Highlights of the book - a menu of possible actions for decarbonization today and tomorrow

Author(s): Wolfgang Lehmacher, Mikael Lind, Gavin Allwright, Jeremy Bentham, David Cummins, Theo Notteboom, Johan Byskov Svendsen, Kirsi Tikka, Louise De Tremerie

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Wolfgang Lehmacher[1], Mikael Lind[2], Gavin Allwright[3], Jeremy Bentham[4], David Cummins[5], Theo Notteboom[6], Johan Byskov Svendsen[7], Kirsi Tikka[8], Louise De Tremerie[9]

This chapter is an extended summary of the contents of this book. It is intended for all those seeking an overview of possible actions to reduce greenhouse gas (GHG) emissions in the various and diverse sectors of the shipping industry. The recommendations should help policymakers, and executives and project managers in the private sector to make better

[1] W. Lehmacher, e-mail: w.lehmacher@gmail.com, ORCID: 0000-0001-7890-1157
[2] M. Lind, Research Institutes of Sweden (RISE) and Chalmers University of Technology, Gothenburg, Sweden, e-mail: mikael@realsearchers.com ORCID: 0000-0003-0402-1741
[3] G. Allwright, International Windship Association (IWSA), London, UK, ORCID: 0009-0006-6127-5931, E-mail: secretary@wind-ship.org
[4] J. B. Bentham, Co-Chair (scenarios) World Energy Council and retired Head of Shell Scenarios, The Hague, The Netherlands, ORCID 0000-0002-9077-1508, e-mail: jbentham@live.com
[5] D. Cummins, Blue Sky Maritime Coalition, Houston, Texas, USA, ORCID: 0009-0000-7398-941X, e-mail: president@bluesky-maritime.org
[6] T. Notteboom, Ghent University, University of Antwerp and Antwerp Maritime Academy, Belgium, ORCID 0000-0003-1203-2571, e-mail: theo.notteboom@ugent.be
[7] J. B. Svendsen, Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, Copenhagen, Denmark, ORCID: 0009-0006-3431-3242, e-mail: johan.byskov@zerocarbonshipping.com
[8] K. Tikka, Board Member Ardmore Shipping, Pacific Basin Shipping, Foreship London, United Kingdom, ORCID: 0000-0003-2936-3801, e-mail: kktikka@outlook.com
[9] L. De Tremerie, European Parliament, Brussels, Belgium, ORCID: 0009-0006-8397-2471, e-mail: Louise.detremerie@europarl.europa.eu

decisions on actions to take, and should be of value to all stakeholders within the global decarbonization movement. It may also lead to identifying individual chapters to obtain greater knowledge in particular areas of interest.

The recommendations, and thus the key take-aways from this extended summary chapter are:

1. Use the 'five decarbonization lever' framework to recognise the full spectrum of levers.
2. Set environmental targets and reflect on concrete outcomes of decarbonization efforts.
3. Understand the global shipping fleet as a key area for decarbonization.
4. Use a four-step model to guide decarbonization efforts.
5. Develop scenarios to build context for decarbonization strategies.
6. Adopt a value-chain focus to tackle decarbonization.
7. Identify and activate relevant decarbonization enablers.
8. Select and contribute to decarbonization partnerships.
9. In respect to outcomes, balance economic with societal value.
10. Place a strong focus on people.
11. Ensure global alignment of regulations related to decarbonization.
12. Leverage circular economy principles as a driver for systemic change.
13. Boost global research in maritime decarbonization.
14. Adjust to finance requirements in a more sustainable age.
15. Be an early-mover: even if you choose not to be a single pioneer, be prepared to be an early adopter.

The following overview of actions with potentially promising outcomes is based on today's knowledge and has been derived from the contents in the chapters in the first half of this book. Complementary perspectives and recommendations have been drawn up in relation to the topics covered in the various chapters. The second half of this book provides case studies and practical examples supporting the recommendations.

We thank the contributors to this book for their inputs. Through sharing their knowledge and insights, they have created a valuable contribution to the public discourse on maritime decarbonization.

1. Use the 'five decarbonization lever' framework to recognise the full spectrum of levers

As outlined in chapter 1 (McKinnon, 2023), the International Maritime Organization (IMO) 4th Greenhouse Gas (GHG) Study predicted that almost two-thirds of carbon reductions in the maritime sector by 2050 will come from the switch to alternative fuels (IMO, 2020), which could include also a wind component such as the use of rigid or soft sails, large kites or wind turbines and rotors on deck. The use of very low carbon fuels is required for the transition and ultimately net zero emission fuels to achieve a net zero shipping future by the middle of the century.

There are two respects in which a pre-occupation with the 'defossilisation' of maritime energy appears to be based on too narrow a view of the subject. First, it under-estimates the carbon-reducing potential of a range of other measures that can be applied more quickly and cheaply to reduce the amount of fossil fuel that needs to be phased-out, sooner rather than later. Second, it is 'voyage-focussed' and fails to fully consider options for decarbonizing the whole supply chain, encompassing ports and hinterland logistics as well as shipping operations (Lind et al., 2023cd).

It is important to recognise the full spectrum of carbon-reducing initiatives and avoid an over-reliance on a few, much-debated and much-researched options. The decarbonization of all forms of transport will be achieved by the application of many mutually-reinforcing measures rather than a few 'silver bullets'. In the process, it is crucial that the sector avoids locking-in transitional solutions that are mostly fossil-based.

Various classificatory schemes are now being used to assess the potential impact of decarbonization measures systematically by grouping them into several categories. The most commonly referenced is the Avoid-Shift-Improve (ASI) framework, distinguishing measures that reduce the demand for transport, shift it to lower carbon modes and improve their carbon efficiency. The Activity-Shift-Intensity-Fuel (ASIF) taxonomy (Schipper and Marie, 1999), adopted by the Intergovernmental Panel on Climate Change

(IPCC) (Sims et al., 2014), uses different words for two of the three categories and introduces a separate one for the switch to alternative fuels. The so-called 'five decarbonization lever' framework covers five levels:

- freight traffic intensity
- choice of freight transport mode
- capacity utilisation
- energy efficiency
- and switching to low carbon energy.

The framework distinguishes capacity utilisation from energy efficiency in the improve / intensity category, as each can be separately influenced by technology, business practice and public policy (McKinnon, 2018).

We recommend using the 'five decarbonization lever' framework which can expose a set of options for decarbonizing maritime supply chains by testing the various outcomes, for example, when free energy (as in wind propulsion) is inserted into the framework. We need to ensure that the approach to maritime decarbonization remains fact-based and that no single party or industry influences the narrative towards biased outcomes.

2. Set environmental targets and reflect on concrete outcomes of decarbonization efforts

Chapter 2 (Raza and Singh, 2023) indicates that, as a general rule, shipowners and operators should set decarbonization targets, prioritise transparency, and use clear and comparable environmental, social, and governance reporting. This can be considered as a recommendation which should be relevant for every actor in the maritime decarbonization ecosystem.

An overarching goal should be to ensure that decarbonization is inclusive. Shipping is a global industry and the transition to a climate net-zero sector is a global challenge. Regional measures and initiatives can take the lead to pressure and influence what happens at the global level, where it is crucial to facilitate the path towards globally addressing GHG emissions from international shipping by both developed and emerging economies. Some

of the revenues generated by a levy or market basket measures (MBMs) should be used to support vulnerable countries in their efforts to mitigate and adapt to climate change, with the remainder going towards research and development and administrative costs. Also, those regions may benefit more than others from certain non-fuel decarbonization enablers such as wind propulsion, especially if relatively simple/easy to fabricate systems are available. Small island developing states (SIDs) in the South Pacific are ideal for wind assisted and primary wind ships that are supporting business models for long distances, low cargo levels and high fuel costs. Concerns have been raised among a number of least developed countries (LDCs)/SIDs that the MBMs being proposed may be 'neo-colonial' instruments, where they will have to pay a carbon price, but the fuels/technologies will be developed and monetised in the developed world and only some compensation will be delivered to LDCs/SIDs. There are of course some winners with large amounts of renewable energy investment, but many view the current approach to MBMs as a perpetuation of the existing economic order, thus not a just/equitable transition. This needs to be addressed to ensure a just, inclusive and equitable transition.

The accelerated development of effective GHG reduction measures requires regulators, policymakers, financial institutions, and customers to de-risk the investments and activities of first and early movers. All stakeholders should support initiatives that drive collective decarbonization, share costs, benefits, and risks, such as ‘green corridors’, while ensuring that green corridors do not become an exclusionary exercise. One way towards an inclusive approach could be to also consider ‘wind corridors’, a concept that would need to be developed further.

Policymakers at regional, national, and local levels should not only set clear targets and provide a clear regulatory framework, but also develop roadmaps that encourage dedicated investments in green energy and fuel infrastructure, as well as engineering capacity, to build these facilities.

The IMO should play a more decisive role in guiding the sector on a global scale towards a net zero future. The organisation should move to the next level of impact and provide clear enforcement mechanisms, tighten compliance levels, and find regulatory solutions to ensure shared responsibility among all parties that influence ship emissions. We may need new institutions that are responsible for areas not covered by the IMO, like ports and commodity trading. In general, the IMO should do everything possible within its powers to drive and accelerate maritime

decarbonization. Recent regional developments by the European Union (EU) may trigger responses at the IMO level opening a window of opportunity to speed-up the work on a global market-based measure for maritime shipping emissions.

In line with these recommendations, it is important for the IMO to define more granular interim decarbonization targets consistent with the ambitions set for the far future so that actors in the industry can gauge where they stand at any time and their progress resulting from implementing their decarbonization measures. All stakeholders should support discussions about more ambitious and intermediate targets in shipping. But the focus needs also to be on attainable targets. Many IMO Member States are uncomfortable about stepping up and declaring support for undeliverable targets, just considering, for example, the likelihood of comparatively little zero-emissions fuel being available by 2030. To make the leaps, it is recommended to engage in a collective effort to set high ambitions backed by roadmaps and supporting actions that align the targets with the ambitions.

3. Understand the global ship fleet as a key area of decarbonization

Chapter 3 (Pålsson and Rydbergh, 2023) deepens the understanding of the state of the global shipping fleet. The industry, and those involved in maritime decarbonization, can see how many ships that are currently trading are due for replacement in the near future and how many could be expected to be trading for several decades more.

The age profile by number of ships and the age profile by tonnage shows that the world fleet is relatively young (an average age of 16 years). Ships which are now more than 20 years old make up 26% of the current fleet by number and most will reach end of use in the next five years. But these 13,973 vessels account for only 161M dwt or only 7% of the total fleet tonnage, given that more modern ships have become increasingly larger.

This is relevant, and important information because it has an impact on how quickly new ships with new propulsion solutions may come into service and when. A slow penetration means that retrofit and operational

solutions of the current fleet becomes relatively more important than if the rate of ship replacement was faster.

We cannot afford to wait until ships are old enough before we start to retrofit. This will not get the industry to a zero emissions state. We need new ships with different engines and support systems on board, that use non-fossil-fuel-based energy sources, and we need to start now. Experts have identified relatively easy fixes, such as wind propulsion which, for example, can be installed within days, with many of the systems being able to be reinstalled on other vessels when ships go for breaking and/or moved to different routes. This also represents a flexible option.

It follows that marine equipment manufacturers need more incentives to enable feasible and economically viable retrofitting solutions. Another recommendation is for the building up of capabilities to recycle ships in sustainable ways, and in accordance with agreed standards and processes in support of green recycling. The pending ratification of the Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships (IMO) and the existing EU Ship Recycling Regulation are important first steps in that direction.

As resources become scarcer and the ecological boundaries of our planet are being stressed, circular economic thinking plays an important role in changing business models towards those that are closer to following the principles of nature and the planet. Enabling market-based incentives can only encourage marine equipment manufacturers to develop feasible and economically viable retrofitting solutions. As one part of the circular economy, the continuous use and re-use of parts and materials will help to avoid GHG emissions. New ship designs should cater for more modularity for retrofitting, reuse, and re-manufacture, and on construction based on sustainable methods and materials, keeping in mind the specific characteristics of certain alternative fuels like the toxic nature of ammonia, and to a lesser extent methanol, which requires specific safety protocols and investments. We believe that shipping can contribute to transforming the economy into a circular economy that not only excels in value creation but also in value preservation.

4. Use a four-step model to guide decarbonization efforts

Chapter 4 (Lind et al., 2023a) presents four foundational concepts for climate action that underpin a '4-step model' that can drive strategies, business cases, the execution of plans, and decision-making. The four concepts are *scenario analysis* (context), *value chain mapping* (scope), *enabler prioritisation* (focus), and *partnership selection* (synergies). Although there is a natural sequence, the four steps support each other in an iterative symbiotic co-development.

Exceeding the current IMO 2018 ambitions for carbon-reduction and thereby reach the EU ambitions and the Paris Climate Agreement goals requires a holistic and inclusive approach. The idea behind the four-step model, as a key recommendation from this book, is to support such a holistic approach.

The way the maritime value chain is designed creates inefficiency, through stepwise, sequential bi-lateral negotiations, which lead to a situation that can be described as the *'Tragedy of the Commons'*. We are unlikely to achieve our decarbonization ambitions unless we approach solutions as part of a collective systems-wide optimisation challenge, and therefore change the very nature of how the global value chain operates. Hence, achieving a low carbon future requires that we drive a systems approach rather than an aggregate of multiple individual solutions by companies/entities or sub groups of the value chain.

5. Develop scenarios to build context for decarbonization strategies

Chapter 5 (Bentham, 2023a) makes clear that maritime decarbonization cannot be seen in isolation and independently from its overall context and that there is therefore an important place for scenario thinking. Powerful influences, transitions and disruptions are shaping our society and economy, indeed our whole world. Every strong influence can also generate others, and you can rarely tell in advance which of these will prove to be

the stronger. Therefore, there are inevitably multiple different plausible pathways for our future. Much of this is beyond our direct control, and even our own actions can affect the future in ways that may surprise us.

However, while not predictable in detail, neither is the future completely random. There are constraints imposed by, for example, physics and biology, and features of society that remain relatively stationary for considerable periods, like birth and death rates, human biases, or the time it takes to build major public infrastructures. It is, therefore, possible to explore plausible futures in a systematic way to identify both critical uncertainties and relatively settled trends. This is the art of building scenarios.

Scenario thinking is a means for grappling with uncertainty. It is acknowledged that the human mind and business logic may struggle with such an approach. Nevertheless, it is recommended that stakeholders use scenario analysis as a learning tool to help them to see beyond the horizon of our necessarily limited personal experiences and current circumstances.

6. Adopt a value-chain focus to tackle decarbonization

As related in chapter 6 (Petersen and Renken, 2023), contemporary value creation is usually distributed throughout extensive global supply networks. Hence, taking a value chain perspective is critical to understanding and assessing decarbonization enablers and building partnerships beyond industry borders. There are obviously three interrelated value chains across the maritime ecosystem that are playing a critical role in decarbonizing shipping. The three value-chains are marine fuel and direct propulsion technologies, shipbuilding, and the maritime operational value chain (Lind et al., 2022).

The asset value of the world fleet stands at USD 1.4 trillion (UNCTAD, 2022). Hence, the most commercial value is likely to be concentrated in the operational value chain. A significant decarbonization potential is expected

from optimising international trade patterns, driving down the demand for international shipping in the first place (Wang et al., 2021).

Energy-efficient newbuilds and retrofits will be needed to reduce GHG emissions from the existing and future shipping fleet. What ships and engines will be built and used sustainably largely depends upon what fuels will or can be made available and at what cost, but also what is required by regulation. Public sector programmes can support retrofitting and incentivise zero GHG emissions newbuilds. But public programmes are not the silver bullet either and it is stressed that only a collective effort will lead to a climate neutral future.

The green energy transition shifts dependencies from fossil fuel producers to renewable energy and e-fuels providers as the feedstocks shift from petroleum towards green electricity (and biowaste). These shifts may reduce the importance of some regions of the world and bring new opportunities to other locations with possible shifts in geopolitical power as newer feedstocks are likely available throughout the globe. Market structures will also shift. Today, the available quantity of alternative fuels is very limited. A huge challenge and responsibility lies with the energy industry to ramp up and scale up production of renewable energy. Similarly, ports need to provide the bunkering infrastructure for alternative fuels, clean sources of power, like renewable electricity, and onshore power supply solutions (OPS) (Lind et al., 2023cd).

A worldwide supply for new alternative fuels also leads to the potential for unwanted emissions from pipelines/bunkering of products. Hydrogen for example is not a direct GHG, but interacts with free radicals that break down methane in the atmosphere. Thus, hydrogen can lead to lengthier methane retention in the atmosphere. This kind of scientific finding is not yet completely clear, so it would be prudent to adopt precautionary principles when contemplating systems that do not produce fuels adjacent to their place of use.

As recommended throughout this book, decarbonization should be seen as a joint undertaking of all stakeholders within multiple intertwined value chains within and beyond the maritime industry across the maritime

decarbonization ecosystem. There is the additional challenge that other value-chains across the wider economy are also competing for currently scarce low-carbon and net-zero emissions fuels and energy sources. The fact that shipping is just one customer for green fuels creates a basket of challenges around supply, competition, fuel price variability, and fuel standardisation, all of which need to be and, in time, will be addressed.

7. Identify and activate relevant decarbonization enablers

Chapter 7 (Tikka and Esau, 2023a) explains that moving towards the current and future global decarbonization targets set by the IMO requires the adoption of multiple enablers with varying GHG reduction impact and different levels of required investment (MEPC.304(72), 2018). The enablers can be categorised within the three value chains: the Marine Fuel Value Chain, the Maritime Operational Value Chain, and the Shipbuilding Value Chain. Some of the enablers contribute to only one value chain, whereas others have contributions to two or all the value chains. The categories of enablers identified are as follows.

Shipboard energy efficiency technology: Large parts of the maritime fleet is already taking advantage of the technologies available today to improve both technical and operational efficiency. Energy efficiency of ships can be improved by reducing the power requirements for the main propulsion and for auxiliary energy generators. Energy savings depend on many variables such as the vessel type, routes, weather conditions, and operational practices, but potential savings are typically relatively small - less than 10%. Although the individual savings are small in percentage terms, a combination of measures can offer significant overall fuel and emission savings. Nevertheless, this will not be a simple addition game, but a more complex undertaking that needs to be understood.

Operational and commercial practices: Some of the measures can be implemented onboard a vessel, others involve multiple stakeholders and commercial arrangements. According to the *Mærsk Mc-Kinney Møller Center* for Zero Carbon Shipping (MMKMCZCS, 2022) the vessel and fleet specific operational energy efficiency measures offer energy efficiency

gains up to 15%. This does not factor in wind propulsion. Wind propulsion is significantly boosted by wind routing, voyage optimisation and speed (MEPC 79 /INF 21 (2002).

Digital technology: Technology tools for real time data sharing and communication can eliminate bottlenecks in the logistics chain. Digital technology can now provide software tools for design and maintenance, weather routing, energy management, data analytics to transform operational data into information, and commercial platforms and satellite communication for value chain optimisation. Onboard automation, and eventually autonomy, allows more efficient operations. Although digital technology and automation are already widely used in the maritime industry, they are expected to have a greater impact on maritime decarbonization in the future. Standardisation of a digital optimisation platform, and associated machine learning predictive algorithms, will be essential for a systems approach to regional and global efficiency within the maritime value chain as well as across connected value chains. However, cybersecurity programmes also need to be implemented and keep up with concerns over the hacking of digital systems.

Zero-carbon fuels and technology: Since the worldwide large-scale availability of zero-carbon fuels is still several years away, the focus is on the transition from the current use of fossil fuels to low-carbon and eventually net zero-emission fuels, as well as the alternative fuel pathways to produce these net zero-emission fuels. The transition focuses on the use of multi-fuel engines that currently burn fossil fuels but offer an option in the future to burn zero-carbon fuels, or the use of biofuel and fuel oil blends, and in the case of liquefied natural gas (LNG), biomethane and LNG blends, that can be burnt in the existing internal combustion engines without modifications (drop-in fuels). It is crucial not to lock-in these transitional carbon-based technologies and instead move towards the deployment at a large scale of net zero-emission fuels. When considering the fuel pathways, it is important to differentiate between well-to-wake (WTW) and tank-to-wake (TTW) emissions. WTW assessments consider the GHG emissions from the fuel production to the end use onboard a vessel, whereas TTW accounts only for the emission from the onboard use of the fuel. If the TTW assessment is used the fuel choice will not account for the full GHG impact. New innovations in the coming years will continue to advance new fuels types and technologies, making flexibility a critical part of any advancement. For example, ports will need to provide for the

bunkering of multiple fuels, and ships will probably need to have propulsion system technologies, such as fuels cells and other advanced technologies that can operate with multiple fuels.

Energy conversion and shipbuilding technology: Ships built today should incorporate the available technology for maximum energy efficiency. However, full maritime decarbonization requires retrofitting and renewal of the fleet to burn zero emission fuels and the use of wind propulsion technologies. Shipbuilding requires large amounts of energy to produce steel and other materials and to construct the ships themselves. Maritime decarbonization will ultimately require green steel produced with zero carbon emissions and designs based on circular economy principles, to enable the re-use of materials when ships reach their end-of-life.

Policies and regulations: Industry and market driven efforts are necessary for decarbonization, but an effective global regulatory framework could accelerate the worldwide adoption of all the decarbonization enablers available today. Global regulations play a critical role to set the targets for the global fleet to improve energy efficiency and fast track the transition to net zero emission fuels. The IMO has a unique role and mandate to regulate ships globally, including the protection and encouragement of first movers. The short-term measures adopted by the IMO to address the fleet's technical and operational fuel efficiency is a start, but more is required from the global regulatory framework. The IMO GHG-reduction targets should be in line with the findings of the more recent 6th IPCC impact assessment report (IPCC, 2023).

Financing and incentives: Market based measures (MBMs), such as the proposed fuel levy proposed at the IMO or the recent decision on the inclusion of shipping in the EU Emission Trading Scheme (ETS) starting from January 2024, are needed to accelerate and expand the adoption of low-carbon (transitional) and net zero emission fuels beyond the early movers. Incentives have to be put in place to drive the uptake of alternative fuels. In the past shipping has been burning fuel that no other industry uses, but going forward and transitioning to more sustainable fuels, shipping will compete with other industries for supplies of the new fuels. Therefore, it is critical that the shipping energy demand is considered in global energy production projections and infrastructure planning. MBMs and their impacts should be carefully evaluated, with taxes that return to the industry being fairly distributed as subsidies for research and development and for the installation of green fuels and technology. It is recommended to

consider including ships under 5,000 gross tonnage (GT) in the ETS as this would help innovation enjoy a fast and strong learning curve for new technologies, as it is in this segment of smaller ships where large numbers of easily/quickly scaled units can be delivered and systems can be optimised further before being scaled-up for larger ships.

Ports will need to fulfill their role as providers of bunkering infrastructure, battery charging stations, and shore-power supply as alternatives for ships alongside. National policies will be important for both energy availability and electricity grid and fuel infrastructure development.

8. Select and contribute to decarbonization partnerships

Chapters 4 (Lind et al., 2023a), 8 (Kuttan, 2023) and 13 (Lind et al., 2023b) underline that one player can activate some enablers, but collaboration between multiple actors is required to activate the full range of decarbonization enablers. In fact, without collaboration no effective decarbonization of the maritime industry and any other sector will be possible. Collaboration helps to align, accelerate, or intensify efforts. Hence, partnerships are critical to driving decarbonization across the larger ecosystem and need to be inclusive to achieve their maximum impact. Making partnerships work effectively requires strategies grounded in a profound understanding of what collaboration means in meeting needs for all parties and the available collaboration options.

Based on what enablers they require to activate, actors can benefit from selecting specific partnerships to align, close gaps, accelerate, and intensify their decarbonization efforts. It is therefore recommended that actors should:

- Select partnerships to gradually establish a portfolio of collaborations to align and cover unmet needs/capabilities at the company and possibly at the industry and ecosystem level.
- Ensure sufficient partnership management capabilities are developed across the organization or accessible through partnerships.
- Establish cross-value chain coordination, for example, along zero-emissions corridors.

- Coordinate wider stakeholder engagement and interaction in view of securing social and public support for decarbonization trajectories.

Partnerships in the shipping industry need to be composed of many more stakeholders than it might appear at first. Decarbonization is everybody's business. However, considering the limited resources of the smaller players in terms of capital and talent, it requires the larger actors to take the action and include them into their efforts. In addition, the public sector or international regulators can support the private sector efforts by crafting conducive policies and programmes to empower the long tail to also accelerate their decarbonization efforts. Furthermore, we suggest that the current partnerships, that mostly consist of larger players in developed countries, should increase their efforts to also bring the myriad of smaller actors on board, and widen their scope to also include less developed countries.

This will make it more likely that the goal, as set by the Paris Agreement, can be achieved (Lind and Lehmacher, 2022). But this requires that the IMO aligns its ambitions with the Paris Climate Accord and that trust is built and the interests of the smaller players and all regions are protected and respected.

9. In respect to outcomes, balance economic with societal value

In particular in today's western countries, citizens and consumers expect more from companies than just good products. Many stakeholders of the private and public sector expect responsible behaviour. Balancing economic and societal capital creation is the call of chapter 9 (Lind and Lehmacher, 2023).

We assert that all industries need to place greater emphasis on the interrelationship between *collaboration* (c) and *digitalization* (d), as this powerful duo impacts *economic* (e) and *societal* (s) success through enhancing human and social capital and preserving and restoring natural capital. A *cdes* mindset can take supply chain management and logistics practices to higher levels of symbiosis.

Collaboration and digitalization are critical drivers of economic and societal value creation. These drivers need to be mutually reinforcing to generate synergistic gains. Digitalisation promotes collaboration through swift and efficient digital information exchange enabling effective coordination. Simultaneously, digitalisation requires collaboration. Otherwise, it is destined to fail or produce suboptimal results. In the biological world, many species have symbiotic relationships, mutual dependencies, with other species to increase their ecological fitness. There is a symbiotic relationship between digitalisation and collaboration. Neither can exist without the other, because they co-determine economic fitness. Successful partnerships co-evolve their collaboration through cooperative digitalisation to contribute to an emerging era of digital symbiosis.

Decarbonization of supply chains thus requires end-to-end, closed-loop, and cradle-to-cradle thinking and particularly digitalisation and collaboration. Decarbonizing shipping is about working together towards an economy in which GHG emissions and waste are avoided and products and materials are used to the maximum extent possible. This is empowered by digitalisation and creates and increases economic and societal capital.

The world needs a new paradigm. The *cdes* model, focusing on collaboration and digitalisation for balanced economic and societal value creation, is intended to guide industry action. While currently, incorporating the *cdes* approach might be a voluntary business model shift, new regulations, particularly in Europe and North America, will make this new recommended way of thinking and operating a prerequisite for economic survival.

It is therefore recommended that all actors place greater emphasis on the *cdes* approach. Focusing only on one of both dimensions of each pair, either on collaboration or digitalisation, or on economic or societal value, leads to suboptimal results. A conscious, holistic approach addressing all four components of the cdes formula ensures durable wealth and well-being for humanity. A *cdes* mindset can take decarbonization in the maritime sector to higher levels.

10. Place a strong focus on people

People, and particularly seafarers, are a critical success factor for maritime decarbonization. This is the message of chapter 14 (Platten et al., 2023). Without a trained workforce in ships and in ports, the decarbonization movement will struggle. To limit the otherwise devastating impacts of climate change, unprecedented collaboration is needed to facilitate rapid moves away from the use of carbon-intensive fuels to renewable energy sources. It is therefore recommended that governments, employers, workers, and all stakeholder groups work together to create positive change, investing in new fuels, technologies, and infrastructure to enable a green transformation.

The guiding principles of a Just Transition are established in the International Labour Organization (ILO) 'Guidelines for a Just Transition towards environmentally sustainable economies and societies for all' (ILO, 2015). These guidelines are the main globally endorsed framework on Just Transition. They reflect the views and perspectives of governments, employers, and workers' organizations and outline principles and potential policy entry-points to promote and manage a Just Transition; and are relevant for all countries and sectors, including shipping.

In the outcomes of the 27th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP27) at Sharm el-Sheikh, Egypt, and in particular, the Implementation Plan, governments 'emphasised that enhanced effective climate action should be implemented in a manner that is just and inclusive while minimizing negative social or economic impacts that may arise from climate action' (UNFCCC, 2022). They also affirmed 'that sustainable and just solutions to the climate crisis must be founded on meaningful and effective social dialogue and participation of all stakeholders' (UNFCCC, 2022).

The global seafaring workforce will be key to powering shipping through a successful transition. Low-carbon (transitional) and zero emission fuels, technologies and ships are expected to introduce new skillsets and training needs for seafarers, requiring a health-and-safety-first approach. A maritime just transition for seafarers will therefore ensure that those seafarers have the adequate skills, education, training and familiarisation, to operate new technology systems on board and to manage new fuels.

Alongside governments, employers and workers (including in shipping) also have a role to play as social dialogue is key. The effort could entail, for example, ensuring that there is Just Transition planning, as part of wider decarbonization plans. Some companies, including from the energy sector, have also developed Just Transition plans. It is recommended that businesses support a just transition through their own policies and strategies (UN Global Compact, 2022).

11. Ensure global alignment of regulations related to decarbonization

Chapter 15 (Tikka and Esau, 2023b) makes the point that the adoption of decarbonization enablers has been led by early movers while others are waiting for regulatory mandates. Consequently, the change in carbon dioxide (CO_2) emissions from shipping is not on track with the Paris Climate Accord target of limiting global warming to 1.5°C. The fluctuations can be attributed to the changes in trade volumes and reductions in ship speed (in other words, slow steaming) rather than decarbonization measures adopted by the maritime industry.

Effective global regulations and climate ambitions play a critical role in achieving steady progress across the global fleet. According to the *Mærsk Mc-Kinney Møller Center* for Zero Carbon Shipping *Maritime Decarbonization Strategy 2022* (MMMCZCS, 2022), even if the net zero pledges made by shipowners in the tanker, bulk, container, and RoRo/car carrier sectors materialise, they would translate to only a 13% reduction in global emissions from the sector.

The shipping industry has demonstrated in the past that environmental goals can be reached once there is regulatory clarity. Successful past regulatory developments include the introduction of double-hull tankers, which has contributed to the significant reduction in oil spills from tankers (NASEM, 2022). However, past regulations were silo-approached and a more holistic climate regulation, taking into account the various effects and different sorts of emissions and pollution, is recommended.

The International Maritime Organization (IMO) has its unique role and mandate to regulate global shipping. Within the IMO structure the Marine Environment Protection Committee (MEPC 79 /INF 21 (2022)) addresses

environmental issues. The process within MEPC, and more widely in the IMO, is largely based on finding consensus. Since the GHG regulations will have wide-reaching impact on IMO Member States, finding agreement can be challenging as it requires that the regulations be perceived as fair and equitable by multiple parties in different circumstances.

In 2018, the IMO agreed on an initial GHG strategy (MEPC 304(72) (2018)) with a goal to cut annual GHG emissions from shipping by at least half by 2050 compared with the emissions in 2008, and to work towards zero GHG emissions as soon as possible. The strategy included an ambition to reduce the international shipping carbon intensity by at least 40% by 2030 and 70% by 2050, compared to 2008. As these targets are not in line with the Paris Agreement the strategy is being reviewed in 2023 with the aim to align with the Paris Climate Accord target of limiting global warming to 1.5°C. There needs to be better alignment with IPCC AR6 (IPCC, 2023) which calls for 50% reduction in GHG emissions across all sectors by 2030.

Recent regional developments in the EU show that it is possible to opt for ambitious maritime regulations that set a price on shipping emissions and regulate the use of certain fuels on board. After more than two years of negotiation, the European institutions came to an adopted agreement on including maritime shipping emissions, including in ports, in the European Emission Trading System (ETS). The system will be phased in between 2024 and 2026 and starting from 2027 also methane and nitrous oxides (NOx) emissions will come into scope (EU 2023/957). This should not be regarded as a measure with only regional impact. The EU maritime ETS will also have an impact on part of the voyages outside EU waters as it covers voyages between the EU and the rest of the world, where ships docking into an EU port will have to comply. There are also provisions to avoid evasive port calls to nearby non-EU ports However, a mechanism to account for potential developments at IMO level, if they occur and are of equal climate ambition, is built in. In addition, a provisional agreement that sets energy intensity targets of maritime fuels used on board for ships that go to or depart from EU ports is set to be adopted very soon. It is an interesting time ahead in terms of maritime regulatory implementation and the EU is taking a very ambitious stance.

A sound regulatory framework with clear and ambitious targets in place is recommended as this is crucial to providing the industry with the direction it needs to invest in technologies that will advance the decarbonization of the maritime sector and meet the climate change targets set out by the

Paris Climate Accord. All those involved in the industry have a part to play. It is recommended that participants should consider:

- Provide input into regulatory development at IMO by engaging directly with the Member Governments, or through NGOs with consultative status at the IMO.
- Provide input to regional regulatory development, such as the EU, by engaging with Governments and NGOs.
- Support a well-to-wake-approach and life cycle assessment (LCA) methodology in emission regulations.
- Adopt a dual-term GHG accounting standard: 20-years global warming potentials (GWPs) alongside the accepted 100-years GWPs as ships are 20 to 30 years assets and environmental and climate tipping points are likely to be reached within a 20 years scope.
- Call for the removal of subsidies for fossil fuels (direct and indirect).
- Support the use of actual cargo carried in the formulation of the Carbon Intensity Index.

The public and private sector need to support each other by providing transparent information in respect to effective decarbonization and other emissions and pollution reducing (technology) measures. Accordingly, the developed countries should support the LDC governments with capacity building and funding and ensure that they can deal with all the documentation issued and are able to derive effective strategies from it.

12. Leverage circular economy principles as a driver for systemic change

Chapter 18 (Jensen et al., 2021) explains that without a competitive global circular economy, we will not be able to reach the global climate and environmental goals. The current leading sustainability measures in the maritime sector, as well as in most other industries, focus primarily on electrification and alternative fuels. However, these two paths together only address 55% of emissions. The remaining 45% comes from producing

the cars, clothes, food, equipment, and other products we use every day (Ellen Macarthur Foundation, 2021).

Although circular economy business models (for example, re-manufacturing) are widespread among sectors that produce capital-intensive and durable goods (including other transportation sectors such as aircraft, aerospace, automotive and rail), they tend to be underdeveloped in the maritime industry (Wahab et al., 2018; Milios et al., 2019; Sornn-Friese, et al., 2021). There are several '*semi-circular business models*' in the existing maritime industry such as sharing equipment in container logistics, chartering, reselling ships, and ship demolition (Jensen, et al., 2021). However, an efficient global circular maritime sector is not yet in reach.

Service-based business models such as renting, sharing, and pay-per-use can increase the utilisation (that is, the intensity of use) of maritime products and assets, as well as their lifetime. During ship operation, numerous interventions can be initiated to enable circularity. These include onboard repairs, drydock, retrofit and refurbishing. Implementing modular designs in shipbuilding and standardising ship parts can greatly enhance the ability to refurbish, repair, upgrade, and recover components and resources when ships reach the end of their operational life. Keeping maritime products and components in use at their highest value at all times means their embodied energy is preserved for longer, and the need for new production and end-of-life treatment is reduced.

At the end-of-life phase, recycling activities help avoid even some of the hardest to abate emissions from production and incineration by bypassing the need for new material production and using less energy-intensive facilities compared to the production of virgin materials. One of the key materials in shipbuilding is steel. Steel recycling is already well established, with a largely electrified process. However, current product design, end-of-life dismantling, and scrap handling processes are polluting and degrade the quality of the steel. Increasing recycling rates would therefore require measures to prevent the downgrading of the steel stock (Önal et al., 2021). Okumus et al. (2022) have identified '*that current practices in the ship recycling yards prevent the full utilisation of the industry's recycling potential'.* Increasing recycling rates for plastics can be reached by improving uptake and quality. Key measures include improving recyclability, collection, and sorting processes, as well as reducing contamination of recycling streams and exploring the potential of chemical recycling to maintain or restore virgin quality (Aurisano et al., 2021; UNEP, 2023). There

is also an untapped potential through harvesting rare-earth materials in the maritime sector, such as cerium (used for ignition in some engine types), terbium (in lighting systems and navigation equipment), and yttrium (used in such things as compressors, radar systems, and turbochargers).

Full decarbonization requires circular thinking. Whether it is in the area of ship recycling or green steel. The circular economy model has the potential to play a pivotal role in addressing climate change. The maritime industry can extract a lot of value from rethinking how it extracts, produces, consumes, uses, re-uses, upcycles, recycles and ultimately rethinks its attitude towards resources. Circular economy thinking will drive new business models that are in line with nature and climate.

It is thus recommended that the maritime industry embraces circular economy principles to capture an additional critical and extensive source of GHG emissions reduction potential and drive systemic change. Of importance are modularisation and the minimisation of toxicity of materials to be recycled. Product information will be critical and the responsibility for breaking and circularity of ships needs to clarified. Banning of last-minute cash sales of ships heading for breaking may also be part of the mix.

13. Boost global research in maritime decarbonization

As outlined in chapter 17 (Manderbacka and Forsström, 2023), the global research communities play an important role in the efforts to decarbonize maritime transport by identifying and developing technologies and strategies that can reduce greenhouse gas emissions from shipping. This can include the development of low-carbon (transitional) but more importantly zero emission fuels, and propulsion technologies, as well as the identification of policies and regulatory measures that can encourage the adoption of these technologies. Open source is a way to spread the benefits of these technologies equally across the globe and ensure a more inclusive approach.

The role of research in decarbonizing maritime transport is to identify and develop technologies and strategies that can reduce GHG emissions from the shipping industry, inform the public and policymakers about the potential benefits and challenges of decarbonization, and assess the potential impacts of decarbonization on different stakeholders.

Substantial research and development (R&D) effort is still required and recommended to make the technologies expected to contribute to the lowering of emissions from shipping by 2050, or even better to be market ready before 2040. The technology readiness level (TRL) of the most frequently discussed alternative fuels, such as ammonia, hydrogen, methanol (bio or CCS), falls in the range of TRL 4-7, meaning somewhere between development and prototyping, where fuels are in an earlier stage of development. Reaching TRL 9 (proven in operational environment) still represents a significant leap in maturity and will take from several years to decades, depending on various factors such as availability of funding and level of collaboration. This highlights the need for large-scale testing, and validation in the real environment with full-scale pilot demonstrations. Many of these demonstration projects are run in form of partnerships. In addition, there are many research groups and initiatives focused on maritime decarbonization within universities and research institutes in the developed world. Capacity needs to be built in less developed countries.

In the report 'Mapping of Zero Emission Pilots and Demonstration Projects' (Getting to Zero Coalition, 2022), pilot and demonstration projects are described as the key to accelerate the energy transition within the maritime industry. In the same report, a comprehensive screening of current pilot projects is presented and reviewed. The number of pilot and demonstration projects has grown rapidly during one year. At the time of publication in March 2022, 203 projects were identified, compared to 106 projects a year earlier. The acceleration in the number of projects indicates the industry's increased interest and need to decarbonize. While these efforts are highly appreciated, the movement needs to pick up more pace to keep up with the needs of the maritime industry.

Research that covers the full field of decarbonization is needed with a specific focus on next generation technologies like fossil free fuels and other zero GHG technologies and solutions. It is recommended that research, regulation, and experimentation are driven in parallel because it is the trio of academia, governments, and business that form the key pillars of decarbonization.

14. Adjust to finance requirements in a more sustainable age

As elaborated in chapter 19 (Biermans et al., 2023), sustainable finance is becoming an important factor in the maritime sector. Sustainable finance refers to financial products, services, and activities that demonstrate a positive impact on the environment and/or on societal matters. It encompasses a wide range of financial instruments (such as sustainability-linked bonds, sustainability-linked loans, green bonds, green loans and sustainable bonds) and practices that support the transition to a more sustainable (and in some cases also a more equitable) society.

Over the past decade, integrating Environment, Social and Governance (ESG) factors into investment decisions has become increasingly important. This shift has been driven by regulatory pressure and investor preferences. During that same period sustainable finance became more prevalent in various financial products. A baseline helps to understand the magnitude of such shifts and make assessments more comparable. The designation by the IMO of the year 2008 as the baseline for its emissions reduction targets was fortuitous, since it was one of the worst years for GHG emissions.

Financing the decarbonization of shipping will require a combination of both public and private funding sources. Governments and international governmental organisations, being the public sector, can and already do, play an important role in providing financial incentives, such as through providing subsidies, tax credits and other financial incentives, to encourage investment in low-carbon (transitional) and (net) zero emission technologies. In addition, these institutions, can alter conditions through new policies in ways that can benefit those companies that are quicker to decarbonize. At the same time, the transition towards a low carbon sector

will require a lot of private sector investment, particularly from ship owners and operators. In addition, innovative financing models, such as green bonds and more general sustainable finance is recommended to be used broadly to play a bigger role in financing decarbonization efforts in the maritime sector.

Leasing models, pay-as-you-save and other types of financing models have been proven helpful when focused on wind propulsion (free energy) and energy efficiency technologies as these have pay back periods that can be leveraged. A key issue around newbuilds of zero emissions and primary wind vessels (Todd, 2022) is the long-term commitment from charters to give for example guaranteed 5 to 10 years contracts to unlock finance for those builds.

Although the maritime sector was not necessarily at the forefront of the advance of sustainable finance, various elements of the sector have embraced it all the same. A number of maritime companies have issued Green and Sustainability linked Bonds and/or have taken out sustainability-linked loans with many more considering obtaining them. In the maritime space, sustainable finance has been used to finance a range of projects that promote sustainability. Green bonds have been used to finance the construction of energy-efficient ships and the retrofitting of existing vessels with more sustainable technologies.

The data shows the very large increase in annual capital deployed in the Maritime Sustainable Finance transactions, from slightly above 2 billion USD in 2018 to more than 9.2 billion in 2021. The largest growth has been in the form of sustainability linked loans.

The EU Emissions Trading System and global carbon credit markets will impact the decarbonization of shipping. Shipping will be gradually included in Emissions Trading System (ETS), with full inclusion by 2027, leading to an increase in costs. Given this anticipated cost increase, the ETS is expected to accelerate the demand for cleaner ships and retrofits, speeding up decarbonization in the sector.

The green finance developments only accentuates the need for ship owners to change their current operations if they want to have access to finance and remain competitive in a rapidly changing market. In addition, market-

based measures also generate significant revenues which can in their turn be used to speed up the green transition. As an example, part of the EU ETS revenues (around 20 million allowances) will be recycled back to the sector (EU 2023/957). Depending on the emissions allowance price, this amount will range between 1.7 up to 2 billion euros. It will be key to focus these revenues on innovative projects that accelerate the update towards net-zero climate solutions.

Concluding thought:

Be an early-mover: even if you choose not to be a single pioneer, be prepared to be an early adopter

Decarbonization challenges business models, contractual arrangements, legal and regulatory frameworks, working conditions and current skills. No one can tackle this piecemeal or in isolation. The maritime ecosystem is critical to the global economy, but it can be fragile, as we have witnessed during the SARS-CoV-2 pandemic when fleet capacity and equipment shortages, port congestion and major crew change issues contributed to supply chain disruptions around the world. Decarbonization requires a holistic approach that addresses the challenges from different angles and is based on collaboration and learning from each other. We do not need to wait and hope for the decarbonization *silver bullet* in order to make progress now.

Without pioneers, little may happen in maritime decarbonization. Pioneer protection is therefore critical. The importance for early-movers is emphasised and discussed in Chapter 10 (Bentham, 2023b) along with the frequently underestimated economic value of forerunners. Decarbonization also needs a nurturing space where inventors and innovators thrive, with an iterative process of development and learning in place. A space where they can also meet incumbents seeking innovation partnerships. System demonstrators are one form of creating a real-life innovation and adoption space.

We stand at a breakpoint in time in terms of investment choices that will be made by shipping companies. Some will be bold and go beyond the targets that are currently set, leading as industry role models. Others will adopt a rather 'wait and see' approach. However, what we need is to avoid that many wait too long and we collectively miss the boat, literally. The course is altered towards a climate neutral sector. It is time to get as many actors on board as possible to keep our planet liveable in which every sector needs to carry its weight, also the maritime sector.

In his TED talk, Derek Sivers[10], author of philosophy and entrepreneurship, explained the critical role of the first follower. If we wish decarbonization to turn into a mainstream movement we need early adopters. For this reason, it is the last, but not least call in our list of calls to action and the final recommendation.

Pioneers and fast-followers, please reflect on the recommendations and encouragements in this book, learn from the knowledge of the broad range of experts that have contributed, the projects, case studies, experiences, and the success stories that they have shared. All can fuel you on your journey of transition towards a climate neutral future.

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