation Diffusion and Inclusion

4.2.1. Tracking and Measuring Innovation in Maritime Decarbonisation

One of the common difficulties in R&D and innovation is how to measure, track and monitor innovation progress and performance. Particularly for maritime decarbonisation, there are no industry-specific or benchmark indicators that measure or track innovation and technological progress at either sector or product/technology levels.

At the same time, traditional indicators such as R&D investments or number of patents fail to capture many levels and dimensions of innovation output in the multi-faceted and complex maritime decarbonisation field. There are indeed many well-established innovation indicators such as WIPO's Global Innovation Index, the Bloomberg Innovation Index, and the BCG/NAM International Innovation Index, however none of these has a specific focus on decarbonisation or a grid for the maritime industry.

One noteworthy effort is the GZC reports on 'the Mapping of Zero Emission Pilots and Demonstration Projects for the maritime industry'. The report maps the number of maritime decarbonisation projects using publicly available information from project websites, trade journals and other trusted sources. The 2nd edition of the Report which was published in March 2021 lists 106 projects focusing on zero emission pathways using alternative fuels and sources of energy.

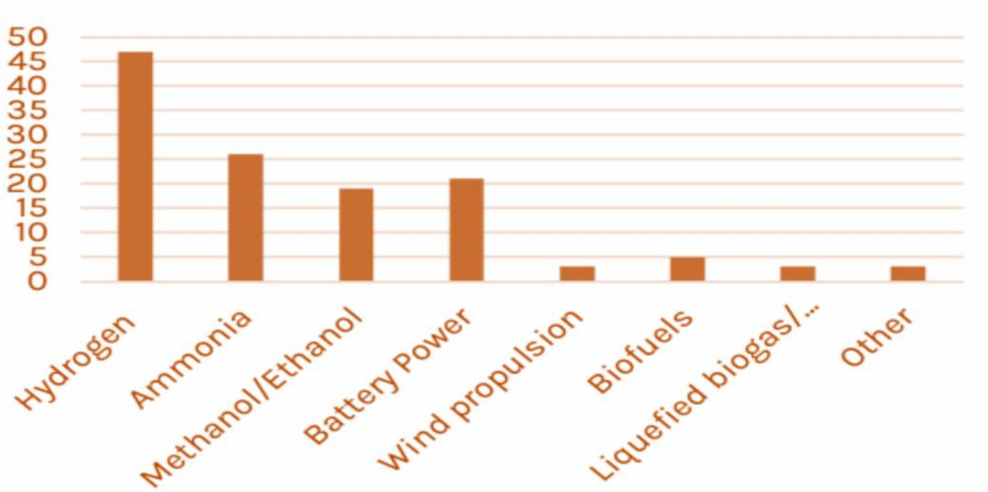

***Figure 3**: Distribution of zero-emission pilot and demonstration projects in 2020 (GZC, 2021)*

The GZC report is neither comprehensive nor inclusive, yet it one of the very few tracking studies providing an update about innovation trends in maritime decarbonisation. As we embark on the global challenge to transform the industry towards zero carbon shipping, there is a need for concrete measures and a systematic framework for tracking, measuring and assessing innovation output, growth and progress with a view to supporting and improving the innovation and technological progress against the targets and ambitions set out in the Initial Strategy.

4.2.2. *Innovation Diffusion and Deployment*

Innovation diffusion is the process by which innovation is communicated and deployed both over time and across agents and users. Ample research has been conducted for identifying the factors that influence the rate of innovation adoption, including the achievement of the critical mass phase which denotes the junction or point in time beyond which the diffusion of an innovation becomes self-sustaining.

Among several frameworks, the diffusion of innovation theory uses an S-shaped curve (logistic growth) to position different types of innovation adopters, from Innovators to Laggards through early adopters, early majority and late majority. As adoption phases progress, an initial exponential growth phase goes through an inflection, then saturates. Such taxonomies are beneficial for conceptualising generic or historical innovation diffusion processes, but they provide little insight on future patterns of adoption, especially for a maritime decarbonisation deployment process that replicates market, regulatory and technology forces.

Evidence from historical and recent events in the maritime industry, especially for regulatory-led innovation programmes, shows that innovation and technological progress has only materialised gradually and incrementally. This may sharply contrast with the need for a radical or disruptive innovation if we are to achieve GHG emission targets within the desired time frame. A paradigm shift is therefore required when studying innovation diffusion and knowledge sharing in maritime decarbonisation especially between regions and countries.

One of the striking observations from Figure 2 shown earlier is the absence of some key stakeholder groups in some mapped innovation networks such as regulators, ports, and onshore supply facilities, which can severe or delay innovation diffusion and implementation. Equally, the mapped innovation networks do not seem to include a high participation from developing countries, especially SIDS and LDCs.

An important aspect in the study of innovation diffusion in a global context is the technology transfer and sharing of knowledge, usually from developed countries to developing countries. To maximize innovation inclusion across the global maritime world, the transfer of knowledge and technology to developing countries, particularly SIDS and LDCs, will be critical.

The topic of technology transfer for development has been studied extensively from the lenses of development and trade economics where factors such as trade, licensing, foreign investment, and to a lesser extent migration have been identified as the most important drivers and enablers to science and technology transfer (UNCTAD, 2014)[5].

Even though, such technology transfer channels may not be sufficient for an inclusive innovation diffusion even in a globalised industry such as maritime transportation. To address these gaps, several international conventions such as the UNFCCC include provisions for the transfer of technology from developed countries to developing countries. A similar approach is used in the maritime sector with the establishment of WMU, IMLI and recently MTCCs.

[5] UNCTAD, 2014, *Transfer of technology and knowledge-sharing for development: Science, technology and innovation issues for developing countries*- UNCTAD Current Studies on Science, Technology and Innovation 8, UNCTAD: Geneva

However, these provisions have often proven difficult to implement beyond academic and research institutions circles. For developing countries, particularly SIDS and LDCs, their limited participation in technology or capital intensive maritime Global Value Chains (GVCs) such as shipbuilding, ship finance, machinery and product technology adds an extra barrier to technology transfer and innovation diffusion.

4.2.3. Towards a New Paradigm of Innovation Inclusion and Growth Pathways

The dominant paradigm of innovation deployment trajectory and rate of diffusion as outlined above implies that the participants in the innovation process are somewhat disconnected from each other and can only access and benefit from innovation in different rates and stages. This is based on the (false) assumption that innovation as captured by a novel technology or product must be absolute and universal, rather than potentially relative, adapted and/or local, therefore leading to systemic exclusion of regions, stakeholders and communities who cannot adopt innovation in the same form, rate or trajectory.

More inclusive patterns of innovation offer a better prospect of accessing to and participating in the innovation process while facilitating the move to more sustainable growth pathways and contributing towards technical and technological progress. This requires a paradigm shift towards inclusive innovation which ensures equitable participation of all countries, regions and stakeholders in the innovation processes and outcomes without necessarily adopting similar products or technologies or following similar marketplaces.

By engaging the inclusive growth paradigm, the maritime decarbonisation agenda offers an opportunity for developing countries, including SIDS and LDCS, to join the innovation process and facilitate the transition to a more inclusive growth and development pathway. This involves the occasional use of frugal innovation and widespread diffusion of small-scale, less complex and less capital-intensive technologies and processes that facilitate distributed and inclusive patterns of maritime decarbonisation.

Several case studies and practical applications of inclusive innovation provide evidence of the opportunities opened by innovation in many regions and sectors of the economy. For maritime decarbonisation, the return to designing and using sail freighters in the Pacific coastal trade is a typical application of inclusive innovation which is not only adapted to local needs and marketplace but also achieves decarbonisation targets much faster and cheaper than what is proposed elsewhere [Box 6]. In addition, it enhances the Pacific countries' growth and development pathways through collaborative and equitable participation in the innovation process, higher GVC contribution in the maritime sector, and broader spill-over effects.

Sometimes, inclusive innovation translates into taking advantage of abundant local resources and scaling them up in ways that benefit the community, reduces costs and achieves sustainable growth. The case of Morocco's remarkable energy transition and use of abundant solar and wind energy is another example of inclusive innovation in environmental management. One of the spinoffs of this transition is the establishment in 2011 of the Research Institute for Solar Energy and New Energies (IRESEN) as the main agency and funding vehicle for collaborative R&D and innovation in solar energy and renewables [Box 7].

Inclusive innovation while calls for coordination of key stakeholders across the value chain, also requires a close coordination and cooperation among stakeholders, both in the developed and developing countries and in particular SIDS and LDCs.

Such a coordination of actions to reduce emissions from shipping can be achieved by bringing the R&D initiatives and R&D Centres in developed countries closer to the regional centres such as MTCCs, the local private sector who is willing to demonstrate appropriate solutions.

This would also require innovative financial solutions to underwrite some of the associated risks through government support and IFI interventions such as blended financing to support technology demonstrations, technology diffusion and eventually wider uptake of innovative solutions.

Any platform that would facilitate such cooperation would bring benefits to both sides – R&D initiatives who are looking to explore market for their innovations and the developing countries and especially their private sector players who could benefit from such technology demonstrations through building confidence in taking up innovative solutions. The Next-GEN initiative jointly by IMO and Singapore addresses some of these needs by creating an online platform to facilitate such collaborations.

Such efforts can be further strengthened by IMO by creating a global framework that would bring together the various innovation champions such as the latest decarbonisation R&D centres, the various IMO projects that includes technology demonstrations, the regional maritime technology cooperation centres in developing regions, the International Financial Institutions and the FINSMART participants, the local private sector, the Global Industry Alliance members, Donors and Strategic Technology Partners who all can work together to accelerate diffusion and uptake of innovative decarbonisation solutions through appropriately funded technology demonstration projects in developing countries.

Box 6

Cerulean Project:
A case for inclusive and collaborative innovation

Project Cerulean is a collaborative partnership between Swire Shipping (a regional subsidiary of China Shipping) and the University of the South Pacific's Micronesian Centre for Sustainable Transport to build the Pacific's first low-carbon, low-cost sail-assisted inter-island cargo vessel and deliver equitable, efficient, and comprehensive transport services to remote communities in the region which lack port infrastructure and terminal's cargo handling facilities.

The 1st part of the project started in 2019 and included feasibility and proof of concept, design specifications, cargo and route selection and evaluation, and the development of the business case and operational plan. In June 2021, an order of the first vessel of the class made, with expected delivery in mid-2022.

Pacific SIDS and their scattered coastal communities rely on shipping as the essential lifeline for mobility and trade connectivity. For many decades, traditional sailing ships were the fast and most efficient ships connecting Pacific islands and communities. With the introduction and expansion of diesel-powered ships, the Pacific region countries became the operating market of one of the oldest and most polluting domestic fleet in the world, which still require government subsidies and support to ply local markets. Using inclusive innovation though the Cerulean project and the proposed Pacific Blue Shipping Partnership, the Pacific Island countries see maritime decarbonisation as the opportunity to transit to accessible, sustainable and affordable shipping solutions while facilitating inclusive and participatory innovation and growth pathways.

Photo credit: Initial Design © VPLP Project Cerulean prototype

Source: Consultant from UPS and other sources

Box 7

Institutional Structures for Innovation Development and Diffusion-
The Case of MASEN and IRESEN in Morocco

Morocco is energy dependent and imports over 90% of its energy needs, of which 95% were sourced from fossil fuels while providing subsidies to these fuels costing up to $4 billion annually. Due to the rapid urbanisation and industrialisation over the past decade or two, there is an even higher demand for energy consumption at a time where the country is trying to manage and rationalise its public costs.

To improve energy supply and reduce dependence on energy imports, while drawing on its vast renewable resources from wind and hydro to solar energy, the country's strategy was to diversify its energy supply through renewable sources for electricity production. The target is to for renewable energy to account for 40% and 50% of installed electrical generation capacity by 2020 and 2030, respectively.

To implement one of the pillars of the above strategy, the Moroccan Agency for Renewable Energy (MASEN) was established in 2010 as the agency responsible for the feasibility assessment, design, development, and financing of solar projects in the country.

By acting as a vehicle for resource mobilisation and a consolidator of concessional loans, MASEN could blend the terms of the IFI loans with domestic public funding and offer a single financing package by allocating risks to key players and ensuring a lower project cost of capital. This institutional and financing architecture has allowed MASEN to develop phase I of the Noor station in 2013, one of the world's largest concentrated solar power plants, and lower the electricity tariff offered by the winning bidder by 25% and the required revenue subsidy by 66%, compared with initial cost projections. Subsequent projects in solar, wind and hydro energy have used similar structures and were able protect existing energy and fiscal structures from technology and innovation risks while still involving a wide range of partners and stakeholders.

Parallel to the establishment of MASEN, the Government created the Institute of Research on Solar Energy (IRESEN) in 2011 to accompany the national energy strategy by undertaking and supporting R&D and innovation in the field. Since its creation, IRESEN has undertaken research in several areas relevant to of solar and renewable energy, supported regular incubator and accelerator programmes, collaborated with regional and international R&D institutes, and shared knowledge and expertise including through its open tools and online platforms.

Source: Consultant from MASEN, ISEREN and other sources

5. Conclusions and Way Forward

The international maritime community has embarked on a shared goal to decarbonise the maritime industry and reduce maritime sector-wide emissions under the leadership of IMO. In addition to the international regulatory framework provided by the IMO, including recent measures that further improve the energy efficiency of international shipping, significant innovation and technological leaps will be required to achieve the targets of the IMO Initial Strategy globally.

Successful innovation is manifested not only through novel products and technologies, innovative investment and financing mechanisms, new business models, and operating systems; but is also the result of adequate and effective innovation models, processes and network structures, all of which should be organised and managed in an efficient, coordinated and inclusive way, ensuring that no one is left behind.

To achieve a synchronised and inclusive transition to low-carbon and zero carbon shipping, coordination of innovation technology, investment, management and policy is required across the maritime value chain and throughout various regions and stakeholders. Furthermore, innovation in low carbon shipping solutions cannot be deployable if it is not supported by interoperable and harmonised innovation in energy supply, storage facilities, bunkering facilities, port and terminal operations, and other associated infrastructure and services.

In a similar vein, the traditionally fragmented financing instruments for research and innovation should be replaced by cross-asset / cross-border financing solutions and there is a need to attract and funnel venture capital and other sources of funding towards innovative efforts that offer decarbonisation solutions across the entire maritime supply chain.

Industry operators must also rethink existing service offerings, business models and management processes in view of decarbonisation both within their markets and sectors as well as across the broader maritime supply chain.

Despite some progress, current innovation models and networks for maritime decarbonisation are still dominated by closed and centralised structures, often with low participation of developing countries, SIDS and LDCs, and marked by the absence of some key stakeholder groups such as regulators, ports, onshore supply operators and venture capital providers. This not only delays innovation deployment and implementation but also severs innovation diffusion and inclusion.

Conversely, successful models of innovation in maritime decarbonisation and other settings have fostered collaboration, inclusion and knowledge sharing. More inclusive patterns of innovation offer a better prospect of accessing to and participating in the innovation process while facilitating the move to more sustainable growth pathways and contributing towards technical and technological progress. This often requires a paradigm shift towards inclusive innovation which ensures equitable participation of all countries, regions and stakeholders in the innovation processes and outcomes without necessarily adopting similar products or technologies or following similar marketplace pathways.

For developing countries, particularly SIDS and LDCs, the barriers to designing, testing and deploying innovation may be further compounded by additional challenges posed by the structure of their maritime markets, the scarcity of their economic and financial resources, and the limited technical capacity of their R&D networks and institutional structures.

Through a quick two-stage survey and mapping exercise of innovation risks and barriers, it was found that many developing countries, SIDS and LDCs face specific challenges related to the access to open knowledge and innovation, scarcity of adequate funding and financing, and lack of technical and institutional capacity to organise and manage innovation. This calls for innovation models and networks that are not only open and decentralised, but also foster knowledge sharing and inclusion.

Several case studies and practical applications of inclusive innovation provide evidence of the opportunities opened by innovation in many areas of maritime decarbonisation in developing countries, SIDS and LDCs. Often, inclusive innovation translates into taking advantage of abundant local knowledge and resources, adapting them to local and marketplace needs, and scaling them up in ways that benefit the community, reduces costs and achieves sustainable maritime growth.

Innovation partnership and inclusion are urgently required to accelerate the transformational process towards zero or low carbon shipping, promoting innovation synergies and knowledge sharing and minimising innovation overlap and redundancy. This would also call for IMO taking a central role in coordinating and connecting the various R&D initiatives and potential technology demonstration opportunities in developing countries that can be supported through innovative financial solutions offered by financial institutions and bilateral donors.

Based on existing best practices, innovation enabling and inclusive models could be formulated and implemented to support innovation diffusion and inclusion processes for maritime decarbonisation. The IMO-UNEP Maritime Zero-Low Carbon Innovation Forum and further future relevant initiatives can play a big part in further expanding the participation and reach of open networks for maritime decarbonisation and make innovation more inclusive and accessible to developing countries, LDCs and SIDS.

Appendix 1: Participants in online and phone interviews

Affiliation	Location	Participants
ADB	Philippines	1
AfDB	Cote d'Ivoire	1
Barbados Maritime	Barbados	1
BMA	Bahamas	1
BSMR	Bangladesh	2
CMU	Jamaica	2
GCMD	Singapore	1
IDB	USA	2
ISEM	Morocco	1
JMA	Jordan	1
LIMA	Liberia	2
MAS	Suriname	1
MASEN	Morocco	2
MFA	Cook Islands	1
MRC	India	2
MPA	Mauritius	1
MTA	Georgia	1
MTC	Maldives	2
MTC	Kiribati	1
MTCC Africa	Kenya	1
MTCC Caribbean	Trinidad and Tobago	2
MTCC Pacific	Fiji	2
MTS	Egypt	2
PTI	Djibouti	1
RMU	Ghana	3
SAMSA	South Africa	1
SIMA	Solomon Islands	1
UNCTAD	Switzerland	1
UNDP	USA	1
UNEP	Denmark	3
USP	Fiji	2
USP	Brazil	1
WMU	Sweden	1