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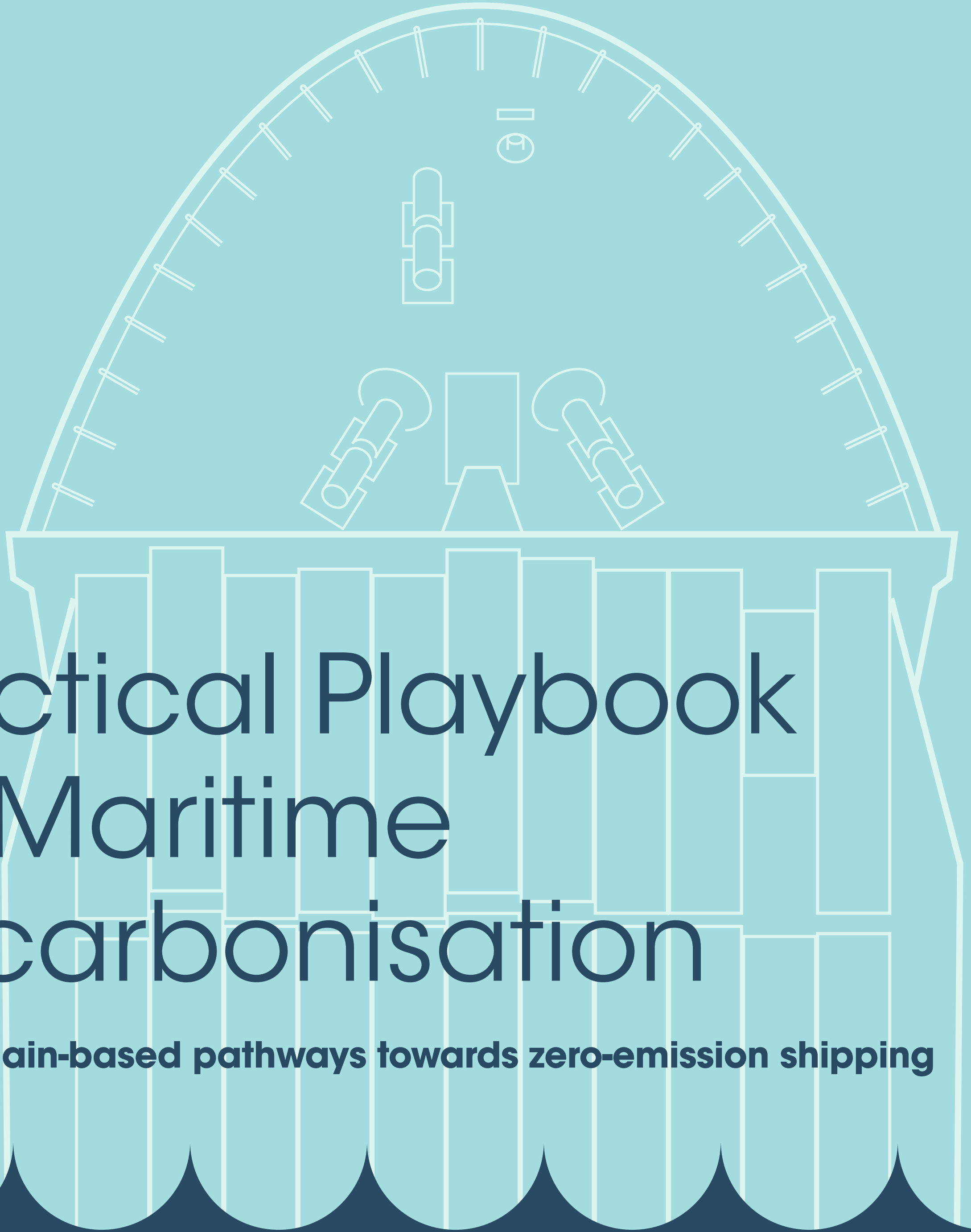

Practical Playbook for Maritime Decarbonisation

– Value chain-based pathways towards zero-emission shipping

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Executive summary

How to speed up the transition to a more sustainable and more profitable maritime ecosystem? How to accelerate the decarbonisation of shipping? Answering these two questions brought together a diverse group of contributors from different parts of the maritime industry and the global decarbonisation ecosystem. The participants included representatives from 13 companies, five international organisations and one academic institution. We have been motivated by a strong commitment to work together for a better future for the oceans and the globe.

Initially, we developed three scenarios that describe three plausible future worlds. Then, we developed pathways and recommendations on how to reach the best possible scenario from a decarbonisation perspective. We set ourselves two timeframes. First, we looked at what could happen to climate change in each of the three scenarios during this century. Second, we analysed what needs to happen in the maritime industry during this decade to produce the best possible outcome.

Illustration: Sandra Haraldson

The reference points to measure the outcome of each of the three scenarios are the IMO 2018 ambitions and the Paris climate goals. The International Maritime Organization (IMO) has challenged the shipping industry to cut annual greenhouse gas (GHG) emissions by at least half by 2050, compared to 2008. The 2015 Paris Agreement commits countries to limit the global average temperature rise to well below 2°C above pre-industrial levels, and to aim for 1.5°C.

Storms

The different scenarios produce different results. The worst outcomes are produced by a scenario labelled Storms. This is a world of nationalism, geopolitical conflicts, and a worsening climate crisis. In this scenario the Paris climate goals, and the IMO 2018 decarbonisation ambitions are both missed.

Swells

The moderately good scenario is called Swells. Swells is a nautical term that refers to the slow up and down movement of the sea with large but smooth waves. In the beginning, businesses and governments concentrate on growth. Everything looks good for a while. Decarbonisation is advancing slowly. Then the climate crisis intensifies increasingly disrupting shipping services and ports. Quick, abrupt changes are needed and finally initiated. But these are costly and cause significant disruptions. Yet, late but accelerated decarbonisation is not enough to reach the IMO 2018 ambitions but eventually the Paris goals are met.

Clear Sky

The best outcomes from a decarbonisation perspective produces a scenario named Clear Sky. Politicians, business leaders, citizens, and investors worldwide are aligning to reach the Paris climate goals and IMO 2018 ambitions.

The private sector takes initiative individually and collectively, and policymakers are supporting the efforts with policies and regulatory frameworks and through promoting sustainable business and innovation. In this scenario, the Paris goals are met but the IMO 2018 ambitions are still missed. Consequently, even in the fastest moving decarbonisation scenario considered, the current state-of-play of enablers, and the progress anticipated, indicates that a move onto the front foot now is not only a non-regret strategy but an indispensable step. This is the only way for the maritime industry to ensure that the maritime industry aligns with the Paris agreement and exceeds the IMO 2018 ambitions.

The participants in the study generally believe that we are living and operating in a Swells environment with increasing tendencies towards Storms. But the group sees also a pathway towards Clear Sky. An initial bundle of actions is summarised in the following seven recommendations for public and private sector stakeholders to act upon.

☸ Recommendation #1: Build scenarios to stress-test current decarbonisation strategies per value chain and across clusters

Underlying finding: Scenario thinking, and their sharing, helps to manage risks for example to avoid stranded assets and develop understanding across the cluster of maritime value chains of different pathways to the future and to outline their implications for decarbonisation

Conclusion: We can leverage the strategic context which the different scenarios provide

☸ Recommendation #2: The maritime industry to urge IMO member states' governments to support[i] the proposed "zero by 2050" plan[ii] and follow through the current roadmaps with detailed targets

Underlying finding: All developed scenario pathways show that we don't get anywhere near the 2018 IMO decarbonisation ambitions, and yet indicate the potential competitive and commercial advantages from acceleration

Conclusion: We need a stronger ambition and more aggressive pathway based on accurate GHG calculation and monitoring

☸ Recommendation #3: Establish cross-value chain coordination, e.g., through partnerships and zero-emission corridors / networks

Underlying finding: We face bottlenecks and gaps in decarbonisation across interdependent value chains, e.g., we have dual-fuel engines but not enough alternative fuel

Conclusion: We need a holistic approach to decarbonisation and a cluster view on value chains of fuel, shipbuilding, and operations

☸ Recommendation #4: Every actor and sector in the industry needs to identify and focus on its relevant enablers across their respective value chains to achieve company, industry, and country milestones

Underlying finding: There is no single silver bullet, however this is not a curse but a cure in our diverse world in different stages of development

Conclusion: We need to remain flexible and develop the "37 enablers" for different cases and sustainable profitability

☸ Recommendation #5: Create a global public-private coalition of the willing to identify / activate scalable enablers across all chains

Underlying finding: Given all circumstances regulators are ill-prepared to decide or guide the maritime sector in respect to what enablers to activate along and across the chains

Conclusion: Leading players in the industry need to take initiative and show what works and what doesn't so that other public and private actors are better informed for their own decisions; but what works for one may not work for others

☸ Recommendation #6: Establish sufficient, transparent, and predictable financing and pricing mechanisms, like a levy on high carbon marine fuels and subsidies for low carbon solutions

Underlying finding: Making decarbonisation in the maritime industry work requires pathways that are financially incentivised and viable across all chains

Conclusion: We need to find ways to trigger and finance the change

☸ Recommendation #7: Act now! In our self-interest to avoid exponential decarbonization costs

Underlying finding: Many decarbonisation enablers are ready to use, and decarbonising shipping is a complex and costly task that will become more costly if further action is delayed

Conclusion: We can already activate a range of decarbonisation enablers across the maritime value chains and accelerate developments that are in the broader self-interest of all stakeholders

This report is to be found at nordicwestoffice.com/maritime

Foreword

How to achieve the transition to a sustainable and profitable maritime economy? The answer to this highly relevant question is at the centre of this report.

The context has changed dramatically since our work began. When we started, the world was emerging from a long pandemic. When we finished, the unprovoked attack on Ukraine had been ongoing for three months. This dramatic turn of events has spotlighted even more clearly the need to review our expected futures and the value of scenario thinking. The scenarios applied in this project are based on Shell Energy Transformation Scenarios which were expanded fully into the maritime context. The resulting maritime transition scenarios were the foundations from where a framework, key takeaways, recommendations, and a call to action were derived.

The transition to a sustainable and profitable future of shipping will be brought about by a focus on interrelated clusters of identified value chains, a collective approach with all stakeholders living up to their roles and responsibilities, and continuous exchange and learning. In our fragmented world, diversity of drivers is not a curse but a potential cure, and flexibility is a prerequisite for effective operations.

This report aims at assisting the members of the maritime industry, including public sector representatives, to align and focus their resources and efforts on the main drivers of decarbonisation through a common framework and a shared nomenclature.

I extend my appreciation to the two authors, the five lead experts, the 19 companies and organisations, the four reviewers, and the 45 individual contributors listed in appendix 10 that were involved throughout this process for their outstanding contributions to this report.

This project is a fine example of what a “coalition of the willing” can achieve. We hope that our message to the maritime business community, the energy industry, regulators, and policymakers will be heard and translates into an acceleration of decarbonisation efforts of the shipping industry.

Risto E J Penttilä
Nordic West Office
June 2022

Setting the scene

The International Maritime Organization (IMO) has challenged the shipping industry to cut annual greenhouse gas (GHG) emissions by at least half by 2050, compared to 2008. These ambitions is currently under review as net zero by 2050 is under discussion. The challenge is enormous and inter-disciplinary. The International Chamber of Shipping points out[i] that," the world's renewable energy generation would need to increase up to 100% just to supply enough (net) zero carbon fuel to power the shipping industry". The international organisation also states that decarbonising shipping will create significant opportunities. Given the harmful effects of global warming, the shipping industry needs in its own interest as ports and ships are facing increasing risks e.g., due to rising sea levels and natural disasters to act urgently, collaboratively, and comprehensively across multiple dimensions to put the shipping industry on a path to zero emissions.

This need for critical and rapid action is acknowledged by many of the industry's major stakeholders.[ii]

The business model, meaning the operator / charterer determines how a ship is built and used during its lifetime. Ships are operating locally, like in inland waterway shipping; regionally, like in shortsea shipping; and globally in deep-sea shipping. Liner services, like deep-sea container shipping, use ships on regular routes visiting a limited number of ports in their port rotation; tramp ships sail where they are in demand visiting a broader variety of ports across the globe; the same is true for cruise ships which call at many and often smaller ports to bring passengers to any touristic paradise accessible by sea. Ships are used by different customers with different types of merchandise resulting in demand for dry bulk ships and wet bulk ships like very large crude carriers (VLCC). 43% of the maritime shipping is occupied with transporting energy across the world[iii]. Some ships stay for decades with the same owner; others change hands after a few years which does not promote a long-term perspective.

With this complex context, decarbonisation in shipping needs extensive knowledge-building

This study, initiated and orchestrated by the Nordic West Office in Finland, brought together a diverse group of contributors from different parts of the maritime industry and the global decarbonisation ecosystem to identify pathways towards a zero-emission shipping sector, bringing to light the most practical approaches and solutions that contribute to reaching the IMO ambitions and a zero-emission shipping future. While a full concensus on every exact detail of the report has not been reached, all participating organisations and experts appreciate the initiative and support the recommendations, and the call to action.

Although this work is not an academic exercise, it follows a clear process to analyse, structure, and complement the contributions of the members of the mixed group of experts (Appendix 10). The process has resulted in outcomes that include an analytical framework, an analysis of the findings with conclusions, and a set of concrete recommendations with a call to action to inform, assist and guide decision-makers in the public and private sector. Derived from the study work, this report includes also a practical playbook helping actors in the public and private sector to plan and drive their decarbonisation efforts.

The study confirmed the complexity of the topic. The maritime industry may draw on past experiences like the slow LNG built-up which was mainly led from the outside by the energy sector which took more than a decade to achieve a relatively small share in the mix and the Sulphur 2020 requirements which after triggering a lot of discussion in the maritime industry were met almost overnight.

Each maritime business model drives different approaches and decisions on energy needs and decarbonisation based on factors that need to be deeply understood.

Navigating uncertainty: Three maritime transition scenarios

The mindsets of decisionmakers are reflected in their visions of the future. Such perspectives can be explored with the help of scenario thinking. Therefore, three Shell Energy Transformation Scenarios have been used to kick off, frame, and inform the discussions during the study work. Those scenarios were chosen as the point of departure as they explore boundaries for how the world might develop in the next decades providing the grounds for decision-making in the public and private sector. They consider the impact of different balances of socio-political priorities in the coming years as societies recover from recent and ongoing crises. All societies seek wealth, security, and health / well-being, but specific circumstances and political choices may lead to one factor being particularly emphasised. This leads to different possible pathways for industrial development, energy transitions and decarbonisation of the global economy and individual sectors.

Concretely, the names of the three Shell scenarios are **Waves** with wealth prioritised first, **Islands** with security first, and **Sky 1.5** with health / well-being first. The primary interests indicate where decarbonisation is placed on the agenda. Only in Sky 1.5 is the decarbonisation effort a top priority, with its focus on well-being, learning from experience and from others, and reforming institutions whose weaknesses have been exposed through recent crises. In Islands, with its focus on autonomy and self-sufficiency, decarbonisation mainly happens when it fits into the local parameters, e.g., the local energy supply. In Waves, with its initial focus on (easy) short-term economic growth, decarbonisation initially happens only when financially viable in the short-term without targeted policy support or effective alignments between stakeholders to open new opportunities. Subsequent backlashes in Waves, however, occur later when extreme weather events are blamed on previous lack of action, leading to knee-jerk regulation driving rapid but disruptive decarbonisation (Appendix 2).

Starting later than required to meet the goal of the Paris Agreement, Waves achieves an energy system with net-zero emissions eventually – *late but accelerated decarbonisation*. The Islands world overshoots the timeline and does not achieve the goal of the Paris agreement – *late, slow and costly decarbonisation leading to adaptation*. In Sky 1.5 leading economies achieve the goal of net-zero by 2050, supporting less developed nations. The goal of the Paris Accord is met – *accelerated decarbonisation now.*

Although this may only be a snapshot based on current sentiment, the group of experts generally thinks that we are living in a Waves environment with increasing tendencies towards Islands. This shows that our priorities are mixed but gravitate towards one or two poles. Today we gravitate strongly towards Waves because of a reality in which financial capital is perceived as a dominant factor in securing resilience. But we also move towards a stronger Island future because of the current (homeland, food, energy etc.) security concerns influenced among other factors by the SARS-CoV-2 pandemic and the Russia-Ukraine war. Although this mixed reality may persist, the experts wish that we eventually transition towards the behaviours explored in Sky 1.5 where lessons are learned from, e.g.:

1. the successful combination of competitive and collaborative dynamics that drove accelerated vaccine development and spread of good medical practices in the face of the Covid-19 pandemic,

2. the effectiveness in job creation of the investments in green technology deployment in responding to the 2008/9 global financial crisis,

3. the domestic industrial advantages surfaced in the past by green technology development and deployment (e.g., in solar photovoltaic and electric vehicles) and the commercial competitive races this initiated

Decarbonizing shipping: Maritime Transition Scenarios

Swells

- Uncertainty about key decarbonisation technologies, but pioneer private and public actors undertake strategic moves
- Starting point for less prosperous stakeholders to adopt greener approaches when obliged following a build up of pressures at extensive costs starting early/mid 2030s

Storms

- Sluggish global trade outlook and focus on domestic economies adding friction to accessing capital for investment in new and greener technologies and practices
- Heterogenous landscape in regulation and a drift away from IMO legislation

Clear Sky

- Increasingly powerful maritime decarbonisation coalitions driving steady reductions in carbon emissions
- Developments emerge across all areas of the maritime industry, with improved alignment between sea and land connections

Figure 1: Maritime Transition scenarios derived from the general (Shell) scenario narratives

The three potential futures developed by Shell were expanded into the maritime transition scenarios: **Swells** with economic recovery first, **Storms** with local / regional interests first, and **Clear Sky** with global maritime decarbonisation first – driven by competitive interests and alignments (figure 1).

Swells is the continuation of the fossil-fuel powered maritime sector until pressures have built up to such an extent that there is no other option left but to force the undertaking of everything thinkable and doable to decarbonise shipping. Storms suffers from reduced global knowledge exchange and coordination due to its focus on local / regional solutions which may benefit inland waterway shipping, shortsea shipping and ferry services but not deep-sea shipping. In this scenario, progress in deep-sea operations is therefore the result of initiatives launched by pioneering players and partnerships transcending the silos. Only Clear Sky brings global exchange, widespread alignments and collaboration that drives steady decarbonisation of the maritime industry across the globe over all sub-segments and types of business models.

Different futures (scenarios) result in different pathways of decarbonisation in terms of intensity and timing. Mapping those scenarios helps us to make better decisions through forcing the consideration of the robustness and attractiveness of actions across different circumstances. We cannot know in advance in detail which type of scenario will unfold and we need to recognise this inescapable uncertainty, but the scenarios can help guide us towards decisions most likely to be robust and attractive.

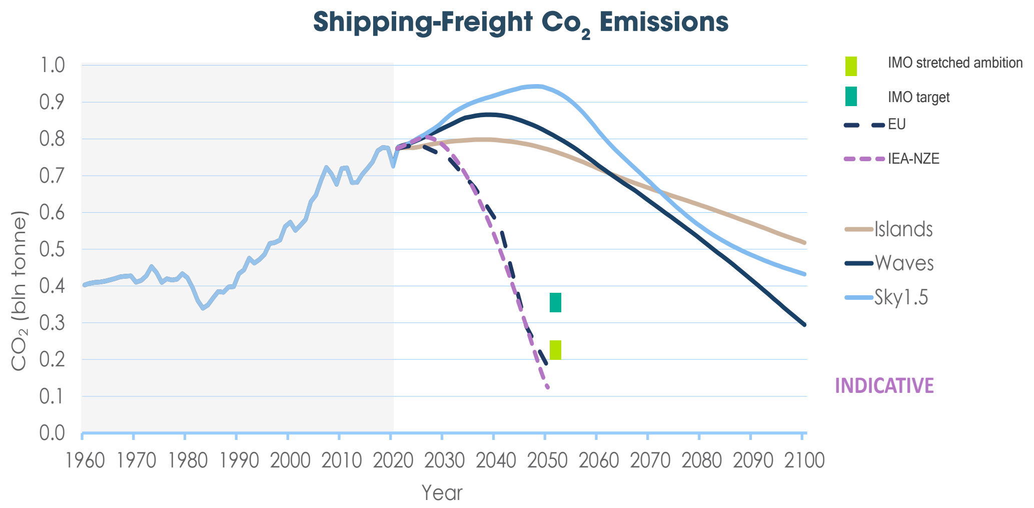


Figure 2: Progression forecasts of Shipping-Freight carbon dioxide emissions (Source: Shell Energy Transformation Scenarios 2021, IEA, IMO and compiled by Wim Thomas)

The projections prepared based on the three maritime transition scenarios show that decarbonisation efforts in the maritime sector need to be accelerated as none of the resulting pathways brings us close to the IMO 2018 ambitions (figure 2).

Scoping out the decarbonisation space: The cluster of critical maritime value chains

It is essential to consider the complete cluster of value chains that are critical for decarbonising the maritime sector, namely the **marine fuel value chain**, the **shipbuilding value chain**, and the **maritime operational value chain**.

This cluster of critical maritime value chains needs to be approached holistically and simultaneously from a carbon calculation, design, planning, financing, management, and policymaking perspective. The entire cluster of chains needs to be decarbonised chain by chain and sector by sector, ideally in parallel to avoid gaps and bottlenecks. The discussions for this project have shown that it is often the gaps across the chains that discourage stronger commitments for decarbonisation. The most important current bottleneck is the lack of alternative fuels (see below), but the required area of focus goes even beyond the maritime-specific clusters.

A key enabler for ensuring that the different value chains in the cluster move in the same direction, and quickly, is a predictable multilateral framework. Investors in all clusters need to be given as much clarity as possible about the emissions targets (will IMO aim at zero, or net zero, by 2050, or later?), carbon prices (market-based mechanisms (MBMs) need to be agreed upon as soon as possible), and technical and operational requirements (efficiency targets, speed limits, et al).

The cluster of maritime value chains overlaps with clusters of suppliers, e.g., of steel and equipment needed for shipbuilding, clusters of beneficial cargo owners (BCOs) from many industries, and clusters of other sectors' decarbonisation efforts across the economy that compete with shipping for scarce resources of green power and alternative fuels, like aviation that uses sustainable aviation fuel (SAF). But there are also synergies. Other modes of transports such as trucking can benefit for example from port storage and fuelling capabilities to cover their own needs. Low-carbon and zero-emissions fuels or green / clean / alternative fuels are defined as fuels that are produced, transported, distributed, and used with zero / low GHG emissions, like green LNG / LBG, biodiesel, green methanol, green ammonia, and green hydrogen.

The good news is that we build and operate ships with dual-fuel engines (for fossil and alternative fuels, like green methanol) but instead of running them on alternative fuels we mainly burn IMO 2020 compliant very low sulphur fuel oil (0.5% VLSFO) or high sulphur fuel oil (3.5% HSFO) when the ship is equipped with a scrubber or exhaust gas cleaning system, because low-carbon and zero-emissions fuels (green fuels, clean fuels or alternative fuels) are hardly available today or are not cost competitive.

The high-level strategies for the three maritime value chains derived from this snapshot of today's state of decarbonisation in shipping are (figure 3):

1. ramp-up the alternative (low-carbon and zero-emissions) fuel value chain,

2. accelerate the low-carbon shipbuilding value chain, and

3. adopt low-carbon and zero-emissions fuels, green ships, and other carbon dioxide (CO_2) emissions reducing measures in the maritime operational value chain.

Shippers and regulators are indispensable for the implementation of such strategies.

In addition, the impact of other difficult-to-abate industries and the levy on steel will shape the price of alternative fuel and low-carbon ships respectively and must be accounted for. This calls for a cross-value chain approach that requires broader understanding, communication, and coordination of activities. While challenging, this will create opportunities, like new combined offers and new jobs resulting from the competencies and capabilities needed. This also requires new training providers and new partnerships across the clusters.

Instead of providing only part-solutions to cover the maritime cluster needs, new consortia may emerge that offer complete turnkey solutions. These could encompass, for example, an entire shipping corridor / network including alternative fuel production facilities, fuel storage and bunkering infrastructure in seaports or floating on water, ships equipped with alternative and upgradeable dual-fuel engines, and CO_2 reducing hull design. Such new offerings can not only accelerate decarbonisation due to will aligned value chains but also create lower prices and higher margins as the basis for new competitive advantages.

Decarbonising shipping means decarbonising value chains which represents a major cross-ecosystem challenge but with the effort also come opportunities in form of new growth, new jobs, and a healthier life.

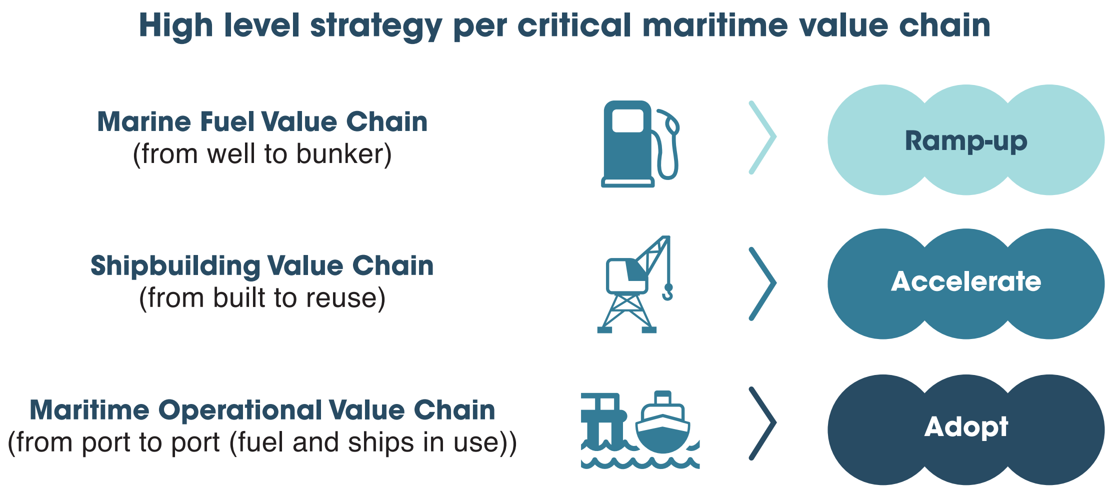


Figure 3: High level strategy per critical maritime value chain

Decarbonisation options: Enablers anchored and assessed

Decarbonisation will be driven by enablers. **37 decarbonisation enablers** were identified in this study and grouped in different categories, namely multi-fuels, regulations, financing, multi-fuel power systems, circularity, port measures, green power-to-X technologies, ship optimisation, and operations controls.

The decarbonisation enablers are sitting across the cluster of maritime value chains. Each enabler may be driving decarbonisation in one, two or all the three maritime value chains (figure 4).

1. One key enabler that cuts across all three maritime value chains is alternative fuel. Many alternative fuels still need to prove their long-term cost competitiveness. But, "wrong picks" may be unavoidable at this stage. As an output of the marine fuel value chain, alternative fuels determine ship design, engines, tanks, storage, bunkering, and ship operations. Another transversal enabler is technology: alternative fuel production technology is needed to produce clean marine fuels, advanced ship engine technology is required to make use of these fuels, and digital technology supports fuel-efficient operations that drive costs and fuel consumption down to reduce the need for scarce renewable energy. A special type of cross-cutting decarbonisation enabler is policies and programmes which set boundaries for the direction of value chain cluster development and incentives for the speed of decarbonisation.

2. Circularity is an enabler that cuts across two value chains: first, the shipbuilding value chain as ships need to be built from recycled material and be themselves again recyclable, and second, the operational value chain as it requires maintenance and repair following circular principles. Alternative bunker marketplaces sit between the marine fuel value chain and the operational value chain.

3. Finally, enablers that support the decarbonisation in only one single chain are, for example, hydrodynamics and low carbon emission hull design in shipbuilding, green power-to-X technologies in the marine fuel value chain, and advanced weather routing in the operational value chain.

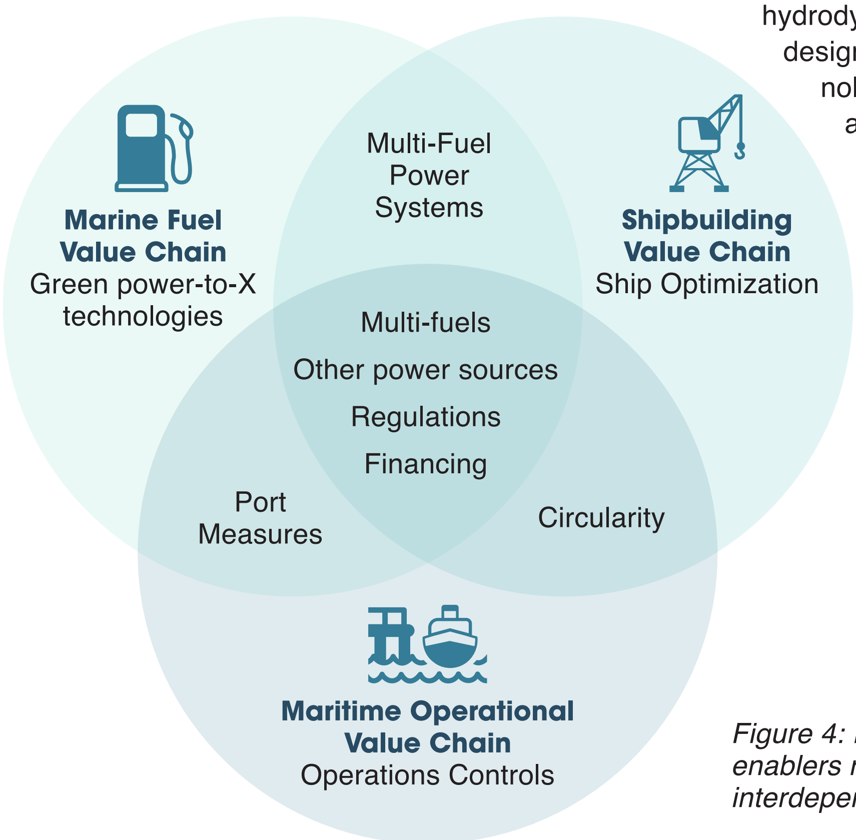


Figure 4: Examples of enablers related to the three interdependent value chains

Many enablers are already mature or close to maturity. Others still need additional research and development (R&D) as well as pilot projects that prove what works and what doesn't. While impact on GHG reduction, ease of implementation, and acceptance across stakeholder are relatively stable criteria, readiness, adoption, and financial viability of the decarbonisation enablers vary from scenario to scenario and sector to sector.

The 37 enablers were assessed using six criteria (figure 5). This is an approximative analysis using scores to provide indications of the merits and the stage of development of the identified enablers dependent on a given scenario. Three factors the enablers were scored on are of a more general nature: impact, ease of execution, and stakeholder acceptance (Appendix 4 and 5). The three other criteria are dynamic: readiness, availability, and financial viability. In line with the horizon in scope of this study the dynamic criteria considered are: now and 2030 in each of Swells, Storms, and Clear Sky (Appendix 6 and 7).

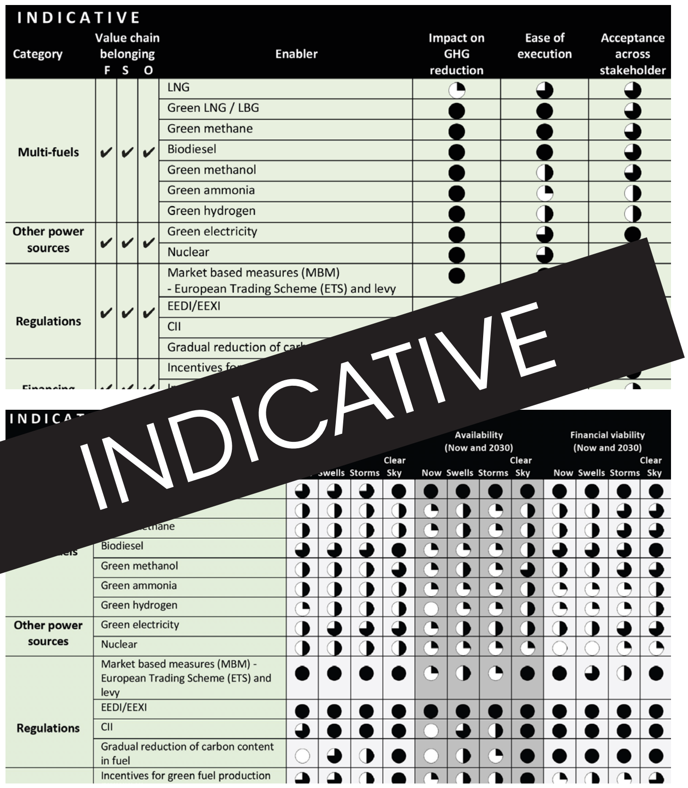


Figure 5: Harvey ball assessment of the 37 enablers explored in the study

Based on this detailed analysis of the 37 enablers we can identify those that are useable at scale or usable within limits now and in 2030 in each of the three maritime transition scenarios (appendix 8). This establishes a deeper understanding of the decarbonisation outcomes per scenario (figure 6). This report calls out five main observations.

1. The enabler analysis shows that actors in the maritime industry can already today leverage a range of solutions to drive decarbonisation; with some enablers having more and others less impact on GHG reduction. The frontrunners in the industry have already activated many of these decarbonisation enablers.

2. An open and collaborative world in Swells and Clear Sky is more favourable to decarbonisation efforts than a siloed one with tensions between the blocs. Speedy and impactful decarbonisation requires globalisation, more precisely joint effort.

3. A fragmented Storms-like global landscape will not bring about a lot of clean developments by the end of the decade but some shifts across the range of usable enablers will occur.

4. A world that makes decarbonisation its priority is the most favourable as this significantly accelerates the clean innovation and adoption creating new opportunities for growth and jobs.

5. The current geopolitical trend that puts focus on food and security concerns does not favour decarbonisation and will not bring shipping anywhere close to its ambitions. Getting closer to the ambitions requires even stronger decarbonisation efforts than those currently envisaged in Clear Sky.

Usable decarbonisation enablers now and in 2030 given the maritime transition scenarios

Figure 6: Usable decarbonisation enablers now and in 2030 given the maritime transition scenarios

The fastest progress in decarbonisation will naturally occur in a world that makes reducing GHG emissions an increasingly explicit priority locally and globally. In this Clear Sky scenario, public and private actors become increasingly aligned on decarbonisation. Actors collaborate on decarbonisation but continue to compete beyond this common goal. This type of world creates over time the highest number of usable enablers (usable at scale or usable within limits) across the cluster of maritime value chains, driving a steady decline of GHG emissions. But such a future may not evolve, or it may take a lot of time till it arrives. Nevertheless, the private sector can push boundaries to accelerate decarbonisation irrespective of potential less favourable scenarios anticipating the costs of non-action.

Irrespective of the direction the world may take, sooner or later the actors in the maritime industry will activate their respective bundles of decarbonisation enablers, either voluntarily or forced by regulators or external realities.

Understanding ecosystem dynamics to execute collectively

Neither the maritime industry nor individual players can decarbonise alone. Decarbonisation requires collective efforts from a broader group of stakeholders that come together to work on and implement decarbonisation solutions.

Such new partnerships are emerging and the relationships have their own stakeholder dynamics in form of dependencies, tensions and synergies (figure 7). Examples for coalitions are the Global Maritime Forum[iv] with the Getting to Zero Coalition,[v] Global Centre for Maritime Decarbonization (GCMD),[vi] Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping,[vii] Blue Sky Maritime Coalition,[viii] Cargo Owners for Zero Emissions Vessels (coZEV), and IMO's initiative on Coordinated Actions to Reduce Emissions from Shipping (IMO CARES[ix]). Some private-public partnerships have also been launched, such as the European Sustainable Shipping Forum (ESSF)[x] and the Zero-Emission Shipping Mission.[xi]

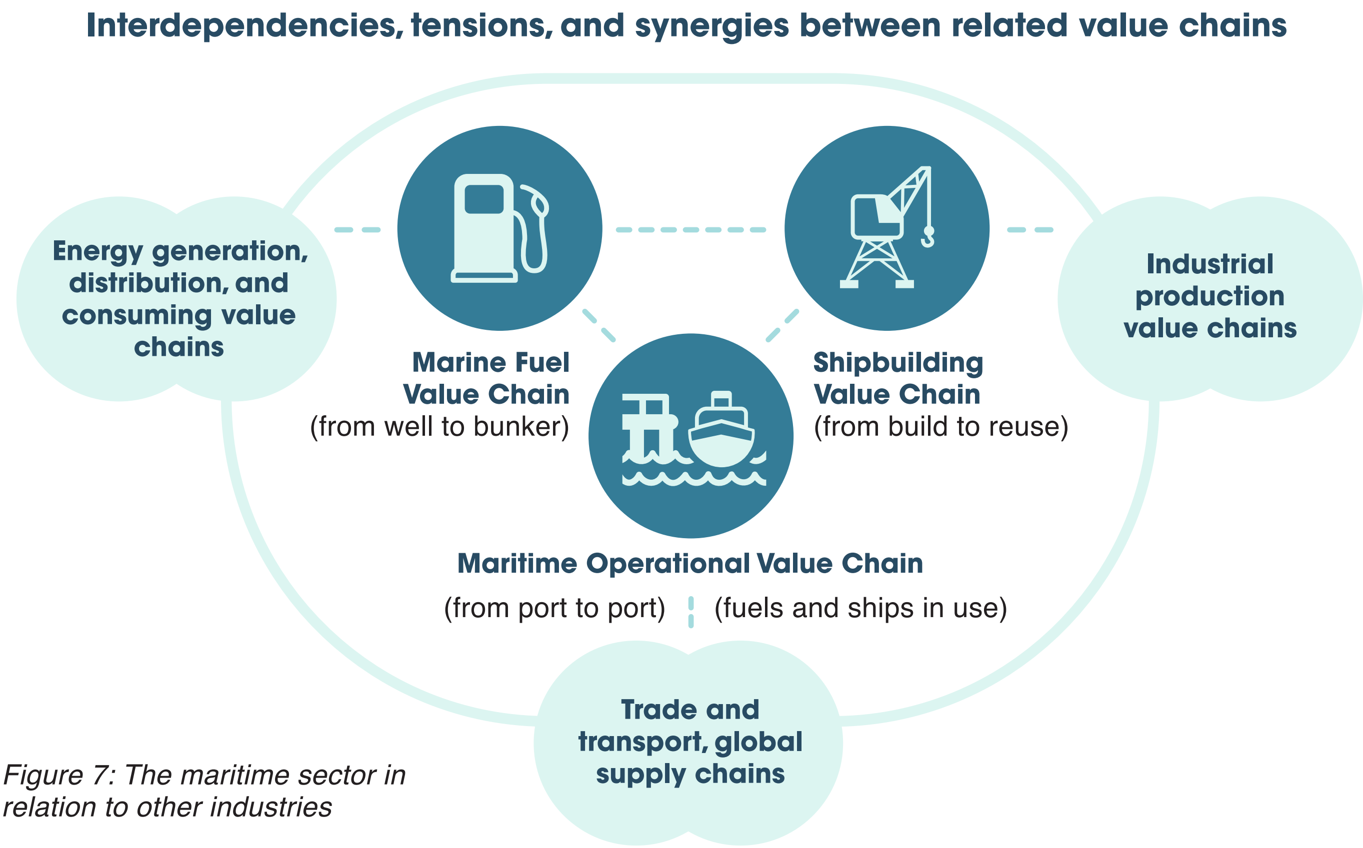


Figure 7: The maritime sector in relation to other industries

Effective execution on decarbonisation enablers requires a focus on the most influential stakeholders. Across the ecosystem beyond the shippers or beneficial cargo owners (BCOs), the ship owners / operators / charterers are the most influential actors. They can drive change as other stakeholders like fuel providers, shipbuilders and seaports follow their decisions. But each chain also has its own key influencers. In the marine fuel value chain, the energy producers are the powerhouses, and in the shipbuilding value chain shipbuilders and engine manufacturers are critical for decarbonisation. In the maritime operational value chain, it is the charterers as well as shippers and shipping companies that need to carry the torch. Governments play an important role too and need to be regularly informed by the private sector to ensure that policies and programmes support and don't hinder the decarbonisation efforts.

While recognising and complying with the anti-competitive requirements in shipping which creates a cost-optimisation culture there are significant benefits in driving decarbonisation together with other public and private players across clusters of value chains but also actors beyond the maritime ecosystem in interrelated clusters, like suppliers of shipbuilding materials or city governments.

Do whatever you can do, and do it now

Many positive developments have been recorded in recent years that shows that the maritime industry makes significant efforts to live up to the decarbonisation challenge.

“Following a surge in orders over the past year, LNG-powered ‘dual fuel’ containerships orders now represent 25% of the total orderbook by TEU capacity. This figure rises to 28% if methanol propulsion is added. The number of LNG-powered ships on order has now risen to 138 vessels of 1.67 MTEU, compared to fewer than 50 ships of around 720,000 TEU a year ago. CMA CGM has made the greatest commitment to LNG, at 80% of its current orderbook and by far most ships in service, but MSC now has more capacity on order. The average size of LNG unit ordered by the main carriers is 14,400 TEU, with Hapag Lloyd’s 23,660 TEU ships currently the only megamaxes on order. So far, PIL is the only major Asian carrier to adopt LNG. The majority of the new vessels will enter the market in 2023 and 2024“, according to Alphaliner (Dynaliners Mai 2022). With its recent order of six 15,000 TEU dual-fuel methanol-powered vessels CMA CGM follows in the footsteps of Maersk which has currently 13 container ships capable running on green methanol on order.

The IMO has introduced the short-term measures energy efficiency design index (EEDI), energy efficiency existing ship index (EEXI), and carbon intensity indicator (CII). The European Union (EU) Commission has proposed the Fit for 55 package,[xii] which adapts a well-to-wake approach through its FuelEU Maritime component. Other contemplated legislative mechanisms to reduce GHG emissions that will increasingly affect the maritime industry are the EU Emissions Trading System (ETS), the Energy Taxation Directive (ETD) and the Carbon Border Adjustment Mechanism (CBAM). But also, the Renewable Energy Directive (RED) and the Alternative Fuels Infrastructure Regulation (AFIR).

In their own competitive interest, the actors in the maritime ecosystem should not only implement individually and collectively decarbonisation strategies but also contribute actively to an open and aligned world. This will counter the risk of being left behind with stranded capital, and in scenarios where the world on average is moving more slowly this front-footed approach opens opportunities to build competitive advantage in premium markets.

> *Even in the most slow-moving decarbonisation scenario considered, the current state-of-play of enablers, and the progress anticipated, indicates that a move on to the front foot now is a non-regret strategy for all key actors.*

Driving the maritime transition: Recommendations and call to action

This study has yielded the following seven recommendations that public and private stakeholders can act upon now.

☸ Recommendation #1: Build scenarios to stress-test current decarbonisation strategies per value chain and across clusters

Underlying finding: Scenario thinking, and their sharing, helps to manage risks for example to avoid stranded assets and develop understanding across the cluster of maritime value chains of different pathways to the future and to outline their implications for decarbonisation

Conclusion: We can leverage the strategic context which the different scenarios provide

☸ Recommendation #2: The maritime industry to urge IMO member states’ governments to support[xiii] the proposed “zero by 2050” plan[xiv] and follow through the current roadmaps with detailed targets

Underlying finding: All developed scenario pathways show that we don’t get anywhere near the 2018 IMO decarbonisation ambitions, and yet indicate the potential competitive and commercial advantages from acceleration

Conclusion: We need a stronger ambition and more aggressive pathway based on accurate GHG calculation and monitoring

☸ Recommendation #3: Establish cross-value chain coordination, e.g., through partnerships and zero-emission corridors / networks

Underlying finding: We face bottlenecks and gaps in decarbonisation across interdependent value chains, e.g., we have dual-fuel engines but not enough alternative fuel

Conclusion: We need a holistic approach to decarbonisation and a cluster view on value chains of fuel, shipbuilding, and operations

☸ Recommendation #4: Every actor and sector in the industry needs to identify and focus on its relevant enablers across their respective value chains to achieve company, industry, and country milestones

Underlying finding: There is no single silver bullet, however this is not a curse but a cure in our diverse world in different stages of development

Conclusion: We need to remain flexible and develop the "37 enablers" for different cases and sustainable profitability

☸ Recommendation #5: Create a global public-private coalition of the willing to identify / activate scalable enablers across all chains

Underlying finding: Given all circumstances regulators are ill-prepared to decide or guide the maritime sector in respect to what enablers to activate along and across the chains

Conclusion: Leading players in the industry need to take initiative and show what works and what doesn't so that other public and private actors are better informed for their own decisions; but what works for one may not work for others

☸ Recommendation #6: Establish sufficient, transparent, and predictable financing and pricing mechanisms, like a levy on high carbon marine fuels and subsidies for low carbon solutions

Underlying finding: Making decarbonisation in the maritime industry work requires pathways that are financially incentivised and viable across all chains

Conclusion: We need to find ways to trigger and finance the change

☸ Recommendation #7: Act now! In our self-interest to avoid exponential decarbonization costs

Underlying finding: Many decarbonisation enablers are ready to use, and decarbonising shipping is a complex and costly task that will become more costly if further action is delayed

Conclusion: We can already activate a range of decarbonisation enablers across the maritime value chains and accelerate developments that are in the broader self-interest of all stakeholders

Call to action

Stress-testing has shown strong support for all recommendations. This appreciation of the approach and recommendations by a representative group of experts of the industry ecosystem makes the work a **strong case for escalating actions and attention immediately**. The frameworks applied and outcomes achieved have shown that scenario thinking, and the fundamental **value-chain / decarbonisation enabler / stakeholder dynamics** concept ensure a structured, holistic, and balanced approach to decarbonisation.

This study provides the framework for practical structural collaborative action now, which is the only way to ensure that the maritime industry aligns with the Paris agreement and exceeds the IMO 2018 ambitions.

Table of contents

1. Decarbonisation in shipping needs extensive knowledge building

This report explores holistic pathways to approaching or exceeding the 2018 IMO decarbonisation ambition to ensure that the maritime industry contributes its fair share to the global effort to fight climate change. This mission brought together a diverse group of experts from different geographies and sectors of the larger maritime ecosystem to crystalise critical elements of decarbonisation strategies, and to identify concrete recommendations that actors in the maritime industry can act upon now.

This report is a compilation of insights and analysis. While a full concensus on every exact detail of the report has not been reached, all participating organisations and experts appreciate the initiative and support the recommendations, and the call to action.

The work summarised in this report should be seen first as a **guide for public and private sector decision-making** and second as a contribution to building **knowledge on decarbonisation** across the maritime ecosystem. A playbook assisting public and private actors to organise, plan and drive their decarbonisation efforts has been included in section 6. Over time, this knowledge will grow in depth, breadth, and robustness. A required next step is to quantify further critical components and the implications of decarbonisation, in particular the impact on economic growth and job creation.

The methodology applied to the exercise is depicted in appendix 1. In summary the approach applied was, a series of discussions organised in four workshops, 17 interviews, and 1 stress-testing exercise outlined and scrutinised three maritime transition scenarios (see section 2); defined a cluster of three key maritime value chains as the scope of decarbonisation (section 3); identified, assessed, and placed 37 decarbonisation enablers positioned across the maritime value chain cluster (section 4); expanded the scope of review and action to a larger system of interdependent clusters of value chains while outlining the dynamics between different stakeholder groups (section 5); derived seven key takeaways and a practical playbook (section 6); and highlighted seven recommendations and a call to action (section 7).

This exercise has been a continual interplay between, on the one side, adopting a systemic view and holistic approach and, on the other side, exploring the detailed characteristics and usability of decarbonisation enablers (technologies / solutions). This is useful as effective decarbonisation requires that multiple enablers across several value chains are adopted in parallel and within a broader framework to avoid gaps and bottlenecks, create synergies, and achieve the targeted decarbonisation impact on the shipping industry.

The industry is far from homogeneous with its broad range of business models and sub-sectors including deep-sea shipping, shortsea shipping, and inland waterway shipping. The sector includes container ships, oil and gas tankers, other wet bulk carriers and dry bulk vessels, passenger and (ro-ro) ferries, tugboats, barges, and cruise ships. These may be operated as fixed-route liner services or based on voyage plans (routes and schedules) laid out years in advance such as is common practise in cruise shipping, or in a flexible but unpredictable way dictated by the immediate demand for ships and the merchandise they carry like in tramp shipping. Financially, the sector has been very cyclical, fluctuating between heavy losses and extraordinary profits very recently. The maritime Industry is highly dependent on fossil fuels and emitted about 1.2 gigatons of carbon dioxide equivalent (CO_{2e}) in 2020, equivalent to about 3% of global GHG emissions.[xv] The International Maritime Organization (IMO) has challenged the shipping industry to cut annual greenhouse gas (GHG) emissions by at least half by 2050, compared to 2008. However, according to the fourth IMO GHG study using 2008 as a base, maritime GHG emissions could increase by 90% to 130% by 2050 in a business-as-usual scenario without major decarbonisation efforts. This target is currently under review with net zero by 2050 under discussion.

The decarbonisation discourse is complex and dynamic as potential partial solutions are many and in differing stages of maturity. With various approaches and types of decarbonisation enablers – like low-carbon and zero emission fuels, ecological ship design, and digital solutions to reduce GHG emissions – the common knowledge base across the relevant areas is generally shallow. Specialists have deep insights into their usually narrower fields but many lack the broader understanding of the whole ecosystem.

The knowledge required for effective and efficient decarbonisation stretches across various dimensions such as how to produce, move, store, and safely utilise different types of fuel; the construction of environmentally sound and efficient ships; and the demands of environmentally friendly, safe, and efficient water transport operations powered by different types of ships operating between different ports within and between different regions of the world. A holistic view on emissions requires a life-cycle assessment (LCA). The LCA includes not only fuel combustion but also emissions from ship manufacturing, maintenance, and repair; infrastructure construction, operation, maintenance, and repair; and fuel production and distribution. Without LCA, emissions can be significantly underestimated.

Life cycle analysis (LCA): What is it?[lii]

Life cycle analysis (LCA) is a method of quantifying the environmental impacts associated with a given good over its lifecycle. The LCA is based on the list of inventories of resources used, and pollutants and carbon dioxide (CO_2) generated during the production and use of a product or asset. This allows a full assessment of the impact of a product, process, or activity on human health, the ecosystem function, and natural resource depletion. In this decarbonization project, LCA is applied to e.g., fuel supply, shipbuilding, and ship operations.

Knowledge developed by institutions, training providers, and through relationships and knowledge transfer across the universe of stakeholders in the maritime decarbonisation ecosystem is needed to inform decision-making on decarbonisation matters in the public and private sector.

The required system-wide knowledge can be built through cross-functional cross-stakeholder “knowledge platforms and teams”. These expert groups should be well connected globally with the relevant parts of the public and private sector to build and constantly update the necessary knowledge on decarbonisation to inform papers and plans that support decisionmakers in their work.

Each maritime business model drives different approaches and decisions on energy needs and decarbonisation based on factors that need to be deeply understood.

2. Navigating uncertainty: Three maritime transition scenarios

Scenario thinking helps to imagine and describe structurally plausible future states of the world and understand their implications to inform our decisions. This is particularly valuable in a volatile industry and times of high uncertainty as these can be moments of shifting paradigms. Considering the high investments in ships, seaports and operations, anticipating these changes is critical. Given the major climate change-caused disruptions, scenario thinking can help us to review public and private sector decarbonisation plans in light of anticipated developments to ensure that our strategies are robust in confronting a wide range of possible futures.

Three Shell **scenarios** (figure 8), namely **Waves**, **Islands**, and **Sky 1.5**, were our point of departure to set our minds, frame, and kick-start the thinking and co-creation process to develop maritime-specific transition scenarios (figure 1). These explore the implications of three different emphasis of socio-political priorities in the coming years, with either wealth first (Waves), security first (Islands) or health/well-being first (Sky1.5).

The world is gravitating towards the Waves scenario with mounting tendencies towards Islands. This results from a strong desire for a swift economic recovery from the pandemic mixed with increasing interest in national autonomy reflected in the political direction many nations have been pursuing over recent years. The expert group does not welcome the emphasis on short-term or narrow self-interests inherent in these drifts and urges the maritime industry to help gravitating towards Sky 1.5. This would require a paradigm shift towards more broadly conceived self-interests that recognise the resilience and competitive opportunities that will arise from alignments and collaborations that pursue human well-being including deep and early attention to reducing GHG emissions.

As the result of the current exercise in scenario thinking, Waves was expanded into **Swells**, Islands into **Storms**, and Sky 1.5 into **Clear Sky** (depicted in Appendix 2) to capture potential futures in a maritime setting.

WAVES

- High initial growth, reform neglect and current fragmentation
- Disruptive, late but fast decarbonization

ISLANDS

- Slow growth, limited domestic reforms, geopolitical polarization
- Late and slow decarbonization

SKY 1.5

- Moderate growth, reform breakthroughs, renewed cooperation
- Early, accelerated decarbonization to reach Paris goals

Figure 8: The general (Shell) scenario narratives used for characterizing maritime scenario narratives in

Swells

In Swells, climate action remains important but is initially secondary to short-term financial interests. Realpolitik and narrow economic focus allow an initial expansion in the use of fossil fuels. However, subsequent severe disruptions in the world driven by climate-change are blamed on the lack of previous attention. This pent-up decarbonisation pressure leads to accelerated but costly efforts later, supported by advanced technological progress. Self-interest has initially been largely perceived in cost terms, and resilience judged in economic strength. Within the maritime sector, developments are driven by multiple entrepreneurial agents with limited new collaboration structures and approaches beyond profit-protecting arrangements. Uncertainty about key decarbonisation technologies prevails until the mid-2030s creating hesitance among the primarily economically driven industry players in respect to green investments. Decarbonisation is mainly motivated by compliance requirements and obviously convincing business cases. Nevertheless, pioneer individual actors undertake strategic moves that position them to access longer-term competitive benefits. Large stakeholders, originating from developed economies with the financial flexibility to manoeuvre, invest in greener approaches in advance of growing anti-fossil regulation, providing a starting point for less prosperous stakeholders to adopt decarbonisation solutions when obliged later.

Storms

In Storms, governments and societies generally emphasise the immediate safety and comfort of their own populations and seek nearby alliances to achieve their goal of security first. In this scenario, international cooperation is fragmented, international trade is constrained, economic progress is subdued, and less money is invested in renewables beyond localised solutions. CO_2 emissions are slowing, but not because of decarbonisation efforts but due to muted economic growth. The lack of investment in sustainable solutions causes pent-up problems to emerge later. Global decoupling is the result of the inability to close the gaps between the nations and establish a new global pact, although local and regional trading relationships may prosper. Within the maritime sector, trade in commodities as well as manufactured goods is depressed in line with reduced growth in the global economy. The sluggish global trade outlook and focus on domestic economies adds friction to accessing capital for investments in newer, and more sustainable, technologies and practices. This scenario results in a heterogenous landscape in regulation and a drift away from IMO legislation. Different fuel types and standards emerge as preferred routes in different countries and different parts of the world, making efficient international operations in the maritime industry increasingly challenging.

Clear Sky

In Clear Sky a new era of global alignments emerges driven by the response to climate change, COVID-19, and the Russia-Ukraine crisis. The world moves towards closer cooperation putting human well-being first. This is not due to an outbreak of altruism but to the recognition of mutual interests and common pressures, and the value of learning from each other and the past. Alignments occur not only through deliberate choice but through responses to common pressures and races to secure competitive advantages. New alliances are formed with new major resource holders for the green energy transition. Climate action is accelerated, supported by broad alignment across industries and nations seeking their individual competitive advantages alongside climate action. Climate policy returns to the centre stage of international and domestic politics, resulting in rapid and deep electrification and decarbonisation of the global economy with growth increasingly dominated by renewable resources. Linked to the maritime sector, developments emerge across all areas of the logistics and transport industry with improved alignment between sea and land connections. There is a changed approach to viewing anti-competitive principles in the maritime industry with more public-private cooperation reflected in increasingly effective maritime decarbonisation coalitions. Companies continue to compete aggressively in business but cooperate in broader decarbonisation frameworks.

The more open world like Swells, and more aligned approaches across the ecosystem offered by Clear Sky, allow knowledge-exchange and broader collaboration to develop. The early alignments and frameworks described in Clear Sky concentrate resources and bring early decarbonisation benefits. In Swells, however, with its focus on economic recovery and growth, the initial neglect of the consequences of climate change leads to an expensive course-correction with massive investments in decarbonisation in the 2030s / 2040s. Storms enables quick local decision-making but mainly on matters that serve the interests of a specific jurisdiction or trading bloc, like using their own local energy resource bases regardless of global implications.

The three potential futures show not only different impacts on decarbonisation and on the maturity of the decarbonisation enablers dependent on the scenario unfolding, but also on the effectiveness and efficiency of the sector along its value chains. In Swells, efficiency is initially the highest because growth and returns are prioritised with a tendency to avoid or postpone investments in decarbonisation. In Storms, value chains get increasingly disjointed with significant repercussions on the performance of the global economy and the climate movement.

While Clear Sky is the steadiest in decarbonisation, Storms can beat Swells regionally up to the 2030s / 2040s due to its faster decision-making and focus on local resources which will be renewable in some geographies. This changes quickly as Swells has seen more technological innovation and remains globally more open which allows a much-coordinated response when there are politically enforced course-changes.

The 2022 common view is that the 2018 IMO ambitions will be missed. This is confirmed by the study as none of the scenarios considered succeed to deliver on the IMO 2018 ambitions which calls for increasing efforts towards more ambitious IMO goals which are currently under review to accelerate decarbonisation efforts (figure 9). As current actions fall short, the maritime industry has proposed a plan to deliver net zero by 2050.

The projections prepared based on the three maritime transition scenarios show that decarbonisation efforts in the maritime sector need to be accelerated as none of the resulting pathways brings us close to the IMO 2018 ambitions.

Shipping-Freight Co_2 Emissions

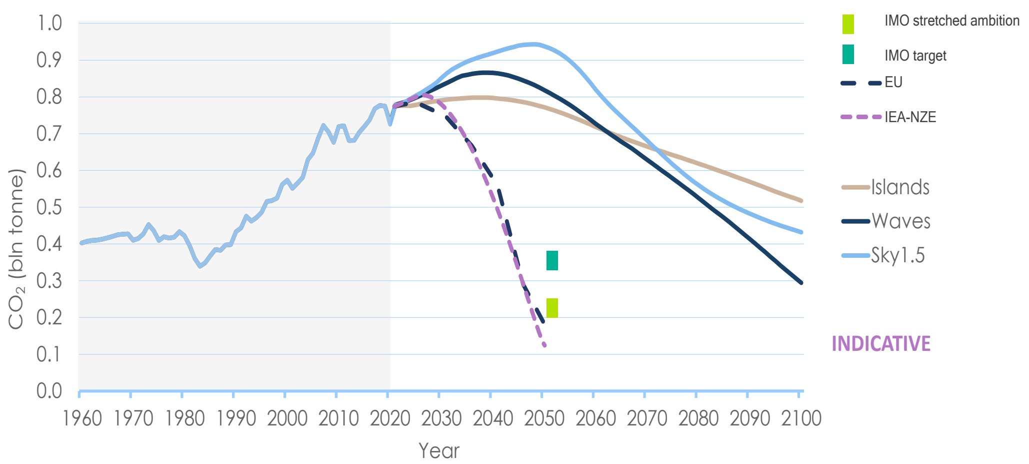


Figure 9: Progression forecasts of Shipping-Freight carbon dioxide emissions (Source: Shell Energy Transformation Scenarios 2021, IEA, IMO and compiled by Wim Thomas)

3. Scoping the decarbonisation space: The cluster of maritime value chains

The carbon reduction discussion in the maritime industry is often focused on decarbonising assets like ships for example through installing lower emissions engines and establishing storage and fuelling spots for alternative fuel. While these are valid considerations it is essential to focus on the entire range of elements needed to decarbonise the maritime industry.

The well-to-wake approach addresses the lifecycle GHG emissions and shows that the industry stakeholders need to expand their vision and scope of decarbonisation beyond onboard fuel consumption. Ship owners, ship operators and charterers need to account for upstream shipbuilding and fuel production equipment and processes and their resulting GHG emissions. Capturing the entire impact requires a full LCA.

The scope and object of decarbonisation should be a cluster of critical value chains. Value in the economy is delivered by such chains. A value chain is a step-by-step business model that brings a product or service from idea to reality. Every step along the chains should add value. With the value come the emissions. Hence, we should apply the value chain thinking to drive decarbonisation across our economy and the maritime sector.

Three interrelated maritime value chains (figure 10) have been identified that play a critical role in decarbonising shipping: the **marine fuel value chain**[xvi] , the **shipbuilding value chain**, and the **maritime operational value chain**.

The three critical maritime value chains are interdependent (figure 11). Allowing for the most effective decarbonisation means aligning supply and demand across this cluster of chains. The alternative marine fuel supply chain needs to supply enough fuel for ships with alternative fuel engines that are demanded by ship owners / operators / charterers given the demands of each sub-sector. The value chains require functioning simultaneously to ensure a seamless process of decarbonization without gaps, bottlenecks, and shortages.

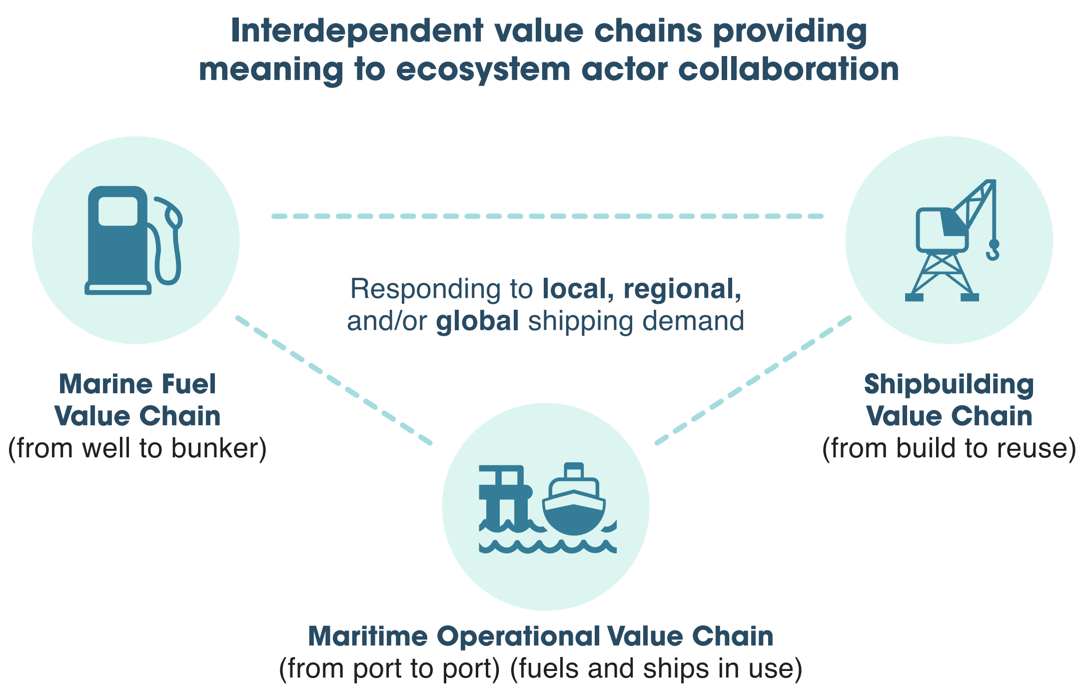


Figure 10: Interdependent value chains in the maritime ecosystem

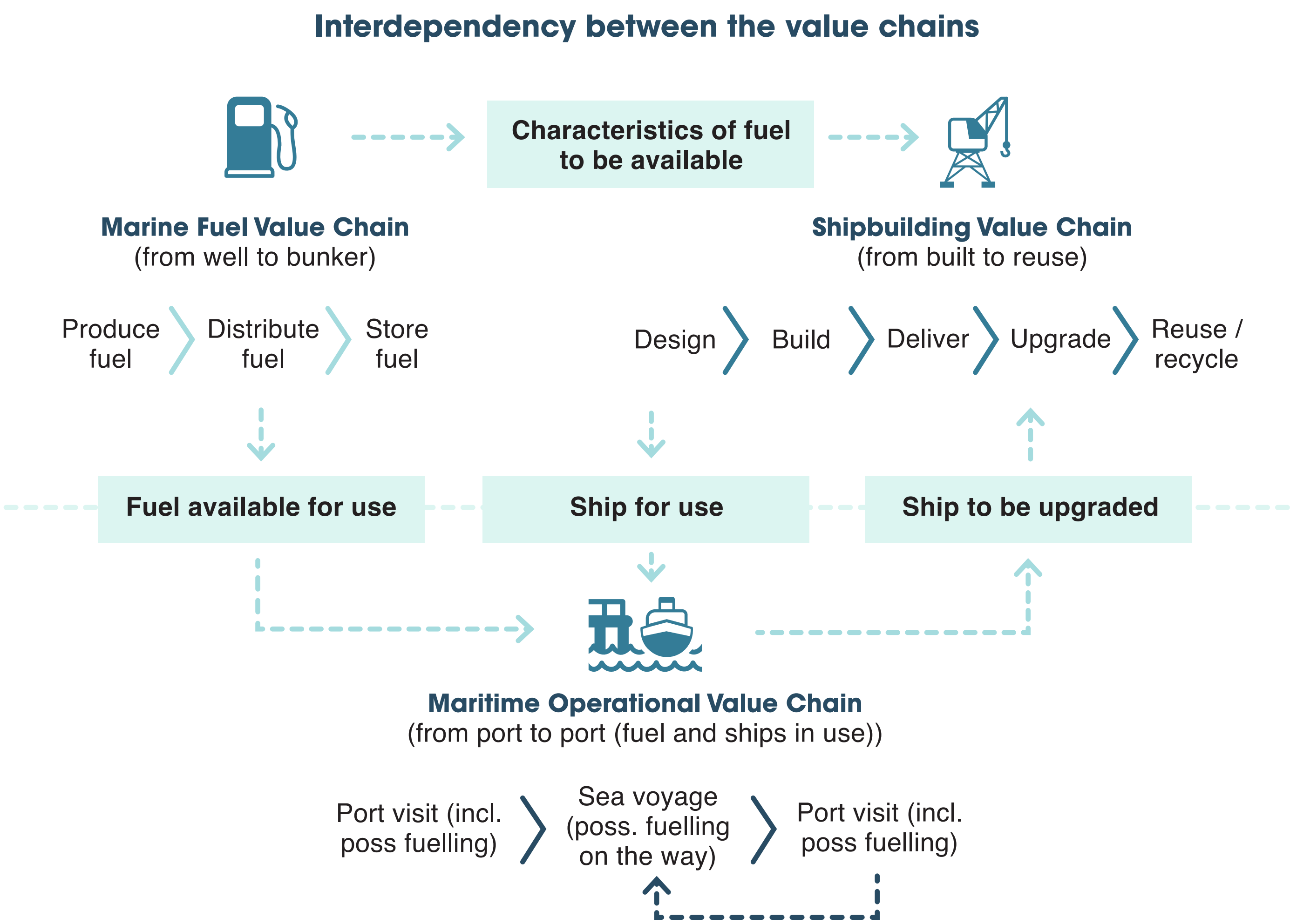


Figure 11: Interdependency between the value chains

The marine fuel value chain

At a high level, the marine fuel value chain involves subsequent steps around primary (renewable) resources provision (for example natural gas), processing (for instance of biomass from domestic waste), transportation (e.g., of green methanol to the storage or bunker spots), and consumption by the ship during a voyage. Vital stakeholders for producing alternative / clean / green fuels are production / processing technology providers, the energy companies that use these technologies and the maritime sector that carries these fuels around the world to the places where they are needed. The energy transition will not eliminate but shift dependencies from fossil fuels producing nations to renewable energy producing countries. This brings new opportunity to the global south.

The shipbuilding value chain

The shipbuilding value chain consists of steps like ship design, procurement (for example of steel), production (component production, assembly, and integration), and post-production (maintenance, repair, and reuse / recycling). A reduction of GHG emissions can be achieved in a variety of ways through decarbonisation enablers including wind support, hydrodynamics and hull design, and dual-fuel and multi-fuel engines. Efficiency measures and retrofits that have successfully reduced GHG emissions in the maritime sector in the past will stay relevant. The more efficient a ship is the less green fuel is needed. This is an important point considering the scarcity of alternative fuels.

The dual fuel engine: what is it?[liii]

Dual fuel engines can use both gasoil and natural gas, contributing to the security of energy supply. They allow ships to be operated on either an interim fuel such as liquified natural gas (LNG) or, on the one hand, the traditional high-carbon very low sulphur fuel oil (0.5% VLSFO) or high carbon high sulphur fuel oil (3.5% HSFO), on the other hand, emerging alternative fuels like biodiesel, green methanol and green ammonia. Change over from one fuel to another is achieved without any interruption in the power output of the engine.

The shipbuilding value chain and marine fuel value chain inform each other. What kind of ships / engines are built depends on what fuels are available and demanded but also on the business model of the owners / operators / charterers, which includes the geography of operation, the type of use, the intended length of ownership etc. Fuels with higher energy density provide more autonomy and require smaller tanks giving more space to cargo and passengers and vice versa.

The maritime operational value chain

Steps along the maritime operational value chain are fuelling / provisioning, loading / boarding, steaming, unloading / disembarking, and refuelling. Faster turnarounds drive higher utilisation of the assets. Bunker locations, fuel prices, as well as weather conditions impact the routing. Speed is an important lever to reduce GHG emissions. But also operating the right size of ships helps to optimise fuel consumption per transported unit. The long tail of companies with only a few ships may make ship size optimisation challenging. But exploring all ways of optimisation is even more important in a world where alternative fuels remain scarce for quite some time. Prices are under upward pressure due to high demand in green fuels as shipping competes with other sectors. A market-based mechanism (MBM) may help us to further close the price gap.

The value chain perspective allows to identify gaps, bottlenecks and shortages that cause imbalances and dysfunction across the cluster (figure 12). Today there is a shortage of alternative fuel supply while manufacturers of ships and ship engines have developed and promote alternative solutions; every new generation of ships emits less. However, the lack of alternative fuels discourages most of the ship owners / operators / charterer to order or operate low-carbon and zero emissions ships. Ramping up alternative fuel production would reverse the situation. The ready availability of alternative fuels (at the right price) would reduce the hesitation to invest in low carbon engines and ships as it would give ship owners increased comfort that they will not at one point suffer from stranded assets. At that point, shipbuilders and engine manufactures would face higher demand for their clean solutions as ship operators and charterers would increasingly adopt.

A focus on the whole cluster of value chains will also ensure that the different components of decarbonisation work smoothly together. This also de-risks investments and prepares the grounds for different ways of financing across the cluster.

The importance of energy density[liv]

Energy density is the amount of energy stored in each system or region of space per unit volume that is released by a given mass or volume of fuel. Different fuels have different energy density levels, and the energy density of the fuel chosen affects the space needed for storage in a ship and for storage onshore.

The state of readiness, availability, and financial viability of the enablers of decarbonisation across the cluster drives different strategies for the three critical maritime value chains. Today, each value chain faces different challenges. The alternative marine fuel value chain needs to ramp up urgently, the shipbuilding value chain needs to accelerate production in line with the growing production of alternative fuels but also anticipate future developments in the R&D focus As ramping up the green marine fuel value chain, actors along the operational value chain needs to adopt non-fuel decarbonisation technologies and practices. Through regular exchange of information shippers and regulators can support these efforts.

Decarbonising shipping means decarbonising value chains which represents a major cross-ecosystem challenge but with the effort also come opportunities in form of new growth, new jobs and a healthier life.

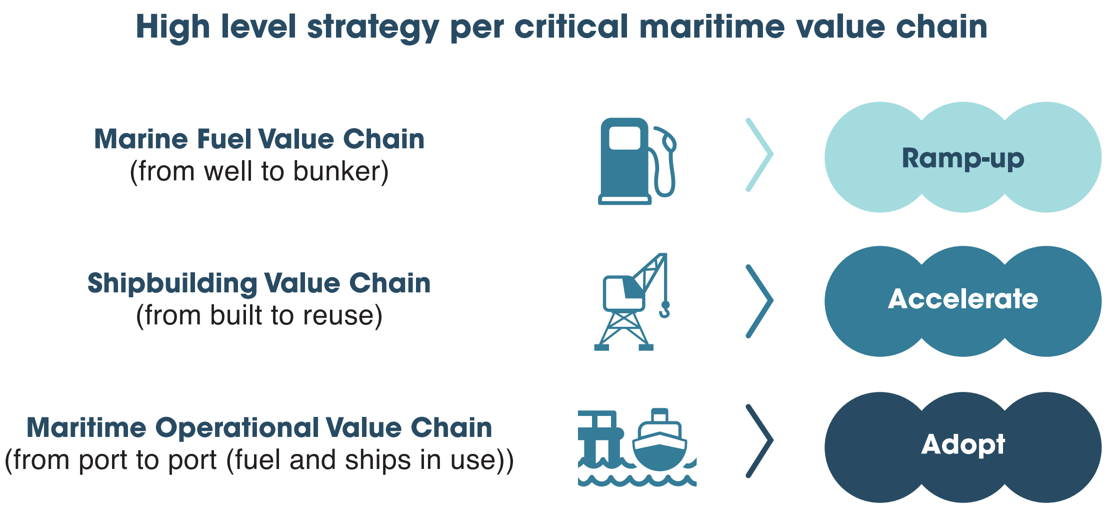


Figure 12: High level strategy per critical maritime value chain

4. Decarbonisation options: Enablers anchored and assessed

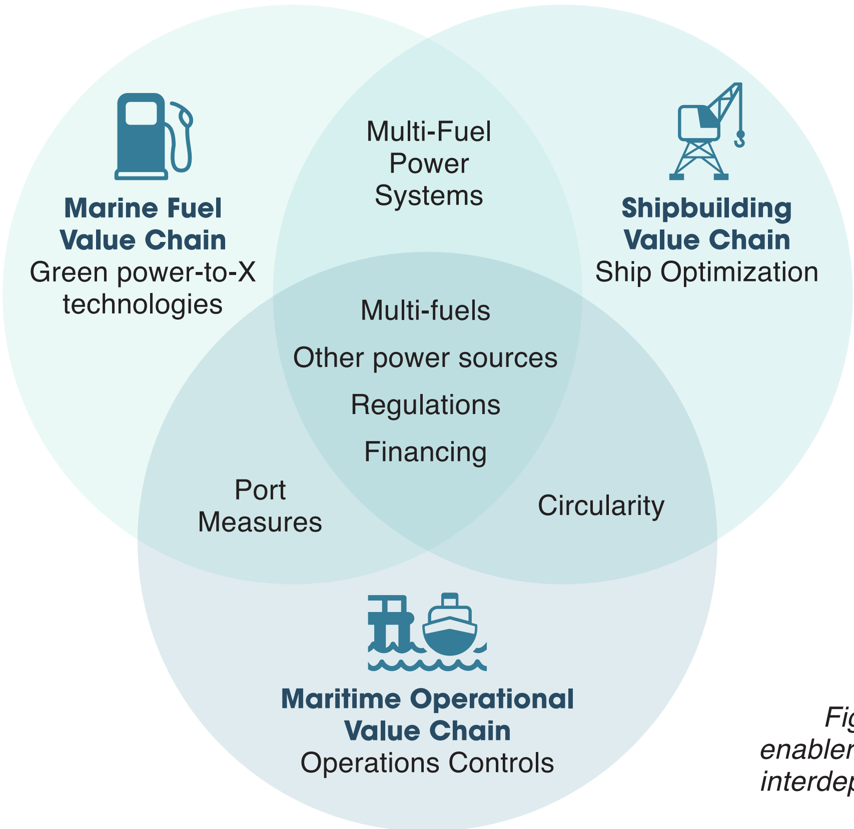


Figure 13: Examples of enablers related to the three interdependent value chains

A broad range of decarbonisation enablers have been identified (appendix 3). In this study 37 enablers have been identified, assessed, and positioned across the cluster. Some of the enablers are specific to only one of the maritime value chains while others cut across two or all three chains. Figure 13 shows a set of selected enablers with their position, and the cross-cutting role of some of the enablers.

Thus, there is no one-size-fits-all solution to decarbonisation but there are multiple options to reduce emissions. Even if some have limited impact they sum up. Today, we need to bundle several enablers to achieve significant results. The actors can pick and choose from a long menu of enablers (figure 14 and appendix 3). Pioneers make multiple bets as it will probably remain unclear which ones will become the most prominent ones.

Most of the decisions made by individual actors in the maritime decarbonisation ecosystem are based straightforwardly on considerations of what is currently possible, for example the types and quantities of fuels provided by the marine fuel value chain in specific regions of the world, the performance of (dual-fuel) ship engines that represents a low-risk solution for those that wish to move towards lower emissions ships and operating more quickly, etc.

Driving decarbonisation in shipping requires that the enablers are clearly understood in respect to their impact, ease of implementation, acceptance across stakeholders, readiness, availability, and financial viability. This assessment is far from being easy and some of the factors can be significantly influenced by the introduction of regulation with associated uncertainties in timing and scope.

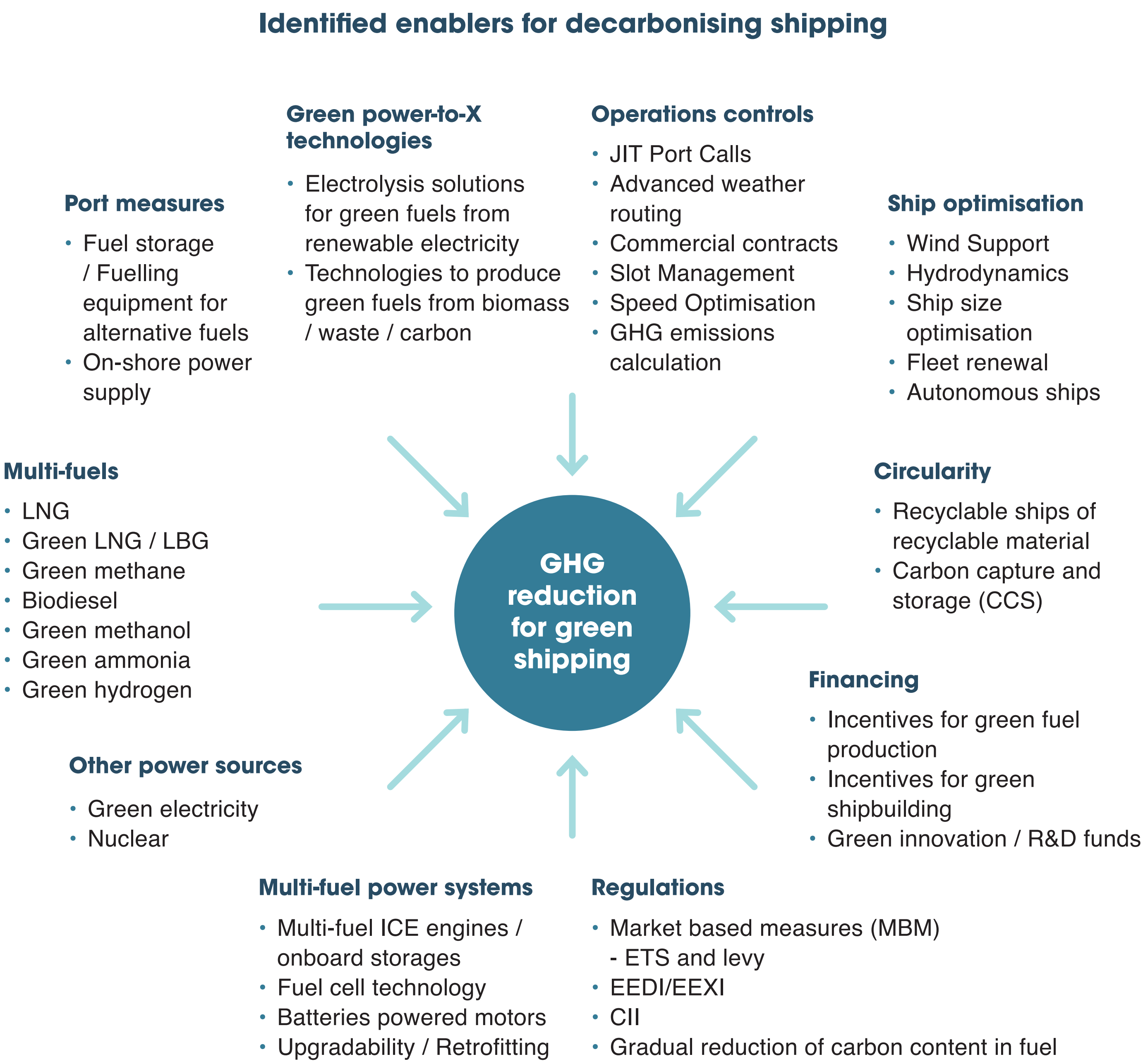


Figure 14: Identified enablers for decarbonising shipping

But it is not only about technical aspect and business considerations. Enablers also differ in respect to their societal acceptance, for example the reputation of nuclear suffers from disasters like Chernobyl and Fukushima and ammonia because of its toxic nature. But, for example, wind-assisted ships enjoy high acceptance across stakeholders. Also, geography plays a role. Preferences and sensitivities vary from country to country and continent to continent.

Understanding the characteristics, impact, costs, and other considerations of the entire set of identified enablers is critical for good decision-making. For this study, each of the 37 identified decarbonisation enablers were scored based on general factors and dynamic criteria on a scale from 0 to 4 (0/1 = no/low, 4 = high).

Three general criteria were used to assess the enablers based on more static factors:

- Impact on GHG reduction, which is an assessment of the contribution this enabler provides to decarbonising shipping
- Ease of execution, which reflects the effort, complexities and risks associated with activating each decarbonisation enabler
- Acceptance across stakeholders, which reflects today's level of approval of each specific enabler by society

Three dynamic factors were used to evaluate the state and potential progress of each enabler between now and 2030 dependent on the specific context and developments outlined for each of the three maritime transition scenarios:

- Readiness of solution, which reflects the state of maturity today and the expected progress made in 2030
- Availability, which considers the expected supply for example of different alternative fuels and the availability of for example digital solutions
- Financial viability, which is an assessment of the current and anticipated cost/price levels of the enablers dependent on envisaged scale and intervention per scenario.

The outcome of this indicative exercise is depicted in two Harvey balls tables. The enabler assessment has been derived from discussions with experts supplemented by secondary research (appendices 4-7). This provides indications that are necessarily preliminary due to the immaturity of some solutions, the uncertainties around the data, and the filters and biases of data providers. In many areas more research and experimentation are required.

Nevertheless, the general patterns are relatively clear, and meaningful conclusions can be drawn about the potential to implement, accelerate or neglect meaningful deployment of decarbonisation enablers at this point and over time. Going forward, experts should commission further work to agree on characteristics and data sources to establish a commonly accepted base for comparisons of the different decarbonisation enablers. This will increase clarity and comfort with key stakeholders in the public and private sector. While "wrong picks" may still be unavoidable for some time we can strengthen our knowledge base and reduce uncertainty through analysis, experimentation, and adoption.

Green fuel: what is it?[lv]

The term "green" describes any type of energy that can be delivered and used without net addition of emissions to the atmosphere / biosphere. For molecular fuels, this generally refers to those derived from non-fossil hydrocarbon sources like biomass. This incorporates all kinds of organic matter, including plant and animal waste. They are considered carbon-neutral when burned, emitting only the amount of CO_2 absorbed during feedstock growth / production. As the feedstocks used to make green fuel are sustainable and naturally replenished, they are considered renewable and eco-friendly. The production of fully green fuels makes use of renewable energy in the production process, such as wind or solar power. Green fuels also include synthetic or electrofuels (e-fuels), which are liquid, or gaseous fuels produced with electricity from renewables, and carbon from biomass or direct air capture. Examples for such e-fuels are synthetic natural gas (SNG), green methanol or green ammonia.

Fuels

A range of alternative sources of power are being considered across all three value chains. Some are currently more accepted than others. Some energy sources and storages are less favorable as the fuels are heavy and take a large share of the total mass of the ship. So, it is not about the volume only. In a holistic approach decarbonisation is a gradual exercise. In a process over years more and more carbon will be taken out of the chains.

While increasingly available, LNG does not yield dramatic CO_2 reductions, so this fossil fuel is considered an intermediary step towards zero-emission shipping. Of course, green LNG is an alternative fuel. LNG also raises concerns because of methane leakage, but which is factored into the GHG reduction assessment applied in this study. Furthermore, LNG engines are compatible with any bio or synthetic methane fuel solution. Other sources of power being pushed are biofuels and green electricity, either stored in batteries or generated onboard, and used in shortsea and inland waterway shipping. Other low-carbon and zero emissions solutions in development include beyond beforementioned green LNG, also green methane, green methanol, green ammonia, and green (or blue) hydrogen. These fuels can be used to generate power or electricity. Biofuels and electricity are widely accepted in society. Ammonia faces some resistance as it is highly toxic. Handling of hydrogen is complex as well and it has low energy density. Fuel-cell technology with sufficient capacity for large ships, is still a decade away. Nuclear powered ships have been in military operation for some time but there is no recent experience of nuclear propulsion in commercial use and the solution is questioned due to safety and cost concerns. In 1959 the NS Savannah, the world's first nuclear-powered merchant ship was launched followed by three other nuclear merchant ships, namely the German ore transporter Otto Hahn, Japan's freighter Mutsu; and the Russian ice-breaking container vessel Sevmorput. All four ships are no longer in service, mainly due to safety incidents and cost considerations. Beyond building the vessels, ports worldwide would need to be equipped with facilities for nuclear waste and refuelling ships with uranium are needed. Issue of insurance and accountability in case of accidents are to be settled and some countries would refuse to accept the docking of nuclear ships. Nevertheless, the nuclear-powered ships remain a topic of discussion.[xviii]

Except for drop-in biofuels all alternative fuels require significant upskilling of the workforce to ensure well-functioning and safety. Organisations like Lloyd's Register Foundation[xix] can support with insights for the maritime training sector. Trainings in maritime informatics[xx] help with digital aspects of fuel usage and with digital decarbonisation enablers, like just-in-time arrivals or data-driven route optimisation.

Alternative fuels impact on ship design and performance

Methane, methanol, ammonia, and hydrogen are promising fuels for marine power systems for lower carbon or zero carbon maritime transportation.

Methane

Methane in the form of liquified natural gas (LNG) is considered as a transition fuel for ships. The development of methane from biomass and synthetic sources means there is a pathway to carbon-neutral energy from LNG. Bio- and synthetic methane can be used initially as drop-in fuels alongside conventional LNG to reduce its fossil carbon content and later, as supply increases, to replace it entirely.

This pathway has both technically and logistical advantages. Engines and fuel supply systems designed for LNG require no changes to use bio- or synthetic methane. And as well as being compatible with existing LNG engines, the future carbon-neutral varieties can also be used in the bunkering infrastructure that has already been established for LNG. This offers a head-start (both in terms of time and financially) compared to other fuels once the carbon-neutral LNG becomes commercially available.

However, methane as fuel is not a perfect solution – methane leakage during production, storage, and combustion is still a challenge that negatively impacts the GHG footprint. Nevertheless, over the last 25 years the methane leakage has been drastically reduced and continuing technology evolutions will reduce it further.

Methanol

Until now, methanol has not been widely used as marine fuel. The easily and cheaply produced industrial alcohol is today predominantly made from natural gas, but the use of hydrogen from renewable electricity and recaptured carbon used to produce green methanol makes it carbon neutral. With better combustion and easier storage and handling compared to ammonia, methanol could be a key component of decarbonising the maritime sector.

Methanol requires approximately double (2x) the volume of fuel tank capacity compared to marine diesel oil to maintain the same level of vessel endurance. As methanol is liquid at ambient conditions it can be stored in conventional fuel tanks and thus the tank arrangements are flexible and simple to apply. Methanol is mildly toxic and must be handled carefully if spilled or leaked in confined spaces or on deck.

Ammonia

Exploration of ammonia as a fuel is progressing fast. Some countries are lending strong backing to ammonia as a fuel of the future. While the current ammonia supply is fossil based it would have to be produced in an environmentally sustainable way with synthetic hydrogen and nitrogen. Ammonia is toxic and highly corrosive, making it challenging to handle. Cargo handling systems capable of handling ammonia have been existing for many years, for use on liquified petroleum gas (LPG) carriers. The basic concept for fuel supply is like that for LNG. Ammonia fuel can be handled in a stainless-steel version of an LNG fuel gas supply system. Due to its lower energy density ammonia requires approximately four times (4x) the volume of fuel tank capacity compared to marine diesel oil to maintain the same vessel endurance.

Ammonia has several other properties that are presently being investigated by engine manufacturers. It ignites and burns poorly compared to other fuels and combustion can lead to higher nitrogen oxides (NOx) emissions unless controlled either by after-treatment or by optimising the engine process. A regulatory framework and class rules will need to be developed for its use as a marine fuel.

Hydrogen

Marine dual-fuel engines and spark-ignited gas engines can already run on a fuel mix comprising up to 15–25% hydrogen mixed into methane. Onboard storage in the quantities needed for deep-sea shipping is more feasible for ammonia and methanol than for hydrogen. Strong government support and strict local regulations may make it feasible for some short-sea shipping applications. But the main role of hydrogen in shipping is expected by some to be as a building block for other fuels.

Hydrogen used as fuel can be stored in the storage tank in a cryogenic liquefied state (-253 C), requiring approx. four times (4x)[lvi] the volume of fuel tank capacity compared to marine diesel oil to maintain the same vessel endurance. It can also be stored in a compressed state with pressure of 350–700 bar, but then hydrogen requires up to ten times (10x) the volume of fuel tank capacity compared to marine diesel oil to maintain the same vessel endurance. However, a hydrogen-powered fuel-cell motor is up to twice as energy efficient as a combustion engine, thereby halving the required storage volume and offsetting some of the storage disadvantage.

The current hydrogen production is largely fossil based. Making hydrogen clean requires producing it in an environmentally sustainable way i.e., by electrolysis of water to hydrogen and oxygen by using renewable electricity. A regulatory framework and class rules is needed for the use of hydrogen as a marine fuel.

Shipbuilding

Within the shipbuilding value chain, several ship optimisation initiatives, such as hydrodynamics and autonomous shipping, are being pushed by shipbuilders as contributors to the reduction of GHG emissions. even though they show lower levels of impact than other categories of enablers they are ready-to-use enablers that can contribute now. Every new generation of ships is expected to be more fuel and emissions efficient than the previous one. Achieving significant GHG reductions requires to include in the bundle of enablers to be activated retrofitting and ship renewal. The Yara Birkeland, for example, is the world's first electric and autonomous short sea container ship. It has conducted its maiden voyage in November 2021 and is expected to be put into service in 2022. Alternative fuels need to be transported. Beginning 2022 the Suiso Frontier the world's first liquid hydrogen (LH2) carrier left Australia with the first LH2 shipment to arrive in Kobe in Japan on 25 February 2022. The ship features a diesel-electric propulsion system.

Tests with scrubbers[xxi] that, in addition to filtering out sulphur, capture carbon dioxide emissions onboard ocean vessels and store it in so-called "CO_2 batteries" are underway. This is a form of carbon capture and storage (CCS). In parallel, some carriers are experimenting with wind support. Wind and solar power might be a good fit for electric vehicle car carriers. Concepts provided by the "circular economy" are gaining popularity across the economy and building recyclable ships from recycled materials which is marginal today may become prominent in the future with significant impact on GHG reduction.

Carbon capture and storage: what is it?[lvii]

Carbon capture and sequestration / storage (CCS) is the process of capturing carbon dioxide (CO_2) formed during power generation and industrial processes before it enters the atmosphere to reuse CO_2 in production or industrial and other processes, transport CO_2 compressed into a fluid mainly by pipelines / ships, and store CO_2 into deep, underground geological formations for very long time (centuries or millennia). The aim is to prevent the release of CO_2 or capture it from air. The technologies used fall into three categories, namely post-combustion carbon capture which is the primary method used in existing power plants, pre-combustion carbon capture which is largely used in industrial processes, and oxy-fuel combustion systems. CCS technologies can capture almost all of the CO_2 they produce (some currently capture 90 or even 100 percent). Since CCS deployment is in its early stages of development, financial returns on CCS projects are riskier than mature operations. Higher risk premiums and mitigating risk for investors is therefore vital for incentivising investment and development of CCS. Carbon capture is more likely economically viable when being combined with a utilisation process when the CO_2 is used to produce high-value chemicals or fuels. Although 40 million metric tons of CO_2 from plants in operation or construction are captured and stored each year more research and development is needed to optimise technology design and integration in maritime shipping.

State of development of fuel cells for marine applications

1. Available fuel cell technologies

Multiple fuel cell technologies are available – the most promising for marine use are Proton Exchange Membrane (PEM) fuel cells and Solid Oxide Fuel Cells (SOFCs)

1.1 Proton exchange membrane fuel cells

PEM fuel cells can be split into Low Temperature and High Temperature technology. If a fuel reformer is added for pre-processing also other fuels than hydrogen can be used.

Low temperature PEM FC

The Low Temperature PEMFC (LT-PEMFC) solution allows flexible and safe operation and a quick start-up with less stringent material requirements. However, low temperature also leads to a lack of waste heat recovery options and a complex system for water management. In addition, the catalysts can be poisoned by carbon monoxide (CO) and sulphur (S) when no pure hydrogen is used.

High temperature PEM FC

As indicated by the names the main difference between a High Temperature PEMFC (HT-PEMFC) and a LT-PEMFC is the operating temperature. The HT-PEMFC can operate at temperatures up to 200°C by using a mineral acid electrolyte instead of a water based one. Reaction and fuel are the same as in the LT-PEM. The High Temperature PEM is less sensitive to poisoning by CO and sulphur and has no need for a water management system. It is also possible to use the excess heat from the fuel cell in a heat recovery system. A HT-PEMFC has a lower power density and does not permit to cold start it.

Fuel reformer + PEM FC

As the electrochemical reaction of fuel cells occurs between hydrogen and oxidizing agents pre-processing in the form of a fuel reformer installed onboard is required when fuels other than hydrogen are used. There are requirements for hydrogen purity, especially for low temperature fuel cells. Low temperature fuel cells are very sensitive to CO. Otherwise, CO clean-up processes are required.

Fuel reformer technology for LT-PEMFC is available for pre-processing of methanol and methane, while ammonia fuel reformer technology is still under development. For HT-PEMFC, fuel reforming technology only exist for methanol pre-processing.

1.2 Solid oxide fuel cells

The basic components of a Solid Oxide Fuel Cell (SOFC) module consist of a SOFC stack, a fuel supply unit, an air supply unit, a reforming unit, an after combustor and possibly a waste heat recovery (WHR) unit, as well as several auxiliary elements serving regulation, measurement, safety, and control functions. Although the development of SOFC for marine use is ongoing, no commercial products are available yet.

SOFC is a very high temperature fuel cell. The SOFC operates at temperatures between 500-1000°C. The SOFC shows the same flexibility towards fuels as internal combustion engines (ICEs), being able to use hydrogen, methanol, and hydrocarbons. The reforming to syngas (hydrogen and carbon monoxide) occurs within the fuel cell. Ammonia SFOC for marine use are under development, where direct thermal cracking of ammonia into hydrogen and molecular nitrogen (N_2) occurs within the fuel cell.

2. Fuel cell outlook

Technology maturity

While there is experience from using fuel cells in marine applications and some of the PEMFC products having type approval for marine use, there's six order of magnitude difference of experience in marine applications compared to the ICE. The installed base of fuel cells can be measured in megawatts (MW), while the installed base of ICE can be measured in terawatts (TW).

Power capacity

The power demands for marine power systems range from hundreds of kilowatts (kW) up to tens of MW. Currently, the maximum power output of the currently applied marine fuel cells is in the region of a few hundreds of kW, while the highest ICEs power output lies above 70 MW. The potential use of fuel cells within merchant marine applications remains therefore limited in terms of power output today.

Safety

The safety of fuel cell power systems depends primarily on the choice of fuel. Key considerations related are fuel density, flashpoint, auto-ignition temperature, flammability limits and toxicity. Different working scenarios including bunkering, onboard storage, daily service, and emergency response should be covered when assessing and managing risks. The same safety aspects apply to ICE as power source.

Reliability

Assessing the reliability of fuel cell power systems is limited at this point due to lack of experience in a maritime environment. Pilot installations are being carried out to verify the favourable assumptions in terms of overall system reliability coming from the use in other industries.

Lifetime

The lifetime of a fuel cell refers to the lifetime of the fuel cell stack. The lifetimes of fuel cells are expected to be between 30,000 to 50,000 hours, after which the fuel cell stack has to be replaced. The lifetime of a FC is strongly correlated to how it is used (fast load variations, etc) and battery hybrids are always to be considered to balance peaks in load demand and to extend the FC lifetime. The lifetime of an ICE is similar to the vessel lifetime (about 30 years, or about 200,000 hours), with periodical overhaul of main components.

Operability

Operability could be reflected by start-up time and transient dynamic response. Considering the fuel cell stack, the start-up time ranges from a few seconds for a PEMFC to tens of minutes for a SOFC since high temperature fuel cells need more time for stack and reformer preheating. A long start-up time can be accepted to some extent. Dynamic response characteristics reflect the response of fuel cell power systems to external load changes. The transient response time ranges from seconds for PEMFC to several minutes for SOFC. The transient response time of reforming systems is typically counted in minutes. Therefore, batteries are typically required for reformers or SOFC systems to allow fasters start-up times or response times to sudden load changes. However, this should not be an major drawback.

Efficiency

ICE has an energy efficiency of approx. 35–50% FCs are typically having 40–60% energy efficiency, depending on the fuel cell technology. There are two aspects that are factored into the system design. Firstly, the efficiency of FCs is degrading slightly over the lifetime, typically being around 10% lower at end-of-life compared to the beginning-of-life. Secondly, the highest efficiency of a fuel cell system is achieved at low loads, typically below 25% and the lowest efficiency at highest load, while the ICE is having the lowest efficiency at lowest load and the best efficiency at high loads, typically above 75%. This is a known challenge but no real constraint.

Seaports

Ports provide measures like clean fuel storage and bunkering or onshore power supply, which improves local air quality but is considered to have low impact on overall maritime industry decarbonisation. Onshore power supply is becoming a regulatory requirement for example in the EU at a time when green electricity generation cannot meet demand and electrical infrastructure is reaching its limits. Fuel storage facilities and bunkering equipment at ports are getting ramped up. Some seaports like Singapore, Rotterdam and Hamburg see themselves as future green energy hubs[lviii]. They see the opportunity and position themselves as important actors in the renewable (marine) fuel value chain.

Operations

Within the maritime operational value chain, enablers that enhance synchronisation between ports and ships, and between ports and hinterland transport vehicles are accepted but show rather limited impact on CO_2 reduction. Just-in-time arrivals[lix] to improve the fluidity of transport and reduce the carbon footprint is mature in concept and in the experimentation stage but requires changing historic contracts. Altering the contracts, which are among the largest barriers in adopting energy efficiency in operations has turned out to be extremely challenging. Commercial structures with asymmetric incentives are an impediment to decarbonisation as they do not incentivise everyone in the business model to save fuel and cut GHG emissions. This slows down capital-intense projects as well as adoption of advanced weather routing which is a quick win for owners / operators / charterers that has been available for some time and is ready to be scaled. Also speed optimisation which contributes to reducing CO_2 is not a new topic, but advanced digital solutions and new data sharing practices can lift this enabler to new heights.

Financing

More attractive financing can be made available for projects that support shipping decarbonisation. Green innovation R&D funds are seen as a necessary instrument to kick-start innovation / implementation and bridge financing gaps where needed.

Regulation

Regulations are affecting all three maritime value chains. It is a major enabler. The introduction of a carbon pricing system is becoming widely accepted and is considered to have the biggest long-term impact on encouraging the maritime transition. The market-based mechanism (MBM) is expected to gradually narrow and ultimately close the price gap between fossil and alternative fuels.

Indexes, such as Energy Efficiency Design Index (EEDI) and Energy Efficiency eXisting Ship Index (EEXI), and Carbon Intensity Index (CII) are guiding ship optimisation efforts but are not being considered having a huge impact on GHG reduction. A carbon tracker that allows to visualise the GHG emissions of every ship for the industry and even the general public could help to show status and progress of decarbonisation in shipping. The obligation to reduce the carbon content in fuels is considered as a means to drive decarbonisation and ramp-up the supply of alternative fuels.

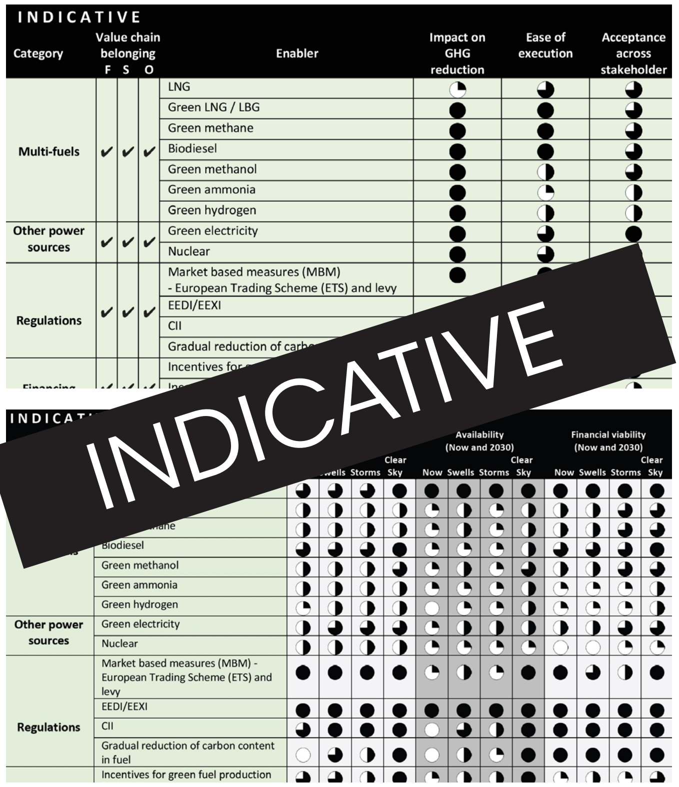


Figure 15: Harvey ball assessment of the 37 enablers pursued in the study

Not all enablers are available or available at the right price (figure 15). The gap can be closed through ramping up supply and demand, and temporarily bridging price gaps through financial mechanisms. An open and collaborative world supports actors in their decarbonisation efforts. Decarbonisation-friendly regulation and R&D funds accelerate the developments. Multiplicity emerged as a critical component for decarbonisation in shipping: multi-fuels, multi-fuel ship engines, and flexible operational models are core to manoeuvring the multi-layered landscape of the maritime industry and the volatile nature of our world. In such an environment, flexibility including upgradable ship engines and the possibility to retrofit entire ships turns out to be a considerable risk mitigator. A price on carbon can contribute to support such efforts. Appendix 8 covers what can be used now and in 2030 at scale or within limits.

Summary of the enabler analysis

Figure 16 gives a high-level picture of the world of maritime decarbonisation now and in 2030 considering the three maritime transition scenarios. The graphs show usable decarbonisation enablers, which are ready, available, and affordable at scale, and enablers that are usable within limits, because of a shortage of supply (see appendix 8). Usable at scale is assumed when readiness, availability, and financial viability of an enabler is assessed 3 or 4. Usable within limits is assumed when the readiness and financial viability of an enabler is assessed 3 or 4 but the availability scores below 3.

Usable decarbonisation enablers now and in 2030 given the maritime transition scenarios

Figure 16: Usable decarbonisation enablers now and in 2030 given the maritime transition scenarios

This report calls out five main observations.

1. The enabler analysis shows that actors in the maritime industry can already today leverage a range of solutions to drive decarbonisation; with some enablers having more and others less impact on GHG reduction. The frontrunners in the industry have already activated many of these decarbonisation enablers.

2. An open and collaborative world in Swells and Clear Sky is more favourable to decarbonisation efforts than a siloed one with tensions between the blocs. Speedy and impactful decarbonisation requires globalisation, more precisely joint effort.

3. A fragmented Storms-like global landscape will not bring about a lot of clean developments by the end of the decade but some shifts across the range of usable enablers will occur.

4. A world that makes decarbonisation its priority is the most favourable as this significantly accelerates the clean innovation and adoption creating new opportunities for growth and jobs.

5. The current geopolitical trend that puts focus on food and security concerns does not favour decarbonisation and will not bring shipping anywhere close to its ambitions. Getting closer to the ambitions requires even stronger decarbonisation efforts than those currently envisaged in Clear Sky.

In June 2022, Members of the European Parliament (EP) rejected proposals to include shipping in the EU Emissions Trading Scheme (ETS)[lx]. The current state of decarbonisation and the direction the world is taking leaves those that wish to drive decarbonisation little choice. Stakeholders need to collaborate even more to change the current slow decarbonisation trend of fragmentation. The private sector is in the driver's seat for decarbonisation and the industry can achieve a lot regardless the external conditions.

Irrespective of the direction the world may take, sooner or later the actors in the maritime industry will activate their respective bundles of decarbonisation enablers, either voluntarily or forced by regulators or external realities.

5. Understanding ecosystem dynamics to execute collectively

Climate change has been caused collectively and also requires a collective response with a shift in value capture and distribution to align incentives to act. The maritime transition will not happen anytime soon if costs and efforts are not spread equally. While the costs of decarbonisation are unavoidable, decarbonisation is also a huge opportunity. Costs for some parties are revenues for others. Losses in some activities are offset by gains in others. As an example, today the renewables sector creates many more jobs than the oil and gas industry and renewable jobs are expected to grow fivefold globally by 2050[xxii]. At a “macro” level, the overall drag of decarbonisation on economic development has been proven minimal and, in any case, negative effects are likely to be offset by avoided costs from climate change. The challenges are not “macro” but “micro”, i.e., the alignment of incentives for action by individual parties that achieve a collectively desired outcome as the detriment of their business or financial performance.

Today, the maritime industry burns fuel that hardly anybody else demands. Tomorrow, the sector will compete for alternative power sources and fuels with other actors that requires green fuels. This creates new competitive relations that drives prices up which will make it harder for each sector to reduce carbon dioxide emissions.

Other dynamics will unfold between shippers and carriers. The ecosystem of shippers consists of a diverse set of players spanning different industries and which depends on the maritime industry to reduce the shippers' scope 3 CO_2 emissions. Between different modes of transport, beside the competition on green sources of power also new synergies may emerge as, for example, trucks can get their own clean fuel at seaports.

These new dynamics drive the need to expand the scope of decarbonisation beyond the cluster of maritime value chains to a larger decarbonisation ecosystem (figure 17).

Interdependecies, tensions, and synergies between related value chains

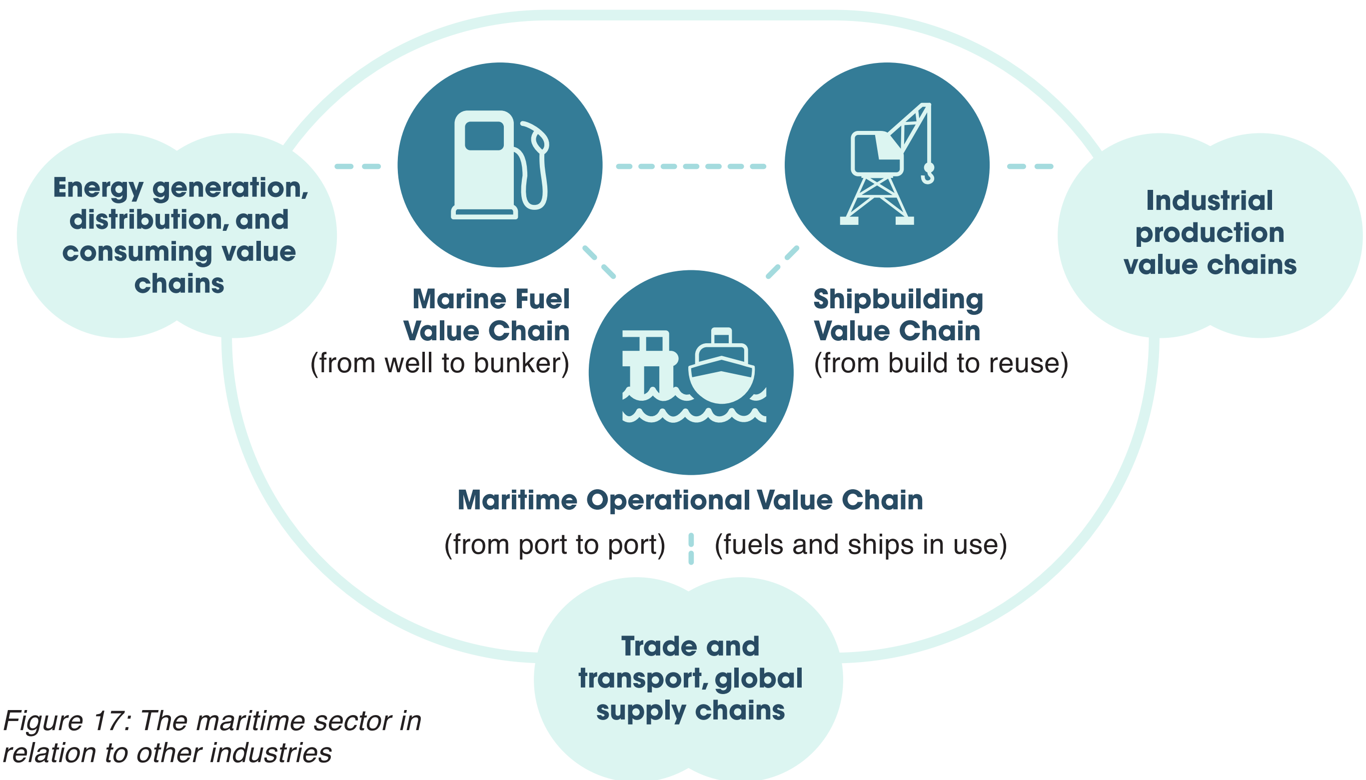


Figure 17: The maritime sector in relation to other industries

The dynamics within the larger decarbonisation system are shaped by the influence actors can exert on other members of the ecosystem.

An important player in the maritime ecosystem is the IMO. The IMO applies an inclusive approach so that every signed-up member is included. The advantage is that once consensus is reached, every IMO member who is signatory to the agreed regulation is obliged to execute on the decisions made. The downside is that the process is long, with the pace determined by the slowest movers. Fast alignment and decision-making are hard to achieve when dealing with a challenging topic in a complex multi-sector industry and a volatile and uncertain world. The inclusive approach of the IMO creates tensions with those who wish to decarbonise quickly.

Therefore, private and public sector pioneers are taking initiative to give impetus and set direction and standards themselves, by means of investments in decarbonisation enablers and low-carbon and zero emissions partnerships. This creates positive energy and potentially makes other major players take initiative too.

Beyond the shippers that pay for the maritime shipping services and that can make their voices heard, ship owners / operators / charterers are also key influencers as they can provide direction to fuel manufacturers, shipbuilders, seaports and technology providers. This can e.g., be observed from what one of the world's largest shipping companies, Maersk, initiated by announcing the order of methanol powered ships. CMA CGM has in the meantime followed in the footsteps of Maersk confirming orders of six 15,000 TEU dual-fuel methanol-powered vessels. Seaports generally supply fuels that are requested by the charterers / shipping companies, equipment providers manufacture what ship owners / operators / charterers demand (e.g. LNG ICEs), shipbuilders produce what suits and supports the business model of their customers, and technology providers supply what is favoured by the shipping companies and fuel producers (figure 18). Energy company Proman has partnered with Stena to jointly develop a retrofit and supply solution, with an aim to promote sustainable shipping through the use of methanol. Stena Bulk and Proman have together invested in five methanol-fuelled medium-range (MR) tankers, all of which will be built by GSI and delivered by the end of 2023.[xxiii]

The ship owners / operators / charterers are core to the decarbonisation of the maritime industry, and they can be instrumental as aggregators of the required parties to drive the maritime transition.

Power dynamics in the maritime industry, in an energy production and societal context

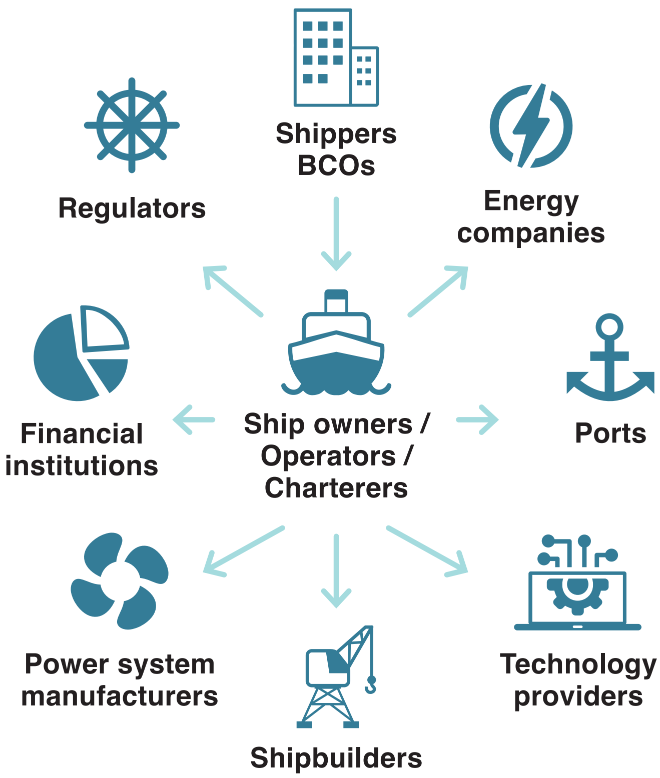


Figure 18: Power dynamics in the maritime industry, in an energy production and societal context

Ship owners / operators / charterers act within the frameworks set by the regulators and with a speed determined by the support given by shippers like decarbonisation premiums, length of contracts etc., and the public sector through incentives.

Citizens also have their role to play. They can influence politicians to initiate supporting policies and launch incentives to motivate fuel suppliers to ramp up alternative fuel production and ship owners / operators / charterers to order green ships. Governments can guide and fund academia and research institutes to focus on low-carbon and zero emissions research and launch decarbonisation projects that foster collaboration across the ecosystem.

A critical mass of stakeholders supporting CO_2 reduction can put the industry on a path of accelerated decarbonisation.

An alternative fuel that reaches 5% in the energy mix can trigger a transition.

Driving decarbonisation across the maritime industry requires bringing actors in the self-organising ecosystem of shipping closer together for enhanced coordination and consolidation of resources. For example, developed in 2013, port call synchronization empowered by Port Collaborative Decision Making (PortCDM),[xxiv] brought shared situational awareness among participants, followed by the just-in-time arrival initiatives by IMO,[xxv] and virtual arrival by BIMCO.[xxvi] These developments enhance synchronising capabilities that reduce GHG emissions, costs, and delays. Just-in-time port calls and route optimisation have been acknowledged as two important enablers which can pave the way to move from synchronisation based on physical presence to virtual tickets and slot management.[xxvii] The concepts have been stress-tested, as driven by the appointment economy[xxviii] in many other sectors. However, so far, digital enablers have a slow uptake, since the digital maturity of seaports is low[xxix], and the distributed nature of shipping does not encourage the necessary collaboration to change the situation rapidly.

Nevertheless, collaboration in the field of decarbonisation is increasing. One example is the strategic partnership[xxx] of A.P. Moller – Maersk, CIMC ENRIC, European Energy, Green Technology Bank, Orsted, Proman, and WasteFuel to boost the global production capacity of green methanol with the intent of sourcing at least 730,000 tonnes per year by the end of 2025. Other examples of collective efforts in research, experimentation, implementation, and uptake of decarbonisation solutions in the maritime sector are orchestrated by the following collaborative initiatives:

- Global Maritime Forum[xxxi] with the Getting to Zero Coalition,[xxxii]
- Global Centre for Maritime Decarbonization (GCMD),[xxxiii]
- Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping,[xxxiv]
- Blue Sky Maritime Coalition,[xxxv] and
- IMO's initiative on Coordinated Actions to Reduce Emissions from Shipping (IMO CARES[xxxvi])
- Cargo Owners for Zero Emissions Vessels (coZEV)[xxxvii]
- Some private-public partnerships launched, such as:
    - The European Sustainable Shipping Forum (ESSF)[xxxviii]
    - The Zero-Emission Shipping Mission[xxxix]

Ultimately, it is the *coalition of the willing* that will drive the change and reap many of the benefits available from early positioning. Successful decarbonisation will be brought about by partnerships across the maritime ecosystem (see figure 19 for the identification of key players in the different value chains).

Such a coalition can contribute to making "carbon-neutrality-as-a-service" the new normal and show what works and what not through scale-up projects.

Pilots and demonstration projects will help the industry to understand the implications of using alternative marine fuels and other decarbonisation technologies and solutions. Lessons from the introduction of LNG as (still limited in share) interim fuel in the shipping industry or the rise of renewable wind energy sector will also be helpful to establish a transition roadmap. As a reference, it took 15 years to set up the LNG infrastructure in shipping. The coalition could establish *decarbonisation funds* to provide financing for shared activities, and to cover common needs and other support measures, including extending help to less developed countries that have concrete decarbonisation plans.

In 2019, the Marine Environmental Protection Committee (MEPC) discussed an industry-led proposal for the establishment of a non-governmental International Maritime Research and Development Board (IMRB) and related fund[xl]. In 2021, a group of governments (Georgia, Greece, Japan, Liberia, Malta, Nigeria, Palau, Singapore, and Switzerland) that are controlling a major share of global shipping tonnage have submitted a proposal, strongly supported by the shipping industry, to the IMO to establish a $5 billion research fund, called International Maritime Research Fund (IMRF). A modified proposal expanded the scope to not only accelerate the development of zero-carbon technologies and fuels but also support the maritime decarbonisation efforts of developing nations.[xli] In June 2022, at MEPC 78 there was little discussion on the IMRB concept, and the R&D fund was rejected by governments.[xlii] "The signal this sends means that the financial risk associated with green investment will remain high, slowing down efforts to switch to zero-carbon fuels as soon as possible," commented Guy Platten, International Chamber of Shipping (ICS) Secretary General.[xliii] The IMO has still the possibility to make use of the Fund's proposed regulatory architecture to support a future global carbon levy on CO_2 emissions, to close the price gap with future zero-carbon fuels and provide funds to help the transition of the maritime sector to net zero by 2050.[xliv]

The coalition of the willing can also advise on the prioritisation of decarbonisation efforts across the low-carbon and zero emissions fuel-constrained global economy, for example answering questions like which industry should be prioritised for bio-fuels supply – shipping or aviation or other industries? But the most important responsibility of the coalition is to drive innovation in the field of decarbonisation and the large-scale deployment of workable solutions.

Changing the context strengthens or weakens our ability to decarbonise the maritime industry. The members of the maritime decarbonisation ecosystem are not only asked to develop, implement, and scale effective decarbonisation solutions alone and collectively but also to lobby for an open and collaborative world to create the most favourable decarbonisation conditions possible. The maritime industry is not at the mercy of individual political decisions but can, as a global industry, determine to a large extent its destiny independently. A strong coalition of the willing can overcome barriers illustrated by the Storms scenario; shortages, bottlenecks and backlashes illustrated in Swells; and accelerate the positive outcomes highlighted in Clear Sky which, otherwise, still falls short of industry aspirations.

Every huge success has started small. Often it is the first steps that are the most challenging part. Transition pioneers can take up that responsibility and drive coalition building and large-scale decarbonisation.

Pushing boundaries positively should be a key objective in all scenarios.

While recognising and complying with the anti-competitive requirements in shipping which creates a cost-optimisation culture there are significant benefits in driving decarbonisation together with other public and private players across clusters of value chains but also actors beyond the maritime ecosystem in interrelated clusters, like suppliers of shipbuilding materials or city governments.

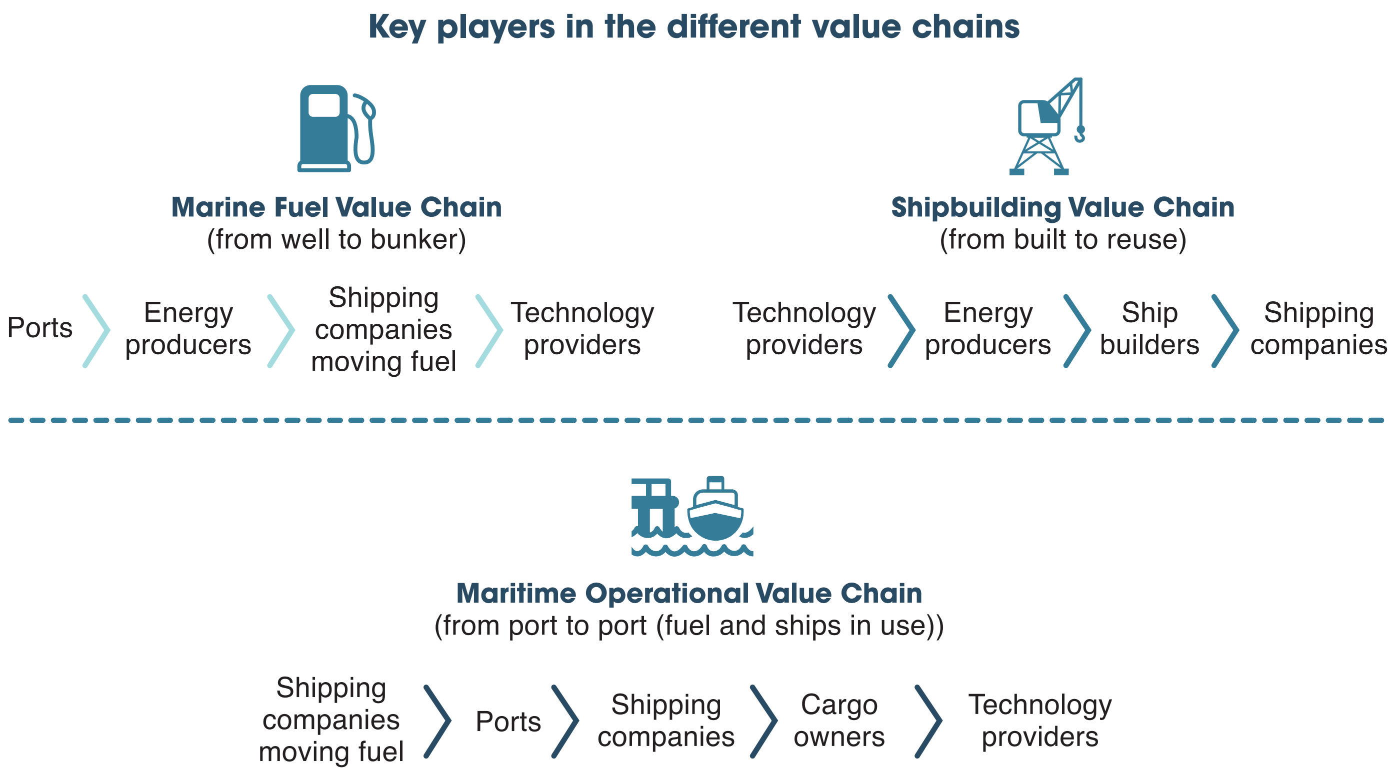


Figure 19: Key players in the different value chains

6. Do what you can do, and do it now

Seven key takeaways from this review can set the scene for deriving individual and collective decarbonisation action in the maritime industry.

☸ Scenario thinking is a great tool to solidify views, encourage alignment, and frame robust decisions

The study work has shown that scenario thinking is a powerful tool to frame a discussion and develop pathways towards a point far out in our future. This forms the basis for projecting the development of different drivers at waypoints along the timeline like the advancing maturity of technologies. This helps companies to prioritise their investments and guide their partnership-building.

☸ All the scenario pathways developed in the context of this study fail to achieve IMO 2018 ambitions

Even the most effective scenario doesn't bring the industry close to the 2018 IMO decarbonisation ambitions. This indicates that we need to rethink our approach to maritime decarbonisation. The long horizons, lead times and life cycles of ships requires decisions early on and a diligent follow-through to ensure that targets are met. We need to increase our investments in research, development, and pilot activities; ramp up the alternative fuel production capacity; drive continuous improvements in ship and engine design; and improve the adoption of non-fuel related decarbonisation measures in ship operations.

☸ The appreciation of full value chains and enablers is central to decarbonisation

The gaps in the current decarbonisation value chain, particularly the lack of alternative fuels, indicate that it is the cluster of critical maritime value chains that needs to be decarbonised, ideally in unison. This requires new forms of alignment, collaboration, and partnerships. But we have seen that this is not enough. We need to look at the areas where clusters overlap and create competitive, cooperative, or synergetic relations between different stakeholders calling for a cross-industry cross-cluster alignment. Shipping corridor solutions, including alternative energy production, bunkering facilities, green ships, and recycling capacities offered by consortia may help to balance our effort across the cluster of maritime value chains in specific geographies.

☸ Flexibility is key; LCA and interim steps / hybrids are critical

Expecting that we can harmonise the different approaches across the world and reach a similar stage of development anywhere may be an illusion. Hence, we need to prepare for a diverse and continuously changing world through flexibility in capabilities, fuels, and regulations. Inland waterway and shortsea shipping can run on power sources compared to those used in deep-sea shipping. The maritime industry needs flexible strategies that not only work across the globe but also across different potential futures. Modularity and upgradability are features of next generation maritime decarbonisation solutions.

☸ Collaboration and alignment are the most critical success factors

Decarbonisation is a Goliath task that requires a lot of innovation like Bill Gates writes in How to avoid a climate disaster (2021). "Innovation is not just a matter of inventing a new machine; it's also coming up with new approaches to business models, supply chains, markets and policies." Only this level of commitment and innovation will enable the necessary unprecedented alignment not only across the maritime sector but across a much larger decarbonisation ecosystem. This is necessary because we need to align our understanding and activities across interrelated systems of systems. This will not happen through an invisible hand or meta-level authority but through willing parties that constantly exchange information and best practices, jointly conduct experiments, and develop new offers. Within the maritime industry, this requires that while competing in commercial business matters companies and countries collaborate in decarbonisation matters.

☸ Satisfying financial considerations is of utmost importance

The private sector is indispensable for the transition. Financial returns and growth in revenues and profits are the core interests of business and should signal successful contributions of business to broader society. The better we can satisfy the financial considerations of the world, the faster sails the decarbonisation ship. At the least, the competitive position should remain unchanged. Of course, there are nuances, but no standard business will drive itself voluntarily into bankruptcy. This reality has been dominating the discussion about the market-based mechanism (MBM) in the industry which recently has taken a positive turn. Without financial mechanisms and incentives like emissions trading, emissions-related levies and emissions-offsetting, decarbonisation will remain an uphill battle that lacks traction.

☸ Don't wait for ideal solutions / regulation or till an open world is re-emerging

The position of many regulators is clear. They are very hesitant to prescribe any single decarbonisation solution like a particular fuel. But business does not need to wait for the regulator to make progress. Any global industry can align around key principles and lobby their governments around the world to support their chosen directions like a net zero by 2050 ambition or a more synchronised flow of transport. This are the signals some governments will pick up to craft supporting policies. It is the private sector that is required to move first so that the public sector can follow and not the other way round. Regardless, key players in the industry will push for MBMs which will impact the economics of the shipping business to help the transition. Better to plan to be ahead than to change under pressure.

These are seven foundations on which the recommendations for decisionmakers in the public and private sector are based. This report should not only be seen as a guide and knowledge-builder but also a springboard from which lots of other thoughts and concepts can be derived. An example is a recent article released by UNCTAD,[xlv] which puts the emphasis on a step-by-step approach to drive decarbonisation in shipping. Furthermore, throughout the current exercise, the structure of a playbook has emerged that can help actors in the public and private sector to plan and drive their decarbonisation efforts.

Even in the fastest decarbonisation scenario considered, the current state-of-play of enablers, and the progress anticipated indicates that a move on to the front foot now is not only a non-regret strategy for all key actors, but an indispensable step.

A decarbonisation playbook

This playbook summarises key steps in the processes to plan and drive your decarbonization efforts whether you are in the public or private sector.

1. Create a multi-functional multi-stakeholder expert and action group to drive knowledge-building, planning and execution

2. Apply scenario thinking to detail and test the robustness of your decarbonisation vision and strategy with long-term goals and early objectives

3. Map out the relevant cluster of independent value chains to be decarbonized which goes beyond companies' and nations' borders

4. Pick your most suitable decarbonisation enablers that are under your control or influence as key components of your decarbonisation action plan, with objectives per enabler derived from the overall decarbonisation goals

5. Map relevant relationships / interdependencies across the cluster of critical maritime value chains, and between the maritime cluster and other interrelated clusters, and manage stakeholder dynamics to drive decarbonisation

6. Continuously record major takeaways from your (collective) decarbonisation effort to expand your knowledge base for next actions

7. Regularly formulate recommendations and calls to actions, and leverage partnerships and coalitions to do what you cannot do alone.

7. Driving the maritime transition: Recommendations and call to action

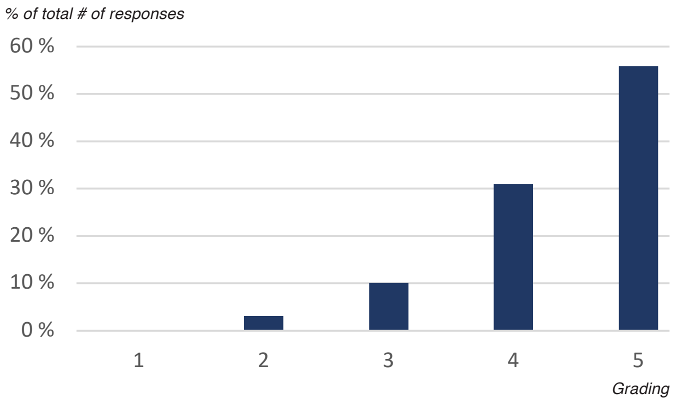
This study has yielded a long list of suggestions which can be found in appendix 9. Seven recommendations that public and private stakeholders can act upon now were extracted and refined through a stress-testing exercise performed by the expert group included in the project and members of the Freight and Logistics Leaders' Forum (F&L) in May 2022. At an F&L meeting in Luxembourg the importance of the recommendation was assessed through answers to underlying questions on a scale from 1 (lowest) to 5 (highest). The result in number of votes is indicated in diagrams associated with the individual seven recommendations.

☸ Recommendation #1: Build scenarios to stress-test current decarbonisation strategies per value chain and across clusters

Underlying finding: Scenario thinking, and their sharing helps to manage risks for example to avoid stranded assets and develop understanding across the cluster of maritime value chains of different pathways to the future and to outline their implications for decarbonisation

Conclusion: We can leverage the strategic context which the different scenarios provide

Stress-test poll #1: Build scenarios to stress-test current decarbonisation strategies per value chain and across clusters (129 votes)

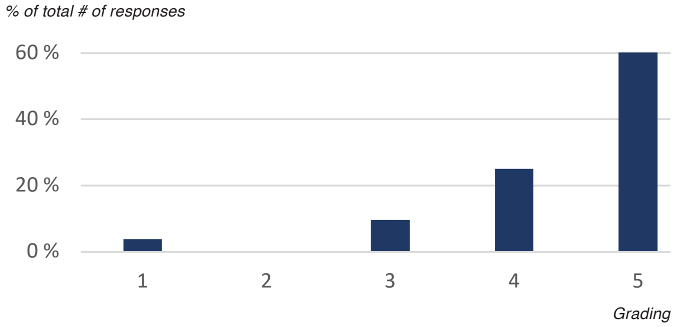


☸ Recommendation #2: The maritime industry to urge IMO member states' governments to support the proposed "zero by 2050" plan and and follow through the current roadmaps with detailed targets

Underlying finding: All developed scenario pathways show that we don't get anywhere near the 2018 IMO decarbonisation ambitions, and yet indicate the potential competitive and commercial advantages from acceleration

Conclusion: We need a stronger ambition and more aggressive pathway based on accurate CO_2 calculation and monitoring

Stress-test poll #2: The maritime industry to urge IMO member states' governments to support the proposed "zero by 2050" plan and follow through the current roadmaps with detailed targets (104 votes)

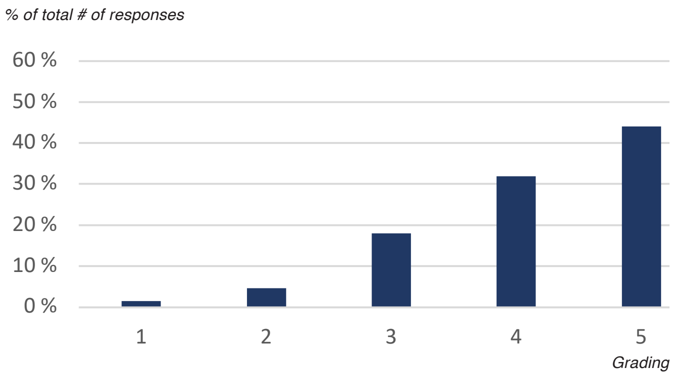


☸ Recommendation #3: Establish cross-value chain coordination, e.g., through partnerships and zero-emission corridors / networks

Underlying finding: We face bottlenecks and gaps in decarbonisation across interdependent value chains, e.g., we have dual-fuel engines but not enough alternative fuel

Conclusion: We need a holistic approach to decarbonisation and a cluster view on value chains of fuel, shipbuilding, and operations

Stress-test poll #3: Establish cross-value chain coordination, e.g., through partnerships and zero-emission corridors / networks (110 votes)

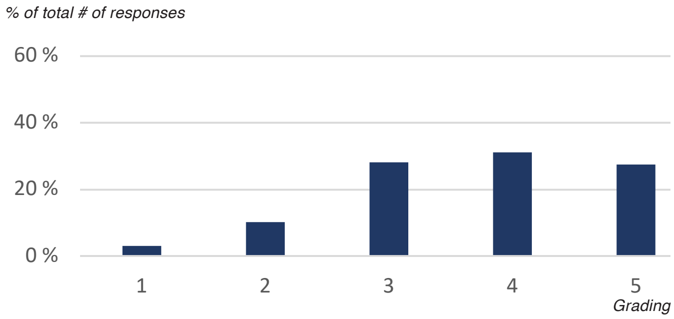


☸ Recommendation #4: Every actor and sector in the industry needs to identify and focus on its relevant enablers across their respective value chains to achieve company, industry, and country milestones

Underlying finding: There is no single silver bullet, however this is not a curse but a cure in our diverse world in different stages of development

Conclusion: We need to remain flexible and develop the "37 enablers" for different cases and sustainable profitability

Stress-test poll #4: Every actor and sector in the industry needs to identify and focus on its relevant enablers across their respective value chains to achieve company, industry, and country milestones (113 votes)

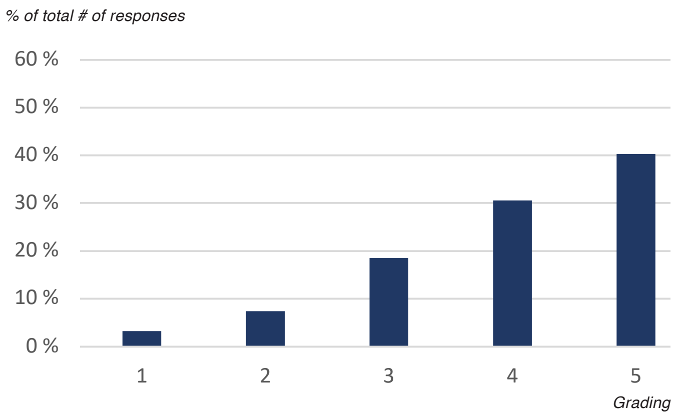


☸ Recommendation #5: Create a global public-private coalition of the willing to identify / activate scalable enablers across all chains

Underlying finding: Given all circumstances regulators are ill-prepared to decide or guide the maritime sector in respect to what enablers to activate along and across the chains

Conclusion: Leading players in the industry need to take initiative and show what works and what doesn't so that other public and private actors are better informed for their own decisions; but what works for one may not work for others

Stress-test poll #5: Create a global public-private coalition of the willing to identify / activate scalable enablers across all chains (108 votes)

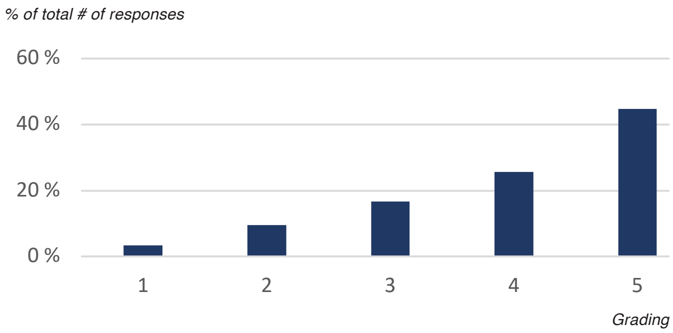


☸ Recommendation #6: Establish sufficient, transparent, and predictable financing and pricing mechanisms, like a levy on high carbon marine fuels and subsidies for low carbon solutions

Underlying finding: Making decarbonisation in the maritime industry work requires pathways that are financially incentivised and viable across all chains

Conclusion: We need find ways to trigger and finance the change

Stress-test poll #6: Establish sufficient, transparent, and predictable financing and pricing mechanisms, like a levy on high carbon marine fuels and subsidies for low carbon solutions (105 votes)

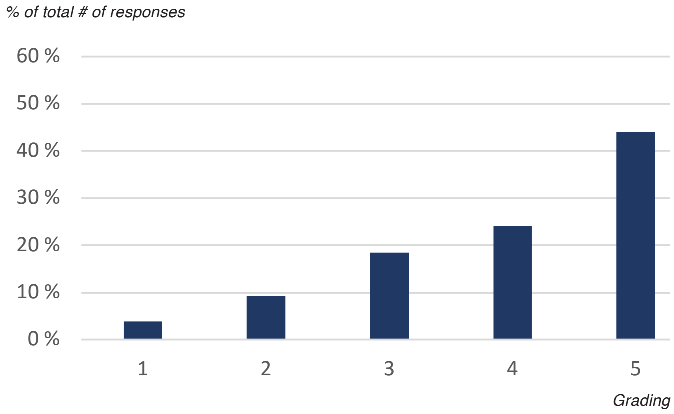


☸ Recommendation #7: Act now! In our self-interest to avoid exponential decarbonisation costs

Underlying finding: Many decarbonisation enablers are ready to use, and decarbonising shipping is a complex and costly task that will become more costly if further action is delayed

Conclusion: We can already activate a range of decarbonisation enablers across the maritime value chains and accelerate developments that are in the broader self-interest of all stakeholders

Stress-test poll #7: Act now! In our self-interest to avoid exponential decarbonisation costs (110 votes)



Call to action

Stress-testing has shown strong support for all recommendations. This appreciation of the approach and recommendations by a representative group of experts of the industry ecosystem makes the work a **strong case for escalating actions and attention immediately**. The frameworks applied and outcomes achieved have shown that scenario thinking, and the fundamental **value-chain / decarbonisation enabler / stakeholder dynamics** concept ensure a structured, holistic, and balanced approach to decarbonisation.

This study provides the framework for practical structural collaborative action now, which is the only way to ensure that the maritime industry aligns with the Paris agreement and exceeds the IMO 2018 ambitions.

Table of appendices

Appendix 1: Applied methodology

A series of discussions, precisely four workshops, 17 interviews, and 1 stress-testing exercise enabled three maritime transition scenarios to be outlined; defined a cluster of three key maritime value chains as the scope of decarbonisation; identified, assessed, and positioned 37 decarbonisation enablers in this value chain cluster; expanded the scope of decarbonisation to a larger system of interdependent clusters; and extracted seven key takeaways, seven recommendations, and a call to action. The structural flow of the exercise is outlined in the figure below.

Building on the need for building holistic and detailed knowledge about decarbonisation in the maritime ecosystem (see section 1 of the report), three Shell scenarios outlining different futures with different priorities: 1- wealth first (Waves), 2- security first (Islands), and 3- health first (Sky 1.5) helped to kick-off and frame the discussions and were expanded into three maritime transition scenarios dubbed: 1- Swells, building on Waves, 2- Storms, expanding Islands, and 3- Clear Sky, derived from Sky 1.5 (section 2). The maritime transition scenarios contain different pathways towards a zero CO_2 emission maritime sector.

As scope of decarbonisation, three value chains were defined and clustered: 1- the marine fuel value chain, 2- the shipbuilding value chain, and 3- the maritime operational value chain (section 3). Ideally, these value chains are approached each in their entirety, and the three in parallel, to avoid decarbonisation bottlenecks.

The three value chains form a cluster with specific and shared / connecting decarbonisation enablers, like alternative fuels, hydrodynamics, and just-in-time arrivals (section 4). These enablers were assessed (grade 0 to 4) based on three more general enabler-specific criteria: 1- impact on CO_2 reduction, 2- ease of execution, and 3- acceptance across stakeholders, and three more dynamic scenario-reliant factors: 1- readiness of the solution (now and in 2030), 2- availability / adoption (now and in 2030) and 3- financial viability (now and in 2030). How these enablers evolve over time depends on the specific scenario. The horizon for action was defined as 2030, and the focus of assessment is primarily on actions that can be taken or initiated in that timeframe. These dynamics inform potential partnerships or coalitions across the three maritime value chains as the basis for developing recommendations for decision-makers in the public and private sector.

The list of decarbonisation enablers and values has been anchored in theory, statements, and assessments from the industry. The different enablers identified during the project can be found in section 4 and appendix 3. The assumptions for the assessment are listed in appendix 5 and 7 and the outcome of the assessment is visually illustrated in Harvey ball tables depicted in appendix 3 and 6.

Driving change effectively requires understanding the power dynamics across the cluster – who leads, who follows, or who may be an aggregator that brings everyone together. Furthermore, the maritime cluster of key value chains needs to be expanded and connected with interrelated other clusters like other difficult to abate industries, suppliers of steel for shipbuilding, and the shippers / beneficial cargo owners (BCOs), to capture the entire stakeholder dynamics (section 5). These dynamics illustrate interdependencies, tensions, and potential partnerships or coalitions across the system.

Considering scenarios, scope, enablers, and stakeholder dynamics results in seven key takeaways (section 6) driving seven concrete recommendations for decision-makers in the public and private sector and a call to action to take this report from concept to action (section 7). The crucial output of the process is this call to action and the recommendations for different stakeholders on how to reduce carbon dioxide (CO_2) emissions.

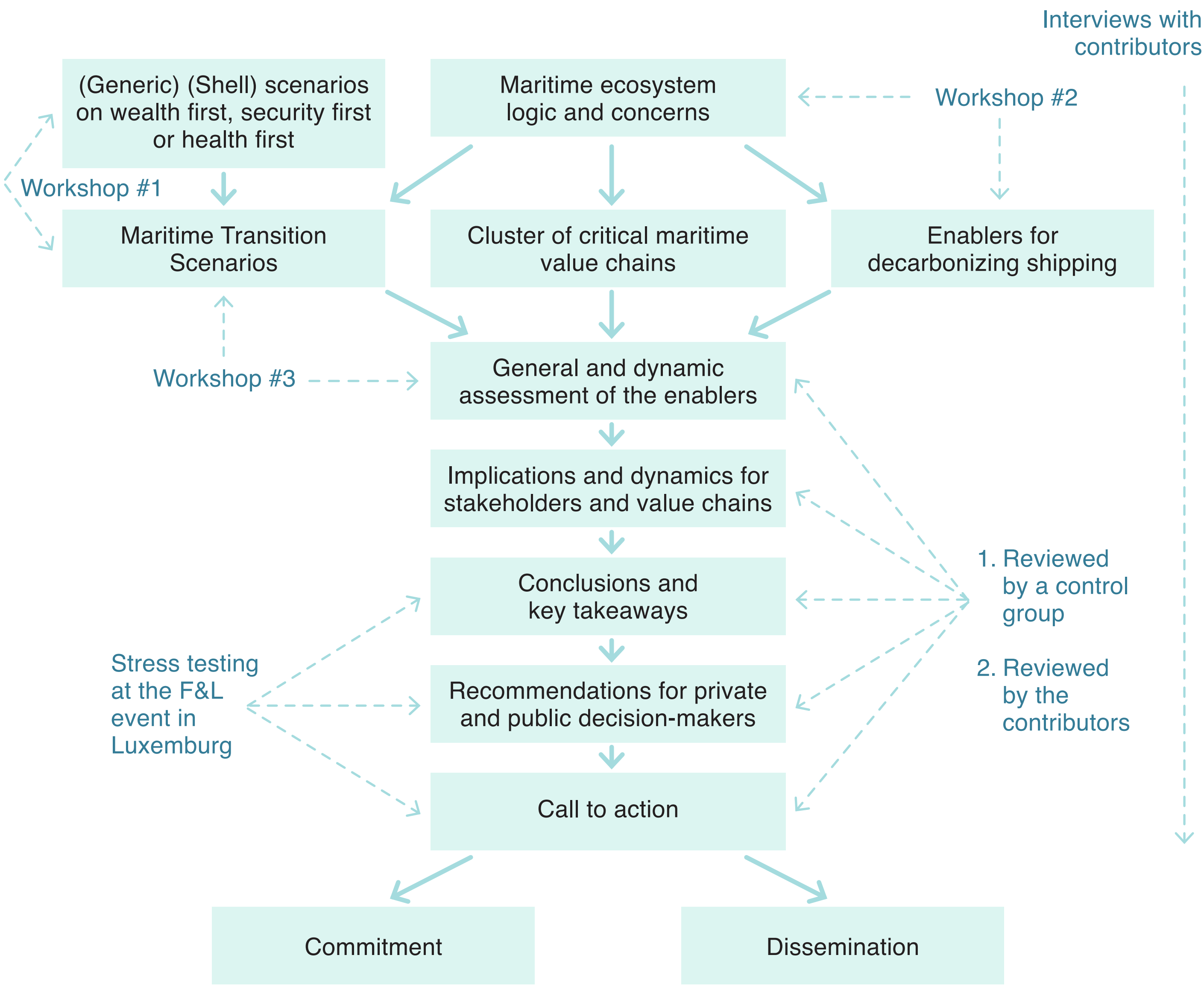


Figure: Structural flow of the exercise

A control panel of selected members of the expert group supplemented by additional practitioners and academics has scrutinised / optimised the list of decarbonisation enablers and the assumptions behind the scoring of the general and dynamic factors. The expert group and members of the Freight and Logistics Leaders' Forum (F&L) (a neutral network of business leaders focusing on freight logistics across the supply chain and operating in all sectors and transport modes, based across Europe and globally) has stress-tested concepts, findings, and recommendations.

By this work a robust framework has been developed using scenarios to set the scene and derive plausible pathways towards decarbonisation of shipping, adopting a perspective of interrelated clusters of value chains, and scoring different decarbonisation enablers. A next step could be that more quantitative data is generated, for example to refine the qualitative assessments through panels with diverse member from all areas of the economic decarbonisation ecosystem. This will bring more certainty to the conclusions to create more confidence in the decisionmakers.

Appendix 2: Maritime Transition Scenarios

Primary topic	Sub-topic	Swells	Storms	Clear Sky
Macro-context in "root" scenarios	Storyline	Economic shocks resulting from the pandemic and the war in Ukraine shift governments focus back on economic growth and supply chains.	The security crisis and energy markets tightness caused by geopolitics like the Ukraine war leads to militarisation and nationalism grouped in regions.	The pandemic and Ukrainian shocks forced attention to securing competitiveness and forge new alignments, on the energy transitions.
	Geopolitics	West and China-centric world. Realpolitik allows Russia to come back as major commodity provider, initially via backdoors in the global markets. The Russian crisis has been overcome through a frozen conflict at the Russian boarder, like it was the case with Nagorno-Karabakh between Armenia and Azerbaijan or South Ossetia in Georgia.	A world of multiple blocs and continuous tensions. NATO is strengthened, EU is becoming (energy) security focussed. U.S. and China continue building up their military capabilities and seek regional spheres of influence. Russia finds itself weakened globally, but stronger locally and in Central Asia. It is important as a commodity supplier.	Pragmatic new alliances are formed, e.g. with new major resource holders for the green energy transition. While frictions persist a new alignment around the fight against global challenges is reached, in part to secure domestic competitive economic advantage. The global accord on climate and other important actions helps to avoid major decoupling. A new form of globalization has emerged.
	Global economy	Rapid growth, as China and the West reach a tense modus vivendi around economic interests.	Higher interest rates, less open with slower economic growth compared to health or wealth scenarios.	Stable inflation, moderate interest rates, decent growth, sanctions are removed step-by-step.
	Climate	Climate action remains on the agenda, but realpolitik allows fossil fuels to grow initially, which causes the need for accelerated costly action later-on, enabled by advanced technological progress.	Fragmented international cooperation, with less investments in renewables required as growth and CO_2 emissions are slowing, but which causes pent-up problems later.	COP27, COP28… Attention to climate policy ranks high on the international agenda providing mechanisms that support the domestic industrial interests of leading economies.
	Scenarios	In Swells, the initial response to the array of crises is to keep the economy going until environmental pressures force a radical change of course and drastic climate actions – *growth first.* Self-interest is largely perceived in financial terms, and resilience is judged in terms of economic strength. Economic recovery is rapid, although at the cost of investments into environmental measures and the health system.	In Storms, governments and societies generally decide to focus on the safety and well-being of their own population and seek nearby alliances to strengthen that position - *security first.* Nationalism and militarism shift the world further away from the post-war geopolitical order. The invasion of the Ukraine starting on 24 February 2020 brought back elements of the reality that prevailed before the fall of the Berlin wall.	In Clear Sky, the response to COVID-19 and the war in Ukraine is to focus on reforming approaches recognised as unsatisfactory, building new competitive strongholds – *wellbeing first.* Following the success of vaccines and the Western unity during the war in Ukraine, there is deeper appreciation of the role of alignments in addressing challenges more broadly – .

Primary topic	Sub-topic	Swells	Storms	Clear Sky
		There is a surge in the use of all types of energy, including fossil fuels. The Russia-Ukraine crisis has re-focused the decarbonisation movement in the short term with Europe dashing ahead with reducing hydrocarbon consumption, which is often pushed aback elsewhere continuing the heavy production of fossil fuels. China staying on its CO_2 reduction course but the U.S. focusing on fossil fuel exports to provide a counterbalance to Russian supply. The apparent economic success disguises a deeper story of growing inflation, as interest rates are kept low, feeding into social discontent and labour unrest. The public begins to react massively to more frequent and more extreme weather events. From an energy perspective, there is then a societal and political doubling down to tackle climate change which forces rapid policy-driven reductions in fossil fuel use. The global use of coal and oil peaks in the 2030s, and natural gas not long afterwards. Moving quickly and accelerating with the decline in costs, starting later than required to meet the goal of the Paris Agreement, global society achieves an energy system with net-zero emissions eventually – *late but accelerated decarbonisation*	The poor suffer the most as commodity prices, especially for wheat and energy skyrocket, but the situation relaxes once the dust settles, helped further by slower economic growth. There is an islands-mentality with resilience understood as autonomy and self-sufficiency. These internally focused recovery efforts have mixed results. There are frictions in international trade and collaboration, so growth in the global economy begins to slacken, and international efforts to address the climate challenge slow. The Paris climate process unravels. Nations focused on their own short-term (energy) security concerns remain dependent on fossil energy for a prolonged period, and global emissions decline only slowly. Extreme weather events eventually cause disruption and suffering, yet the 'blame' for this is largely placed on 'others' rather than embraced in domestic politics. Although the normal course of equipment and infrastructure replacement and the deployment of cleaner technologies bring progress but does not lead to a net-zero economy. The world overshoots the timeline and does not achieve the goal of the Paris agreement – *late and slow decarbonisation leading to adaptation.*	both deliberately engineered alignments and those simply emerging from common pressures and circumstances. The new drive for energy and food security is combined with a commitment to speed up the green transition in leading countries. The U.S., China and other technology-focused economies in Asia and Europe target the development of clean technologies as an economic and security goal that boosts domestic industrial and technological competitiveness. There is rapid and deep electrification and decarbonisation of the global economy, with growth dominated by renewable resources. Global demand for coal and oil peak in the 2020s, and natural gas in the 2030s. In the economic sectors that are harder to abate, liquid and gaseous fuels are progressively decarbonised – sometimes head over heels – through biofuels, hydrogen, CCR[S], with more focus on recycling carbon than its storage. The circular economy is emerging also encroaching the maritime industry through recyclable ships. Leading economies achieve the goal of net-zero by 2050, supporting less developed nations. The goal of the Paris Accord is met – *accelerated decarbonisation now.*
Maritime sector	Scenarios impacts	In Swells, behaviour within the maritime industry reverts largely to pre-pandemic dynamics. Developments are driven by multiple entrepreneurial individual agents with limited new collaboration beyond profit-protecting arrangements. Despite the global disruption caused by the Russia-Ukraine crisis economic growth and trade volumes	In Storms, trade in commodities as well as manufactured goods is depressed causing slowing growth in the global economy and an increased focus on inter-regional self-sufficiency. The sluggish global trade outlook and focus on domestic economies adds friction to accessing capital for investment in greener technologies.	In Clear Sky, the accelerated pressure on national and international decarbonisation commitments, and steady technological progress and investment across all sectors of the economy, encourages and is reflected in the balancing across key value chains (fuel, ship, operations) of the maritime sector.

Primary topic	Sub-topic	Swells	Storms	Clear Sky
		provide a favourable context for the industry that provides some resilience in subsequent backlashes against fossil fuels. Perceived uncertainty about the main decarbonisation technologies and availability of alternative fuels prevail until the mid-2030s creating a certain level of hesitance in respect to green investments. Advances in digitalisation are affordable and boost efficiency across the industry and broader logistical operations. Large stakeholders originating from developed economies with financial room to maneuver invest continuously in greener approaches in advance of growing anti-fossil regulation, providing a starting point for less prosperous stakeholders to adopt greener approaches when forced later. The broader societal backlash provides some new opportunities to the maritime sector as other sectors are disrupted and freight patterns change. Marine value chains (mainly fuel, ship, operations) are partially balanced. The eventually rapid decarbonisation brings new trade in light weighting material to help drive efficiencies in mobility. Nevertheless, the knee-jerk policy changes hurt the industry and force a period of uncertainty and very high capital investment in the 2030s that prove beyond the capacity of financially weaker players to respond to. The shift from continuing growth in oil demand with global economic expansion to sharply enforced reductions in demand leads to over-capacity in tankers.	There is a heterogenous landscape in regulation and a drift away from IMO legislation. The gaps across fuel, ship and operations supply chains widen. Different fuel types and standards emerge as preferred developments in different countries and parts of the world, making efficient international operations a challenge. Japan, California, the Nordics and Europe as a whole drive decarbonisation rapidly compared to lagging North America, South America, South-East Asia and the Middle East. However, these differences enable some opportunities for arbitrage for instance through commodity price differences for instance for LNG and new optimisation opportunities like those enabled by the Clydebank the declaration for zero-emission corridors. While climate turbulence is locked in over the next couple of decades in all scenarios, in Islands the elevated emissions in the later decades stokes greater storms and sea-level rise affecting all ports and maritime operations. Trade patterns are significantly affected as climate change causes shifts, for example agricultural activity moves from water scarce areas to water rich regions. The Arctic route becomes viable. Decarbonisation of inland and short sea shipping progresses in Europe, the U.S. and East Asia while the global deep sea shipping liners, including cruise ship operator and tramp shipping companies face severe challenges caused by a fragmented regulatory and technology landscape pushing operating cost and freight rates up.	Developments take place across all areas of the logistics industries, with improved alignments between sea and land connections. Already in the 2020s, alignments strengthen significantly compared to the past, with EU and IMO, and China and U.S. approaches to climate action converging. There is a changed approach to viewing anti-competitive principles in the industry, with more public-private cooperation emerging, reflected in increasingly impactful global maritime coalitions. Establishing a level playing field and mitigating the risk of stranded assets are the main motivators. These support the development of different ship types and sizes, driven by the requirement for greener less-dense fuels which requires major adaptations in design to ensure stability and safety. Changes in domestic waste management increase the supply of biofuels. Maritime decarbonisation technology trade becomes a highly lucrative segment. Trading patterns adjust, with some ports benefitting from these or choosing to benefit through their investments in energy production and fueling infrastructure. New ships are increasingly made of recycled materials and are also recyclable. As overall investment to fund decarbonisation is relatively high (increasing investment in physical assets from less than 7% of global GDP to more than 8%), competition for capital becomes tighter. Shipping costs increase, adding to consumer prices and driving inflation.

Primary topic	Sub-topic	Swells	Storms	Clear Sky
	Trade flows impacts	Bounce-back in global trade volumes in the 2020s but below earlier forecasts due to the Russian crisis. The later rapid reduction in demand for oil and gas in the 2030s/2040s affects the oil and LNG tanker segment but the shortfalls are compensated by new transport needs for green fuels. Late regulatory action and lack of availability of sufficient capital leads to a shortage of compliant ships in the 2030s to support the trade volumes. Freight rates soar again. The Russia-Ukraine crisis make regions rethink their (energy) supply chains; for example, commodities will be sourced from new geographies which tend to be further away increasing ton-miles for waterborne transportation.	Sluggish growth in global trade and shipping volumes but an increasing emphasis on local/regional shipping. Minimal improvements in global trade efficiency. Affected by climate change, geopolitical formations, and geographical shifts in agricultural but also industrial production as the trend towards strong regional economic platforms accelerates causing benefits for certain ports and challenges for others. Shipping market suffers from volatility in the 2020s. Slower economic growth and trade frictions depress growth in shipping. Trade tends to be more reginal. Climate change-driven changes in trade patterns alter the business models of ports.	Steady trade growth. Reduction in demand for oil and gas affects the oil and LNG tanker segment which moves gradually towards transports of green fuels in the 2030s. Broader carbon tax adjustments are enforced and affect trade operations. The investments in and adoption of green technologies in many parts of the world creates new trade opportunities. Decarbonisation contributes to a new golden era of - sustainability driven - globalization. Decent economic growth and increasing cooperation to accelerate the energy/green transition stimulates globalisation. Sky1.5 / Clear Sky has the highest growth in ton-miles shipping services of all the scenarios.
Decarbonisation / Collaboration / Optimisation / Automation	Overall focus	Effort in some segments of the maritime industry, like cruise shipping and wet bulk to push LNG as interim fuel in the 2020s and 2030s. Pioneers drive more radical solutions picking proven fuels like methanol and pushing other enablers (e.g. hydrodynamics, weather routing etc.) to further their research and innovation efforts. Inefficiencies in general continue to create profit opportunities in shipping for example through demurrage for some time. Companies remain reluctant to make the investment in digital solutions except for the larger shipping companies and ports of the world. As of 2020 only 80% of the ports of the world do have the relevant digital capabilities for being integrated in a global digitally connected maritime network.	Moderate diffusion of technological lessons and lack of global regulations slow overall progress in decarbonising in particular in the deep sea segment of the industry. Greater focus on optimising regional and local operations and using local solutions to decarbonise and digitally optimise maritime flows. Some countries invest billions in climate preparedness and early warning systems. Others lose billions through natural disasters and for reconstruction. Overall, the costs of a fragmented world are enormous. Technology is mainly used on a local/regional scale. Global solutions are hindered by local regulations and technology tensions and even wars driven by fear, mistrust, geopolitics and political agendas. Digitalisation across the world is dispersed and connectivity fractured.	The dense patchwork of collaboration and competition ensures rapid diffusion of technological progress across the globe. Cross-sector partnerships focus on technologies that boost mode connectivity and the competition for green fuels across the economy already in the 2020s. Digital optimisation tools find quickly broader adoption. Push to convert to LNG as interim fuel and methanol ships are in service too. The use of biofuel and batteries in inland and short sea shipping expands quickly. Recycling is accelerated and the technology plays an important role in decarbonisation in the 2020s and 2030s. Green steel for newbuilds is incentivised. Ships are increasingly made of recycled materials and can be recycled at the end of their use.

Primary topic	Sub-topic	Swells	Storms	Clear Sky
		After slow start in the 2020s and 2030s, laser-sharp focus on reducing emissions from fossil fuels in the 2040s. Eventually, everything is thrown into the mix, including hydrogen-ammonia, wind, carbon capture and storage technology, methanol and even nuclear, digitalisation-based optimisation tools and regulatory measures on local and global level. Century-old contracts and practices are thrown overboard to deal with the massive consequences of climate change. Autonomous ships emerge in the 2030s/2040s.	Some countries move fast and some private actors are establishing global communication network. But global coordination to extract significant value is lacking. Local automation produces limited benefits for the global maritime ecosystem. The lack of common frameworks and standards are additional hurdles in the way of implementing global decarbonisation solutions. The west suffers from cyberattacks of Russian and other criminal cyber syndicates.	Every technology is brought to the test, including fuels, hydrodynamics, and digital tools. Digitalisation is a mean to help decarbonise through optimised operations, automation, visibility and carbon calculation. ICT-communication coverage increases supporting digitalisation. Synchronization with just-in-time arrivals reduces emissions by up to 20%. Better routing yields 3-15% reductions and autonomous ships are introduced in the 2030s.
	Ecosystem / coalition	Multiple industry coalitions with overlapping missions and limited impact to begin with chaotic global collaborations that arise later in response to pressures of knee-jerk policies. Shipping lines with zero-emission goals aim at cooperating with countries, energy producers, etc. to ensure supply of green fuels. As lighthouses they provide impetus for closer co-operation across the cluster of value chains. Customers seek closer collaboration with shipping lines to reduce their carbon footprint. Initiatives like zero-emission corridors move at a slow pace till the 2030s. Then an increasing number of coordinated efforts are launched.	The ecosystem gets more fragmented. International collaborations weaken as the emphasis grows on local conditions and regional and domestic connectivity and relations. Some regions increase their decarbonisation efforts, like Europe, while other areas stick to their commitments and plans with the highest level of collaboration like China and Japan. Efficiency improvements occur locally but not globally, and high emission fleets are allowed to continue operating. But they face carbon tax in certain regions, like Europe. Countries in favor of rapid decarbonisation install zero-emission coalitions and corridors within their sphere of influence.	Steady convergence among major international and national regulatory authorities. Business sector coalitions and partnerships emerge driven by both external pressures and competitive opportunities. The maritime industry competes heavily on fuels with other parts of the economy. The initial efforts of large ocean liners to build decarbonisation coalitions become the foundations of a new global coalition with regulators supporting the private sector actors. The IMO enjoys a new role in the decarbonisation effort with the support of all their members. The critical interdependent value chains, fuel, ship, operations get increasingly balanced.

Primary topic	Sub-topic	Swells	Storms	Clear Sky
	Fuel types	Adoption of LNG as an available, affordable and lower-emissions interim fuel combined with high trade demand. Methanol makes early inroads as an easy option of the alternative fuels for deep-sea shipping- it is in liquid state in ambient temperature which make it easy to handle and store usable in internal combustion engines (ICE). The fossil-fuel backlash also accelerates the development of commercial hydrogen/ammonia powered vessels. In the next three decades, LNG rises to become 10-15% of all shipping fuel, and hydrogen-ammonia approaches 5%. The fuel cell capacity increase takes time which pushes application beyond 2030. Anti-fossil developments bring the LNG era to an end in the 2040s.	LNG makes steadily inroads as a fuel. Global industries test and drive flexible solutions to cope with the fragmentation balancing the critical value chains fuel, ships and operations. More methanol-powered deep-sea ships are put into service and ammonia-powered ships emerge in the 2020s. By the end of the century hydrogen-ammonia accounts for around 10% of marine fuels. Regionally companies use what's available, i.e. what is produced locally, e.g. biofuel or batteries for inland waterways and short sea shipping. Others experiment with methanol and ammonia. Ports adjust their storage and filling capabilities to the local production and demand at the detriment of a global approach to decarbonisation.	On deep sea, LNG fuels rise in share until the 2030s before they decline to make room for greener solutions including green LNG. Adoption of methanol-powered ships, other than methanol tankers, starts in the 2020s. Wind is also part of the mix. Ammonia ICE available in mid 2020s applied in certain areas where safety can be ensured. Large capacity hydrogen fuel cells will be tested in the 2030s. Even nuclear is considered for deep sea shipping but with highest scrutiny as health/safety is the utmost priority in this scenario. In inland waterways and short sea shipping biofuels are important but also battery-powered ships take their share growing quickly. Regulators help the uptake.
	Ship types	The IMO ambitions and regulated carbon reductions are too low to achieve the Paris Agreement goals. By 2030 this becomes a bigger concern, and the IMO raises ambitions and targets. Green Corridors are established in some parts of the world but progress in the corridors is slow. Cluster of interdependent supply chains is fractured. Different levels of investment in the different regions slows down the progress. A few large operators are piloting alternative fuels and technology eventually adapted globally.	A two-tier market emerges driven by a regional push to improve the fleet. In some regions the port states push for improvements, whereas in other areas less energy efficient vessels are allowed to operate. Green Corridor efforts are not supported by the regions. The focus is on short-sea shipping and inland waterways with often older vessels. The sector is comparably easier to decarbonise because of lesser propulsion capacity, and it can be supported with existing technology, such as batteries, fuel cells, and biofuels.	Strong incentive to improve vessel energy efficiency and ratings across the fleet. Green Corridors are established widely, becoming pilots for stakeholder collaboration. Lessons learnt will help to build the worldwide zero carbon network. Investment in R&D and infrastructure development supports the gradual renewal of the fleet. First older less energy efficient ships are phased out. By 2030 first zero carbon ship are in operation, with the fleet replacement gradually continuing towards 2100.

Primary topic	Sub-topic	Swells	Storms	Clear Sky
Regulation	Direction and pace	IMO raises decarbonisation goals but struggles with implementation. Incremental change shifts suddenly to accelerated anti-emissions and anti-fossil fuel regulation in different parts of the world, starting in Europe, then Japan, China followed by the U.S. The Russia crisis accelerates focus on renewable energy in Europe. Japan and China stay on their decarbonisation track while the U.S. initially increases its focus on fossil fuels. Regulation is fragmented with duplications, e.g. multiple ETS systems. In the 2020s and 2030s broader parts of the maritime industry push LNG as an interim fuel. Short sea shipping lines are driving biofuel and electric solutions. The U.S. and China push electric boats/tugs for inland waterways shipping. Major deep sea shipping lines select specific decarbonisation technologies, like methanol to drive them towards broader adoption. Which eventually succeeds in the 2030s/2040s.	Weakening IMO influence over regional and local regulations leads to a heterogenous approach towards decarbonisation, with tighter regulation of emissions in some areas like Europe and California and slow change in other regions such as Latin America. The IMO applies a consensus approach causing slow decision-making. The situation allows some reginal or local governments take decisions faster than before. East Asian countries implement what they need to do to live up to their commitments. While pressures exerted through western customers in tenders is raising, the decoupling offers an easy escape. The U.S. contribute on a short sea and inland waterways transport level but leaves direction and speed entirely to the private sector players. The fragmented world stands in the way of a high pace decarbonisation effort in the maritime industry and the entire global economy.	Gradual convergence of EU, China and US regulatory approaches which strengthen the IMO, as all stakeholders recognise the advantages of clarity, standards and a level playing field in the area in the pursuit of decarbonisation, building competitive advantages and new business opportunities like carbon trading through accelerated emissions reduction. Regulations support fair transition in which developed nations' share of the cost is proportional to the climate change impact of the past helping developing nations to finance green energy production to cover their increasing energy needs to support economic growth. Governments support the effort with fiscal measures, penalising emitters and incentivising "decarbonisers". Regulations support different solutions suitable for different sectors, allowing to close gaps across the cluster of maritime value chains.
	Financial reporting obligations	Incremental change driven by the ESG requirements which forces companies and banks to apply more sustainable operational and investment practices and report on their progress of their efforts to decarbonise their businesses.	Heterogenous requirements prevail beyond those companies that operate globally with global financing needs which follow the ESG rules. The lack of transparency and comparability confuses consumers and financial markets.	Accelerated broad requirements for financial reporting. Decarbonisation becomes a central reporting item with companies to show progress in reductions. Progress on CO_2 reduction is part of the value proposition.
	Emissions trading	EU ETS placed under great pressure as initial deployment of new technologies across the economy fails to reduce demand in line with legislated caps, so is weakened by increased allowances. In later decades, however, it is reinforced along with other schemes as the pace of demand reduction is forced.	Sluggish economic growth reduces pressure on schemes like the EU ETS. However, disappointing deployment of new technology eventually puts pressure on the system and nationalistic sentiment ensures it is weakened to the point of irrelevance.	The IMO adopts a global ETS / levy. Such schemes are essential for financing the transition. Continued expansion of regional and local schemes, through convergence facilitated by Article 6 mechanisms under the Paris Agreement.

Appendix 3: Identified enablers and their characteristics

Category	Value chain F	S	O	Enabler	Description
Multi-fuels	✔	✔	✔	LNG	Although the cleanest, liquified natural gas (LNG) is a fossil fuel which is currently in the ramping up phase as fuel solution for shipping; potential transition to eLNG or bio LNG. Natural gas emits ~24% less CO_2 than oil per unit of energy.
				Green LNG / LBG	Green LNG (Liquefied Natural Gas) refers to either reducing greenhouse gas emissions or offsetting GHG emissions associated with some or all of the LNG value chain. LBG refers to Liquid BioGas
				Green methane	Green Methane refers to either reducing greenhouse gas emissions or offsetting GHG emissions associated with some or all of the Methane value chain.
				Biodiesel	Biofuels in internal combustion engines (ICEs) are in use and play a role across all scenarios but causing biodiversity and food concerns; domestic waste may be worth a look. High conversion losses from biomass to biofuel makes it a costly option.
				Green methanol	Green methanol is carbon neutral and can be used in ICEs and can be used as hydrogen carrier. Although tank-to-wake fuel efficiency is slightly less than diesel, the well-to-tank fuel conversion losses strongly reduces overall efficiency and hence increases system costs.
				Green ammonia	Green ammonia is carbon free but highly toxic, can also be used in ICEs; can be used as hydrogen carrier, but will need some diesel blend to ignite. Same fuel efficiency issues as for green methanol.
				Green hydrogen	Hydrogen produced using alternative non-hydrocarbon energy. Hydrogen in itself is always carbon free and can be used in ICEs but also in fuel cells to produce electricity.
Other power sources	✔	✔	✔	Green electricity	From Wind, Solar or decarbonised power plants with Carbon Capture and Storage (CCS), stored in batteries and used to power electric motors, especially for shorter voyages
				Nuclear	Nuclear is a mature technology but with security and safety concerns and high costs
Regulations	✔	✔	✔	Market-based mechanism (MBM) - European Trading Scheme (ETS) and levy	EU emissions trading system (ETS = emission trading scheme); carbon price
				EEDI/EEXI	Energy Efficiency Design Index / Energy Efficiency eXisting ship Index; Requirements for new and existing ships correspondingly
				CII	Carbon Intensity Indicator; Operational index
				Gradual reduction of carbon content in fuels	Minimum percentage of clean fuels as a part of the total fill

Category	Value chain F	S	O	Enabler	Description
Financing	✔	✔	✔	Incentives for green fuel production	The use of incentives to stimulate ramp-up of the green production of multiple types of green fuel
				Incentives for clean shipbuilding	Additional cost of building zero or low carbon emission ships should be compensated with financial incentives.
				Green innovation / R&D funds	Closing the funding gaps for green maritime innovation, e.g. between feasibility and scale
Multi-fuel power systems	✔	✔		Multi-fuel ICE engines / onboard storages	Engines that can run on different fuels, e.g. heavy fuel oil or VLSFO and methanol with the respective storages for the respective fuels
				Fuel cell technology	A fuel cell technology that uses hydrogen, methanol, or ammonia to produce electricity
				Batteries powered motors	Electricity from batteries' powered motors, needing higher capacity batteries (solid state with next generation anodes)
				Upgradability / Retrofitting	Replace higher carbon-intense power plants with more carbon-efficient power plants and storage
Circularity		✔	✔	Recyclable ships of recyclable material	Recycling ships and building ships from recycled materials takes significant carbon out of the life cycle of a ship
				Carbon capture and storage (CCS)	Carbon captured from the process of producing fuels or from using fuel to generate power, and storing the captured carbon in so that it does not release into the atmosphere
Port measures	✔		✔	Fuel storage / Fuelling equipment for alternative fuels	Facilities and equipment to store fuels (including methanol, ammonia or hydrogen beside existing fuel).
				On-shore power supply	Powering auxiliary engines from the onshore grid
Green power-to-X technologies	✔			Electrolysis solutions for green fuels from renewable electricity	Hydrogen produced with green electricity is used to make easier to transport energy carriers like methonol, ammonia and synthetic fuels
				Technologies to produce green fuels from biomass/waste/ carbon	Synthetic fuels made from green hydrogen and carbon from biomass, waste or direct air capture.
Ship optimisation		✔		Wind Support	Wind as a supportive measure contributes to fuel reduction and consequently carbon emissions
				Hydrodynamics	Hull design, silicon paint, air lubrification etc.
				Ship size optimisation	Operate ship size in line with demand for capacity
				Fleet renewal	Taking advantage of new generation lower emissions ships
				Autonomous ships	Autonomous ships are operated without crew onboard. They are not by default optimised for fuel consumption, but they have a potential for improved operational efficiencies

Category	Value chain F	S	O	Enabler	Description
Operations controls			✔	JIT Port Calls	Just-in-Time arrival in port to avoid delays in loading or discharging. JiT optimises the vessel utilisation.
				Advanced weather routing	Weather routing provides guidance for the vessel to choose the best route for the given environmental conditions.
				Commercial contracts	Commercial contracts defining the commercial terms for the voyage and to secure integration within and across the three value chains, as e.g. the provision and storage of fuel, virtual port approaches etc.
				Slot Management	Slot management moves beyond JIT arrivals and includes the departure perspective as well
				Speed Optimisation	Speed optimisation optimises the speed for the selected parameters, e.g. fuel consumption, fuel price, charter rates, regulatory requirements. Slower speeds reduce fuel consumption and GHG emissions.
				GHG emissions calculation	Methodology and tools that calculate the GHG emissions of a voyage taking fuel carbon factors into account.

Appendix 4: Scoring (Harvey balls) of general enablers

INDICATIVE

Category	Value chain belonging F	S	O	Enabler	Impact on GHG reduction	Ease of execution	Acceptance across stakeholder
Multi-fuels	✔	✔	✔	LNG	◔	◕	◕
				Green LNG / LBG	●	●	◕
				Green methane	●	●	◕
				Biodiesel	●	●	◕
				Green methanol	●	◑	◕
				Green ammonia	●	◔	◑
				Green hydrogen	●	◑	◑
Other power sources	✔	✔	✔	Green electricity	●	◕	●
				Nuclear	●	◕	◑
Regulations	✔	✔	✔	Market based measures (MBM) - European Trading Scheme (ETS) and levy	●	●	◕
				EEDI/EEXI	◔	●	●
				CII	◔	●	◕
				Gradual reduction of carbon content in fuel	◑	●	◕
Financing	✔	✔	✔	Incentives for green fuel production	●	○	◕
				Incentives for green shipbuilding	●	○	◕
				Green innovation / R&D funds	◕	◕	◕
Multi-fuel power systems	✔	✔		Multi-fuel ICE engines / onboard storages	◕	●	●
				Fuel cell technology	●	◔	●
				Batteries powered motors	●	◑	●
				Upgradability / Retrofitting	◑	◑	◑
Circularity		✔	✔	Recyclable ships of recyclable material	◑	◔	●
				Carbon capture and storage (CCS)	◕	◔	◑
Port measures	✔	✔		Fuel storage/ Fuelling equipment for alternative fuels	●	◑	●
				On-shore power supply	◕	◑	◕
Green power-to-X technologies	✔			Electrolysis solutions for green fuels from renewable electricity	●	◑	●
				Technologies to produce green fuels from biomass/waste/carbon	●	◑	●
Ship optimisation		✔		Wind Support	◔	◕	◕
				Hydrodynamics	◔	●	◕
				Ship size optimisation	◔	●	●
				Fleet renewal	◕	◑	◕
				Autonomous ships	◔	◑	◕
Operations controls			✔	JIT Port Calls	◔	◕	◕
				Advanced weather routing	◔	●	●
				Commercial contracts	◑	◑	◑
				Slot Management	◑	◑	◑
				Speed Optimisation	◔	●	●
				GHG emissions calculation	●	◕	●

Appendix 5: Arguments for the evaluation of the general enablers

Category	Value chain F	S	O	Enabler	Impact on GHG reduction	Ease of execution	Acceptance across stakeholder
INDICATIVE							
Multi-fuels	✔	✔	✔	LNG	1 = 30% less CO_2 emissions (Tank-to-Wake) than fuel oil but with the risk of methane leakage	3 = Technology first implemented on LNG ships and now also on other ship types	3 = LNG enjoys high acceptance except the methane leakage
				Green LNG / LBG	4 = Green when produced with renewable energy and CO_2-free equipment, transported with zero carbon vehicles, and stored in and filled with zero carbon emission infrastructure	4 = Capabilities are in place	3 = Widely accepted as fuel
				Green methane	4 = Green when produced with renewable energy and CO_2-free equipment, transported with zero carbon vehicles, and stored in and filled with zero carbon emission infrastructure	4 = Capabilities are in place	3 = Widely accepted as fuel
				Biodiesel	4 = Carbon neutral fuel; Biofuels produced entirely from biomass offer reductions in life-cycle greenhouse gas emissions from 67% to 93% less than HFO	4 = Biofuels are in operation today and can be used in internal combustion engines (ICE)	3 = This alternative fuel is widely accepted but there are biodiversity and food competition concerns, beside large-scale biomass availability issues and cost competitive issues with sectors that can afford paying higher prices (Aviation)
				Green methanol	4 = Carbon neutral fuel: Green when produced with renewable energy and CO_2-free equipment, transported with zero carbon vehicles, and stored in and filled with zero carbon emission infrastructure	2 = Methanol powered tankers are in service, but the engines are dual-fuel engine and can burn HFO	3 = This alternative fuel enjoys a relatively high acceptance across stakeholders, but Well-to-Tank conversion technologies may prove (too) costly with alternatives.
				Green ammonia	4 = Green when produced with renewable energy and CO_2-free equipment, transported with zero carbon vehicles, and stored in and filled with zero carbon emission infrastructure	1 = Highly toxic and although ammonia is used in fertilizer factories it is complex to establish the value chain	2 = Because ammonia is highly toxic it faces a certain level of resistance among stakeholders, but Well-to-Tank conversion technologies may prove (too) costly with alternatives.
				Green hydrogen	4 = Green when produced from Natural Gas with CCS or renewable energy and CO_2-free equipment, transported with zero carbon vehicles, and stored in and filled with zero carbon emission infrastructure	2 = the production from large scale electrolysers and renewable electricity is ramping up for industrial purposes and to replace natural gas (EU), while (liquid/high pressure) storage tank technology is being developed.	2 = There is a need for fuelling infrastructure and large-scale reliable fuel cells. Electric drive chains are established technology. Need for more public awareness / acceptance

INDICATIVE							
Category	**Value chain F**	**S**	**O**	**Enabler**	**Impact on GHG reduction**	**Ease of execution**	**Acceptance across stakeholder**
Other power sources	✔	✔	✔	Green electricity	4 = Zero-emission powering. Green when produced with renewable energy and CO2-free equipment, transported via zero carbon systems, and distributed via zero carbon emission infrastructure	3 = Fully electric driven ships are starting to become used in ferry transports and inland waterway shipping. Broader use dependent on better battery technology emerging.	4 = Broadly accepted across stakeholders, as this is the most energy efficient route to use renewable electricity for propulsion
				Nuclear	4 = Zero-emission powering when the process is green	3 = Small Modular Reactors (SMR) would enable this, especially as it reuses nuclear waste, but handling nuclear remains risky; recent technology development with molten salt reactors	2 = In several countries' population is highly concerned about the use of nuclear power while other nations remain relatively comfortable
Regulations	✔	✔	✔	Market-based mechanism (MBM) - European Trading Scheme (ETS) and levy	4 = MBMis an effective mechanism to support the transition towards clean shipping	4 = Straight forward concept but difficult to agree implementation globally	3 = Increasingly accepted concept
				EEDI/EEXI	1 = Regulatory requirements on ship design	4 = EEDI requirement since 2011 and EEXI in 2023.	4 = Accepted
				CII	1 = Regulatory requirement on ship operations	4 = Entry into force in 2023	3 = Concerns raised in respect to calculation for cruise liners and the 5,000 GT threshold
				Gradual reduction of carbon content in fuels	2 = Supports the green transition	4 = Simple to implement	3 = Has not been accepted globally
Financing	✔	✔	✔	Incentives for green fuel production	4 = Support ramp up of value chain	0 = Concept to be developed	3 = Large acceptance
				Incentives for green shipbuilding	4 = Support ship optimisation	0 = Design concepts and technology needs to be developed	3 = Large acceptance
				Green innovation / R&D funds	3 = Drives required innovation	3 = Not everyone is on board on how it should be funded	3 = Not everyone supports a dedicated R&D fund

INDICATIVE Category	Value chain F	S	O	Enabler	Impact on GHG reduction	Ease of execution	Acceptance across stakeholder
Multi-fuel power systems	✔	✔		Multi-fuel ICE engines / onboard storages	3 = They exist but not for all fuels	4 = Can be used for new-builds but also used for retrofitting	4 = No objections
				Fuel cell technology	4 = Zero-emission drive chain	1 = Progress is expected to be made but solution for large capacity fuel cells required for ocean going ships will be ready in about a decade	4 = No objections, but drive chain costs need (much) improvement
				Batteries powered motors	4 = Zero-emission drive chain	2 = First battery-powered ships have been built but batteries are still not large and powerful enough and too expensive	4 = Appreciated by stake-holders
				Upgradability / Retrofitting	2 = Available but expensive in particular for old ships and limited scope	2 = Available, limited scope and expensive in particular for old ships as the focus is on newbuilds	2 = Incremental and eco-nomics need to improve
Circularity		✔	✔	Recycla-ble ships of recyclable material	2 = Circular economy ap-proaches reduce signifi-cantly carbon emissions due to reduced need for extraction and production, but recycling uses energy itself as well	1 = Although first efforts have been made by leading players in the industry large scale knowledge and capa-bilities are lacking	4 = There is a general high acceptance of recycling as concept, but cost picture brings realism
				Carbon cap-ture and stor-age (CCS)	3 = CCS is an efficient way to abate carbon emissions	1 = Difficult to execute on ships and land infrastructure is lacking	2 = The solution faces doubts and concerns across stakeholder groups
Port measures	✔		✔	Fuel storage / Fuelling equipment for alternative fuels	4 = For zero-emission fuels	2 = Many alternative fuels cannot use the existing infrastructure. Some require cryogenic conditions or high pressure to remain in liquid phase.	4 = No objections
				On-shore power supply	3 = Some CO2 reduction potential existing situation and high impact for renewa-ble power supply	2 = Technology is available but challenges with the on-shore energy supply (holistic approach required)	3 = Largely accepted
Green power-to-X technolo-gies	✔			Electrolysis solutions for green fuels from renewa-ble electricity	4 = Technology helps to produce zero-emission fuels	2 = Technology is in use but needs time for ramping up to mainstream application and scaling	4 = Generally accepted
				Technologies to produce green fuels from bio-mass/waste/carbon	4 = Technology produces zero-emission fuels	2 = Technology is in use but needs time for ramping up to mainstream application and scaling	4 = Generally accepted, but technology needs to be developed and cost greatly reduced.

INDICATIVE

Category	Value chain F	S	O	Enabler	Impact on GHG reduction	Ease of execution	Acceptance across stakeholder
Ship optimisation		✔		Wind Support	1 = Wind is weather dependent and only a supplementary solution, zero-emission option	3 = Wind is weather dependent and only a supplementary solution. The supporting technology exists and is in developing stage for scale-up but not easily implemented on all ship types.	3 = Broadly accepted across all stakeholder groups
				Hydrodynamics	1 = About 20 % CO2 reduction potential	4 = Leaders in decarbonisation are using various solutions	3 = Broadly accepted as concept across all stakeholder groups, but sparsely executed
				Ship size optimisation	1 = About 20 % CO2 reduction potential but effect is limited as there is a long tail of many shipping companies operating few ships	4 = Practiced by many carriers for decarbonisation but also cost reasons	4 = Broadly accepted across all stakeholder groups
				Fleet renewal	3 = Supports the transition	2 = Financing needs to be ensured	**3 = It is generally accepted that fleet renewal will be needed to get to net zero emissions but there is no agreement on the pace of the renewal**
				Autonomous ships	1 = Autonomy can yield fuel efficiency - more on longer voyages by optimising vessel routing	2 = Autonomous ships are not yet there- what when something goes wrong?	3 = Widely accepted concept with some concerns
Operations controls			✔	JIT Port Calls	1 = JIT Port Calls can reduce carbon emissions up to 20%	3 = Solution faces headwinds due to existing contractual arrangements	3 = Low resistance experienced/expected by any stakeholder group
				Advanced weather routing	1 = Routing optimisation can reduce carbon emission 3%-15%	4 = Solution just to be installed	4 = No resistance experienced/expected by any stakeholder group
				Commercial contracts	2 = Prerequisite for just-in-time arrivals and slot management both will make trade more efficient, support optimum speed s and eliminate emissions caused by port congestion	2 = Historic contracts and routines need to be broken and redesigned	2 = Some stakeholders in the maritime industry are sceptical and some protect their self-interest
				Slot Management	2 = Higher impact than JIT arrivals as it takes the whole port call into account enabling better planning for the routing	2 = Faces similar headwinds than JIT arrivals	2 = Higher resistance due to the need of changing contractual arrangements and operational practices
				Speed Optimisation	1 = 20% decarbonisation potential	4 = Practised since the mid 2000s	4 = Commonly accepted
				GHG emissions calculation	4 = Without measuring we can't manage; the basis for ensuring progress	3 = Not yet fully scaled with some complexities in the way, such as access to real-time accurate data. IMO and EU requirement to report CO2 emission data	4 = No objections

Appendix 6: Assessment (Harvey balls) of dynamic enablers

INDICATIVE													
Category	Enabler	Readiness of solution (Now and 2030)				Availability (Now and 2030)				Financial viability (Now and 2030)			
		Now	Swells	Storms	Clear Sky	Now	Swells	Storms	Clear Sky	Now	Swells	Storms	Clear Sky
Multi-fuels	LNG	◕	◕	◕	●	●	●	●	●	●	●	●	●
	Green LNG / LBG	◑	◑	◑	◑	◔	◑	◔	◑	◑	◑	◕	◕
	Green methane	◑	◑	◑	◑	◔	◑	◔	◑	◑	◑	◕	◕
	Biodiesel	◕	◕	◕	●	◔	◔	◔	◑	◕	◕	◕	●
	Green methanol	◑	◑	◑	◕	◔	◑	◔	◕	◑	◑	◕	◕
	Green ammonia	◑	◑	◑	◑	◔	◔	◔	◑	◔	◔	◔	◑
	Green hydrogen	◔	◑	◑	◑	○	◔	◔	◑	◔	◔	◔	◑
Other power sources	Green electricity	◑	◕	◕	◕	◔	◑	◑	◑	◑	◑	◕	◕
	Nuclear	◑	◑	◑	◑	◔	◔	◔	◔	○	○	◔	◔
Regulations	Market based measures (MBM) - European Trading Scheme (ETS) and levy	●	●	●	●	◔	◑	◔	●	●	◕	◑	●
	EEDI/EEXI	●	●	●	●	●	●	●	●	●	●	●	●
	CII	◕	●	●	●	○	◕	◑	●	●	●	●	●
	Gradual reduction of carbon content in fuel	○	◕	◑	●	○	◑	◔	●	●	●	●	●
Financing	Incentives for green fuel production	◕	◕	◑	●	◔	◑	◑	●	◔	◑	◔	◕
	Incentives for green shipbuilding	○	◑	◔	◕	○	◑	◔	●	○	◑	◔	●
	Green innovation / R&D funds	◔	◕	◕	●	◔	◑	◔	●	◔	◕	◕	◕
Multi-fuel power systems	Multi-fuel ICE engines / onboard storages	◑	◕	◑	●	◔	◕	◔	●	◑	◕	◑	●
	Fuel cell technology	◑	◑	◑	◑	◔	◑	◔	◑	◔	◑	◔	◕
	Batteries powered motors	◑	◕	◕	◕	◔	◔	◔	◑	◔	◑	◑	◕
	Upgradability / Retrofitting	◑	◑	◑	◕	◔	◔	◔	○	◑	◔	◑	◕
Circularity	Recyclable ships of recyclable material	◔	◑	◔	◕	◔	◔	◔	◑	◔	◔	◔	◑
	Carbon capture and storage (CCS)	◔	◑	◑	◑	○	◔	◔	◔	○	◔	○	◔
Port measures	Fuel storage / Fuelling equipment for alternative fuels	◔	◕	◕	◕	◔	◕	◑	◕	◑	●	●	●
	On-shore power supply	◑	◕	◕	●	◑	◑	◑	◕	◔	●	●	●
Green power-to-X technologies	Electrolysis solutions for green fuels from renewable electricity	◕	◕	◕	●	◔	◑	◔	◕	◑	◔	◔	◑
	Technologies to produce green fuels from biomass/waste/carbon	◔	◑	◔	◑	○	○	○	◔	○	○	○	◑
Ship optimisation	Wind Support	◔	◑	◑	◕	◔	◑	◔	◑	○	◕	◕	◕
	Hydrodynamics	◕	◕	◕	◕	◔	◑	◔	◕	●	●	●	●
	Ship size optimisation	●	●	●	●	◑	◕	◑	◕	◕	◕	◑	●
	Fleet renewal	◔	◑	◔	◕	◔	◑	◑	◕	◕	◕	◕	●
	Autonomous ships	◔	◑	◑	◑	○	◔	○	◔	●	●	●	●
Operations controls	JIT Port Calls	◔	◑	◔	◕	◔	◔	◔	◑	●	●	●	●
	Advanced weather routing	◕	●	●	●	●	●	●	●	●	●	●	●
	Commercial contracts	○	◔	◔	◑	○	◔	◔	◑	●	●	●	●
	Slot Management	◑	◕	◕	●	○	○	○	◔	●	●	●	●
	Speed Optimisation	◕	●	●	●	◑	◕	◔	●	●	●	●	●
	GHG emissions calculation	◑	◑	◑	●	◔	◕	◑	●	◑	◕	◕	●

Appendix 7: Arguments for the evaluation of the dynamic enablers

INDICATIVE			Readiness of solution (Now and 2030)		
Category	**Enabler**	**Now**	**Swells (2030)**	**Storms (2030)**	**Clear Sky (2030)**
Multi-fuels	LNG	3 = LNG technology is in use, but infrastructure needs still to be ramped up	3 = More infrastructure will be available in 2030	3 = Slower ramp up of infrastructure due to varying priorities	**4 = Push for LNG as interim fuel by IMO, the EU, Japan and China**
	Green LNG / LBG	2 = produced today in very limited quantities	2 = More availability	2 = Localised use	2 = More availability
	Green methane	2 = produced today in very limited quantities	2 = More availability	2 = Localised use	2 = More availability
	Biodiesel	3 = 1st gen technology is available but production and fuelling systems are limited	3 = Sluggish development	3 = Fragmented development	**4 = Biofuel is a drop-in fuel and does not require new types of engines. Push for 2nd gen technologies (PtX)**
	Green methanol	2 = Technology is in limited maritime use today with limited fueling infrastructure	2 = Technology has matured, fueling infrastructure slightly expanded	2 = No major progress made	**3 = A push for green methanol has helped to expand infrastructure**
	Green ammonia	2 = Ammonia is a zero-carbon fuel option but highly toxic, emits NOx and not yet in use	2 = Although promising as zero-emission solution the development remains slow	2 = Selected development in South Korea, Japan, China and the EU	**2 = The need for a zero-carbon solution has pushed ammonia towards maturity**
	Green hydrogen	1 = First with a small vessel in Europe; Tugboat ordered in the US with methanol reformer and hydrogen fuel cell; fuel cell capacity is a constraint	2 = R&D continues	2 = R&D continues	2 = R&D is pushed
Other power sources	Green electricity	2 = Ready but renewable energy supply limited and grid capacity insufficient	3 = Technology has matured but still lack of grid and volume scale	3 = Technology has matured but still lack of scale as countries focus on road applications	3 = Technology and volume has been pushed
	Nuclear	2 = Technology is ready in defense by not commercial shipping	2 = Idem	2 = Idem	2 = Idem
Regulations	Market-based mechanism (MBM) -European Trading Scheme (ETS) and levy	4 = Ready for implementing in the maritime industry; challenging political climate	4 = Idem	4 = Idem	4 = Idem
	EEDI/EEXI	4 = Ready to use	4 = Idem	4 = Idem	4 = Idem
	CII	3 = Regulatory requirement	4 = CII is implemented	4 = CII is implemented	4 = CII is implemented
	Gradual reduction of carbon content in fuel	0 = Fuel standard proposed as a regulatory measure	3 = Technologies required sorted, but fuel standard not agreed	2 = Technologies required sorted; fuel standard not agreed	**4 = New regulation put in place**

INDICATIVE			Readiness of solution (Now and 2030)		
Category	**Enabler**	**Now**	**Swells (2030)**	**Storms (2030)**	**Clear Sky (2030)**
Financing	Incentives for green fuel production	3 = Many programs and incentives are currently available, but more is required to specifically ramp up the maritime fuel value chain	3 = Not a lot of changes globally because further exploration and production of hydrocarbons is continuing in the fossil fuel driven economy	2 = Dispersed world and fuel value chain with limited scope for ramping up also limits the expansion of financial products	4 = Financial products to finance the transformation of the fuel value chain has been expanded aggressively
	Incentives for green shipbuilding	0 = Idea stage	2 = Except in the OECD and China limited efforts to change practices	1 = Except in the EU and China limited efforts to change practices	**3 = Globally financing practices have been altered to incentivise CO_2 reduction efforts**
	Green innovation / R&D funds	1 = Fragmented policy and efforts; proposal on the table in the IMO	3 = Companies focus areas of interest and growth funds set-up	3 = Fragmentation in policy and efforts remain	**4 = International mechanisms in place**
Multi-fuel power systems	Multi-fuel ICE engines / onboard storages	2 = Ready for some fuels	3 = More options available	2 = Some progress made	**4 = Heavy investment in engine innovation**
	Fuel cell technology	2 = Technology is ready but requires more stress-testing	2 = First fuel cells de-risked	2 = First fuel cells in test	2 = Fuel cells de-risked and further R&D pushed
	Batteries powered motors	2 = First small ships are in service but batteries need to have better power/weight ratio and be cheaper	3 = Gradual improvement at pace of battery improvement	3 = Idem	3 = Idem
	Upgradability / Retrofitting	2 = Available for some solutions	2 = Solution matured	2 = Solution matured	**3 = Solution matured**
Circularity	Recyclable ships of recyclable material	1 = Capabilities still lacking	2 = Certain countries and companies invest in circular capacity building	1 = Capacity building has not seen lots of progress	**3 = Despite major push towards circular economy, other sectors have more gvt focus**
	Carbon capture and storage (CCS)	1 = Technology is not mature for shipping in 2022	2 = Technology demonstrated	2 = Idem	2 = Idem, as it is not seen as a spearhead tech for shipping
Port measures	Fuel storage / Fuelling equipment for alternative fuels	1 = Build-up for some green fuels in few seaports	3 = More fuels can be stored	3 = More fuels can be stored	**3 = Infrastructure development parallel with the new fuels and new low carbon ships**
	On-shore power supply	2 = Solution is ready, but the supply of (green) electricity is still limited	3 = Solution available across OECD	3 = Solution available in EU and East Asia	**4 = Solution available in many countries across the globe**

INDICATIVE			Readiness of solution (Now and 2030)		
Category	**Enabler**	**Now**	**Swells (2030)**	**Storms (2030)**	**Clear Sky (2030)**
Green power-to-X technologies	Electrolysis solutions for green fuels from renewable electricity	3 = Solution in R&D stage and used at small scale	3 = Solution in use at larger scale	3 = Solution in use at small scale	**4 = Solution in use at large scale**
	Technologies to produce green fuels from biomass/ waste/ carbon	1 = mainly R&D and test phase	2 = First industrial demonstration plants	1 = First demonstration plants	**2 = First industrial demonstration plants**
Ship optimisation	Wind Support	1 = The technology is in R&D stage	2 = Progress has been made; experimental use	2 = Some progress has been made	**3 = Technology matures due to more experiments; first ships in service**
	Hydrodynamics	**3 = Many pieces of the puzzle are there**	**3 = More pressures from shippers to reduce CO2 footprint**	3 = Idem	**3 = Idem, but even stronger due to effective carbon pricing**
	Ship size optimisation	**4 = Different sizes of ships are available for different purposes**	4 = Idem	4 = Idem	4 = Idem
	Fleet renewal	1 = Largely voluntary renewal sometimes required by customers, sometimes incentivised	2 = Largely competition driven renewal in certain subsectors	1 = Largely driven by customer value proposition and markets	**3 = Incentives programme for systematic fleet renewal**
	Autonomous ships	1 = On the path to readiness many hurdles still to be overcome	2 = Autonomous technology significantly improved	2 = Autonomous technology improved, but hampered by knowledge sharing barriers	2 = Autonomous technology significantly improved but not a gvt priority
Operations controls	JIT Port Calls	1 = Solution is developed	2 = Solution is in use at limited scale but hampered by contracts	1 = Solution improved but tests are hampered by local interests	**3 = Rising pressures forces to rework contracts and expand adoption**
	Advanced weather routing	**3 = Solution is ready**	4 = Solution has matured	4 = Solution has matured	4 = Solution has matured
	Commercial contracts	0 = Contracts are in the way of optimised operations	1 = Little effort is made to change what works	1 = Little effort is made to change what works	2 = Push for change of limiting contracts
	Slot Management	2 = Concept is ready	3 = Thinking matured	3 = Thinking matured	**4 = First test at limited scale**
	Speed Optimisation	**3 = Concept is ready**	4 = Concept refined	4 = Concept refined	4 = Concept refined
	GHG emissions calculation	2 = Important starting point but does not decarbonise	2 = Provides indication where to reduce	2 = Provides indication where to reduce	4 = Is used to hold companies accountable to targets

INDICATIVE		Availability (Now and 2030)			
Category	**Enabler**	**Now**	**Swells (2030)**	**Storms (2030)**	**Clear Sky (2030)**
Multi-fuels	LNG	4 = LNG is available with some concerns for competing applications and supply availability	4 = 2030	4 = 2030	4 = 2030
	Green LNG / LBG	1 = Early-stage systems	2 = Value chain slightly ramped up	1= Value chain slightly ramped up	2 = pushed as green fuel
	Green methane	1 = Early-stage systems	2 = Value chain slightly ramped up	1 = Value chain slightly ramped up	2 = pushed as interim fuel
	Biodiesel	1 = In 2022 there is a lack of sufficient biofuel quantities (in addition maritime industry competes with other sectors like aviation)	1 = Production of biofuel is ramping up slowly	1 = Fractured development, Europe moves fastest	2 = policies helping to expand biofuel production and infrastructure development
	Green methanol	1 = The entire total production of green methanol accounts for less than 1% of the maritime industry's consumption[lxi]	2 = Production and infrastructure is slowly ramping up	1 = Production and infrastructure is slowly ramping up	**3 = Green energy production and infrastructure build up is supported by policy**
	Green ammonia	1 = Limited availability; engines not yet available	1 = Volume remains limited	1 = Volume remains limited	2 = Green energy production and infrastructure build up is supported by policy
	Green hydrogen	0 = Only demonstration projects	1 = More demonstration projects with some early adopters	1 = Regional experiments with some regional adoption	2 = Adopters in various regions; R&D, green energy production and Infrastructure build up is supported by policy
Other power sources	Green electricity	1 = First adopters / movers, e.g. Scandinavia and China, small vessels in coastal service	2 = More electrification in the Nordics and in China	2 = More electrification in the Nordics and in China; adopted in short sea shipping	2 = Renewable energy is supported by policy and incentives, but scope remains short distances
	Nuclear	1 = Due to maturity in commercial shipping, security and safety concerns limited availability	1 = Idem	1 = Idem, but some countries/regions experiment within own jurisdiction	1 = Idem
Regulations	Market-based mechanism (MBM) -European Trading Scheme (ETS) and levy	1 = Adopted in Europe	2 = Adopted on OECD routes	1 = Adopted in Europe	**4 = The systems is applied across the globe**
	EEDI/EEXI	4 = EEDI is in force	4 = Idem	4 = Idem	4 = Idem
	CII	0 = Ready to be implemented	3 = CII is implemented but not followed everywhere	2 = CII is implemented but with limited impact	**4 = CII is used as instrument to reduce emissions**
	Gradual reduction of carbon content in fuel	0 = Regulation has not been agreed	2 = OECD introduced regulation	1 = EU introduces regulation	**4 = Policy introduced globally and enforced**

INDICATIVE		Availability (Now and 2030)			
Category	**Enabler**	**Now**	**Swells (2030)**	**Storms (2030)**	**Clear Sky (2030)**
Financing	Incentives for green fuel production	1 = Little products available	2 = Some improvements in certain regions and mature parts of the value chain, across OECD and China	2 = Limited developments, beside EU and China	**4 = Aggressive expansion of globally available financial instruments and structured products**
	Incentives for green shipbuilding	0 = Not implemented beyond normal efficiency improvements to reduce overall costs	2 = ESG practices penetrate on all global routes and many local routes	1= Regional regulations force local financing conditions	**4 = Regulators provide frameworks for financial institutions to force low emission designs**
	Green innovation / R&D funds	1 = Small capital available and fragmented	2 = Capital is provided by companies and growth funds	1 = Some capital is provided mainly by gvts	**4 = Significant Capital is provided by gvts, companies and growth funds**
Multi-fuel power systems	Multi-fuel ICE engines / onboard storages	1 = Low level of adoption (newbuild)	3 = Adoption gradually increased through market pressures	1 = Regions go their own way	**4 = Incentives provided to drive adoption**
	Fuel cell technology	1 = In its infancy	2 = Available, but slow start due to initial focus on multi-fuels	1 = Available, but not main focus of gvt incentives	2 = First systems installed
	Batteries powered motors	1 = Still demonstration phase	1 = Gradual uptake in short routes (China/Europe/US)	1 = idem	2 = Uptake incentives given outside the road transport
	Upgradability / Retrofitting	1 = Many owners have carried out retrofits to their fleets (new paints, energy saving devices, new propellers, changed lighting, better fuel consumption monitoring, etc.)	1 = Regional adoption where a full jump in new technology is difficult	1 = Regional adoption in regions lagging full push to new technology	0 = Uptake of leap frogging tech incentivised instead
Circularity	Recyclable ships of recyclable material	1 = Adoption at very low level	1 = Knowledge building increases, but efforts stay within general industry context	1 = Adoption difficult in a fragmented world and remains very low	2 = Push towards a circular industry, but no specific ship focus
	Carbon capture and storage (CCS)	0 = No adoption beyond pilots	1 = Limited uptake as focus is on alternative fuels	1 = Limited testing	1 = Push for de-risking if LNG route is to remain open
Port measures	Fuel storage / Fuelling equipment for alternative fuels	1 = Limited adoption through lack of fuels	3 = Market based gradual uptake	2 = Local focus hamperd uptake	3 = Market based gradual uptake
	On-shore power supply	2 = Solutions and standards starting to be adopted to meet legislation 2025	2 = Only established in regions that legislation require (such as EU)	2 = Onshore power established in different regions	**3 = Many ports and ships crossing regions will be equipped with onshore capabilities incentivised by carbon charges**

INDICATIVE		Availability (Now and 2030)			
Category	**Enabler**	**Now**	**Swells (2030)**	**Storms (2030)**	**Clear Sky (2030)**
Green power-to-X technol-ogies	Electrolysis solutions for green fuels from renewable electricity	1 = Low production capacity	2 = Gradual capacity increase, but limited by cost hurdle	1 = Progress is limited due to focus on biofuels and electricity	3 = Push for green fuels, supported by carbon charges
	Technologies to produce green fuels from biomass/ waste/ carbon	0 = No production capacity beyond R&D projects	0 = First commercial plants yet to be built.	0= Idem	1 = First plants built
Ship optimi-sation	Wind Support	1 = Only demonstration applications in 2022	2 = Adoption is limited to the Atlantic route	1 = Adoption is lagging	2 = Carbon charging incentivises more uptake
	Hydrodynamics	1 = Only environmentally conscious players adopt	2 = Shippers push for adoption	1 = Only environmentally conscious players adopt	**3 = Policy-push for adoption through effective carbon pricing and higher fuel costs**
	Ship size optimisation	2 = Due to the distributed nature of shipping it is challenging to have an optimal fleet	3 = Capacity pooling becomes allowed under competition rulings	2 = Ships available for different purposes for different regions	**3 = Collaboration across shipping companies for sharing the efforts of sea transports**
	Fleet renewal	1 = renewal when required	2 = adoption driven by competitive pressures	2 = Legislation within particular regions	**3 = Knowledge and experiences shared on best GHG reduction**
	Autonomous ships	0 = No adoption due to control concerns	1 = Readiness with first tests	0 = Close to readiness with first tests	1 = Readiness with first tests
Oper-ations controls	JIT Port Calls	1 = Still limited adoption	1 = Little progress has been made. Vested interest stands in the way	1 = The fragmented world hampers progress	2 = Through supply chain pressures adoption increases but lower priority for gvts
	Advanced weather routing	4 = Technology available	4 = Technology available	4 = Technology available	4 = Technology available
	Commercial contracts	0 = No adoption	1 = Some adoption where regulator exerts pressure	1 = Idem	2 = Push but change is slow
	Slot Management	0 = Very low adoption	0 = Still low adoption, because …	0 = Fractured world made implementing such concepts difficult	1 = Market ressures drives change in line with first adoption
	Speed Optimisation	2 = Some adoption	3 = Increased adoption	1 = Some adoption due to different priorities	4 = Increased adoption (including push by policymakers)
	GHG emissions calculation	1 = In its initial stage, but already a global regulatory requirement to report CO2 emissions annually	3 = Focus on greening shipping by society, ESG investors and carbon pricing mechanisms	2 = Focus on greening in some parts of the world	4 = GHG emissions calculation a must to comply with regulation and drive progress

INDICATIVE		Financial viability (Now and 2030)			
Category	**Enabler**	**Now**	**Swells (2030)**	**Storms (2030)**	**Clear Sky (2030)**
Multi-fuels	LNG	4 = Carriers expand their LNG powered fleet indicating that LNG is economically viable	4 = Idem	4 = Idem	4 = Idem
	Green LNG / LBG	2 = Storage and transport more expensive and lack of scale	2 = Competitive in certain subsectors	3 = Locally "competitive"	**3 = Capex subsidized to reach market price level and scale**
	Green methane	2 = Storage and transport more expensive and lack of scale	2 = Competitive in certain subsectors	3 = Locally "competitive"	**3 = Capex subsidized to reach market price level and scale**
	Biodiesel	3 = Less cost effective than HFO and LNG	3 = Less competitive	3 = Local incentives	**4 = With a stronger focus on biofuel production, and fuelling infrastructure financial viability improves**
	Green methanol	2 = It is very expensive to produce green methanol	2 = Broader adaptation brings costs down, but remains expensive	3 = Only regional incentivised developments	**3 = Policy support helps to scale and bring costs down, but additional incentives remain required**
	Green ammonia	1 = Producing green ammonia cost two to four times[lxii] more than conventional ammonia	1 = Idem, pertaining high system costs due to low overall well-to-wake fuel efficiency	1 = Idem, pertaining high system costs due to low overall well-to-wake fuel efficiency	2 = Ammonia production is scaling up which brings some cost reductions, but additional incentives remain required
	Green hydrogen	1 = Technology not yet developed fully in combination with large scale fuel cells	1 = Low value, high initial system costs low viability	1 = Low value, high initial system costs low viability	2 = More volume with medium viability
Other power sources	Green electricity	2 = Lack of scale; battery capacity	2 = Remains niche due to high costs	3 = Increased volumes of fully electric very short distance inland waterway ships in regions that provide (green) shore power	**3 = Electrification is on the way to become a standard in inland short distance waterway shipping**
	Nuclear	0 = Low viability due to expensive technology with little reduction potential	0 = Idem	1 = Idem, but some countries/ regions are willing to incentivise	1 = Idem but plays a role in shipping either as a primary energy source to produce alternative fuels or as molten salt reactors onboard ocean-going ships that do not enter ports.
Regulations	Market-based mechanism (MBM) -European Trading Scheme (ETS) and levy	**4 = The concept is an enabler of decarbonisation**	3 = Idem	2 = Idem as some countries will protect their own interest and will not apply MBM, ETS, or levies	4 = Idem
	EEDI/EEXI	4 = The concept is an enabler of decarbonisation	4 = Idem	4 = Idem	4 = Idem
	CII	4 = The concept is an enabler to drive gradual but continuous change	4 = Idem	4 = Idem	4 = Idem

INDICATIVE		Financial viability (Now and 2030)			
Category	**Enabler**	**Now**	**Swells (2030)**	**Storms (2030)**	**Clear Sky (2030)**
	Gradual reduction of carbon content in fuel	**4 = The concept is an enabler to drive gradual but continuous change**	4 = Costs can be absorbed	4 = Costs can be absorbed	4 = Costs can be absorbed
Financing	Incentives for green fuel production	1 = Generally low due to lack of scale	2 = De-risked technologies become investable in OECD corridors	1 = De-risked technologies become investable with local gvt guarantees	**3 = Massive expansion in scale which brings new asset classes in the financial markets**
	Incentives for green shipbuilding	0 = High risk and overrun cost for changes in design with little option for recovery	2 = MBM, ETS and other Levies tip the balance for investability	1 = Fear of local penalties enables investability	**4 = Financial and rating institutions have adequate policies and instruments in place to enable clean ship building**
	Green innovation / R&D funds	1 = Mainly governments through subsidising institutes and start-ups	3 = Idem plus some very large companies in parts of the value chain as well as IMO	3 = Idem plus some national champions brought in by gvt (including EU) incentives	3 = Idem plus some large companies throughout the value chain, incentivised by tax breaks
Multi-fuel power systems	Multi-fuel ICE engines / onboard storages	2 = Viable but still expensive	3 = Scale brings price reduction and part of costs can be passed through	2 = No significant change in scale. Difficult to pass through costs	4 = Scale brought cost and prices for multi-fuel engines down with full pass through
	Fuel cell technology	1 = Still in R&D stage	2 = De-risked technology, MBM, ETS and other Levies tip makes for investability in the OECD corridor	1 = Fragmented financial markets keep investments low and local	3 = Financial and rating institutions have adequate policies and instruments in place to enable investment
	Batteries powered motors	1 = Low volume high price	2 = Investable in niche markets	2 = idem	3 = Investable in niche markets with strong gvt support
	Upgradability / Retrofitting	2 = Medium financial viability as the current high fuel costs there are many retrofit options that have a short payback period.	1 = Expected longer term regulations tightening makes financing difficult	2 = Only under gvt incentives	3= Push for retrofitting / upgrading in worldwide fleet
Circularity	Recyclable ships of recyclable material	1 = Financial viability is low in 2022	1 = Financing does not specifically reward this beyond overall cost containment	1 = Idem	2 = Push for circularity which benefits from incentives
	Carbon capture and storage (CCS)	0 = Financially not viable	1 = Financial viability remains a challenge without shipping falling under an ETS	0 = Financial viability needs gvt support	1 = Financial viability determined by emission charges
Port measures	Fuel storage / Fuelling equipment for alternative fuels	2 = Low number of installations	4 = becomes naturally part of overall fuel infrastructure finance by companies	4 = Idem	4 = Idem
	On-shore power supply	1 = Extra costs for some ships making visits to ports in specific regions	4 = Minor costs in overall costs and easily to incorporate in financing structures	4 = Idem	4 = Idem

INDICATIVE		Financial viability (Now and 2030)			
Category	**Enabler**	**Now**	**Swells (2030)**	**Storms (2030)**	**Clear Sky (2030)**
Green power-to-X technologies	Electrolysis solutions for green fuels from renewable electricity	**2 = In use for other sectors and different higher value applications**	1 = Overall low well-to-wake conversion efficiencies limits financability due to limited cost pass through	1 = Idem	2 = Gvt incentives may help somewhat to overcome structural cost issue.
	Technologies to produce green fuels from biomass/waste/carbon	0 = Needs to come out of R&D budgets / grants	0 = Tech Readiness Level 9 required for financing	0 = Idem	2 = Idem, with strong gvt support
Ship optimisation	Wind Support	0 = Financial viability is unclear	**3 = Cost relatively modest in overall new build cost and will be financeable within normal constructs**	3 = Idem	3 = Idem
	Hydrodynamics	**4 = Technology economically viable as it produces cost efficiencies**	4 = Idem	4 = Idem	4 = Idem
	Ship size optimisation	3 = Different ship's sizes used for specific purposes	3 = Brings fuel consumption reduction	2 = Reduced financial viability due to negative impact on trade volumes caused by fragmentation	**4 = Closer collaboration improves load factor and profitability**
	Fleet renewal	**3 = Financially viable when new ships are bought**	3 = Idem, costs can be absorbed by the sectors applicable	3 = Idem, costs can be absorbed by niche markets	**4 = Idem, costs can be fully absorbed by the market**
	Autonomous ships	4 = Expected to produce cost efficiencies in fuel consumption and crew	4 = Idem	4 = Idem	4 = Idem
Operations controls	JIT Port Calls	4 = Technology has not been tested in real life, but solution produces significant fuel consumption/ cost savings	4 = Minor investments required.	4 = Idem	4 = Idem
	Advanced weather routing	4 = Short payback period	4 = Idem	4 = Idem	4 = Idem
	Commercial contracts	4 = Yields cross industry benefits	4 = Idem	4 = Idem	4 = Idem
	Slot Management	4 = Financially viable concept	4 = Idem	4 = Idem	4 = Idem
	Speed Optimisation	4 = Saves fuel and emissions, no financing of investment required	4 = Idem	4 = Idem	4 = Idem
	GHG emissions calculation	2 = All owners and operators are required to do this regardless of how they do it. They don't need to invest in an expensive system	3 = Essential to get ESG funding	3 = Essential to get gvt licenses	4 = Regulatory requirements, standardized accurate GHG reporting driving gradual GHG reductions

Appendix 8: Usable enablers now and per scenario in 2030

Category	Now	Swells (2030)	Storms (2030)	Clear Sky (2030)
Multifuels	Biodiesel **LNG**	Biodiesel **LNG**	Biodiesel **LNG**	Biodiesel **Green methanol** **LNG**
Other power sources	–	–	Green electricity	Green electricity
Regulations	CII MBM **EEDI / EEXI**	Gradual reduction of carbon content in fuel MBM **CII** **EEDI / EEXI**	CII **EEDI / EEXI**	**Gradual reduction of carbon content in fuel** **CII** **EEDI / EEXI** **MBM**
Financing	–	Green innovation / R&D funds	Green innovation / R&D funds	**Incentives for green fuel production** **Incentives for green shipbuilding** **Green innovation / R&D funds**
Multi-fuel Power systems	–	Multi-fuel ICE engines / onboard storages	–	Batteries powered motors Upgradability / retro-fitting **Multi-fuel ICE engines / onboard storages**
Circularity	–	–	–	–
Port measures	–	On-shore power supply **Fuel storage / Fuelling equipment for alternative fuels**	On-shore power supply Fuel storage / Fuelling equipment for alternative fuels	**On-shore power supply** **Fuel storage / Fuelling equipment for alternative fuels**
Green power-to-X technologies	–	–	–	–
Ship optimisation	Hydrodynamics Ship size optimisation	Hydrodynamics **Ship size optimisation**	Hydrodynamics	Wind support **Fleet renewal** **Ship size optimisation** **Hydrodynamics**
Operations controls	Speed optimisation **Advanced weather routing**	Slot management **Speed optimisation** **Advanced weather routing**	Slot management Speed optimisation **Advanced weather routing**	JIT Port calls Slot management GHG emissions calculations Speed optimisation Advanced weather routing

Usable within limits

Usable at scale

Appendix 9: Long list of suggestions

Suggestions for stakeholder in the marine fuel value chain

The supply of alternative fuels is the current bottleneck across the cluster of critical supply chains for decarbonisation. The ramp-up of the maritime fuel value chain requires a new focus and incentives for renewable energy producers, refining technology and infrastructure manufacturers, ports as energy hubs etc.

- Significantly increase R&D funding for hydrogen fuel cell electric motors to prepare for a potential step change
- Support R&D in battery technology to reduce size and prices of batteries for short sea and inland waterways shipping
- Support the acceleration of production and supply of green ammonia, methanol/ethanol, and hydrogen
- Invest in green LNG development
- Use grey LNG as interim fuel until step-change solutions are available not absorbing too much and too long financial funds - possibly only till 2030
- Launch studies to identify ideal locations of fuelling spots for methanol, ammonia, hydrogen and biofuel, considering also floating refuelling solutions
- Establish fuel infrastructure for green fuels, also leveraging the Clydebank Declaration for green corridors; ports' role as energy nodes is growing
- Encourage ports that are involved in inland and short sea shipping to provide electric power supply for battery powered ships
- Strengthen renewable energy / green electricity supply and strengthen electricity grids around ports
- Aggressively expand biofuel production and distribution capabilities, increase the use of domestic waste and sewage

Suggestions for stakeholders in the shipbuilding value chain

Ship designers, shipbuilders, engine, and equipment manufacturers, as well as software vendors and technology companies, offer a broad range of ship-related enablers that can help to reduce carbon emissions.

- Accelerate development of multi-fuel upgradable ship engines
- Invest further in experiments for wind-supported shipping which is a support that can reduce CO_2 emissions significantly
- Ensure that newly built and refitted ships also adopt the latest improvements on hydrodynamic and thermodynamic efficiency and contra-rotating propellers and propulsion efficiency devices
- Encourage collaboration among shipping companies to jointly establish fleets that have ship sizes that corresponds to the needs of the transport buyers and helps reducing CO_2 emissions
- Build capacity in circular shipbuilding
- Financial institutions need to change their financing practices to allow for more flexibility to include new green solutions without penalties
- Ensure high operational efficiency over the lifecycle by simulating operational conditions on actual voyages and weather conditions in the concept design phase

Increase competitive edge with the ability to future-proof the next generation green ship designs with the help of simulation of the operational profile

Suggestions for stakeholder of the maritime operational value chain

Shipowners, ship operators and charterers have a range of enablers they can use to reduce carbon emissions during steaming

- Make speed optimisation practices (slow/optimised steaming) the norm and change contracts that stand in the way
- Capture the potential of route optimisation to avoid adverse conditions, like bad weather (weather routing)

- Encourage the telecommunication industry to (collaboratively) expand the global coverage to support data exchange across the maritime industry
- Ports need to support the change of practices to allow for better utilisation of port infrastructure through just-in-time arrivals and slot management
- Ports to live up to their role as information nodes to support digital solutions that improve the synchronisation of flows
- As all ports are not started in digitalization, and comprehensive implementation of just-in-time and slot management practices is likely to take a long time, probably decades, the industry needs to immediately collaborate to improve port call scheduling even in cases where ports are not providing their support for just-in-time arrivals
- Shipowners, charterers, and cargo owners need to collaborate to change the shipping contracts to incentivise optimisation
- Invest in re-skilling the maritime workforce ensuring they have a higher level of awareness and the skillset to support the decarbonisation efforts
- A carbon tracker that allows to visualise the GHG emissions of every ship for the industry and even the general public could help to show status and progress of decarbonisation in shipping

Suggestions specific for policymakers

Regulation is critical as policies and programmes can direct and accelerate decarbonisation efforts. Regulators can be bridgebuilders and orchestrators as e.g. demonstrated with the initiative on IMO CARES.[xlvi] Policymakers should continuously consult private sector players and subject matter experts[xlvii] to ensure refinement of their approach and measures which include:

- Spur the uptake of decarbonisation technologies and alternative fuels by e.g. IMO interim decarbonisation targets and metrics (e.g., CII), as well as life-cycle analysis (LCA) of emissions
- Review the IMO data collection system and lower the threshold of 5000 gross tonnage
- Support R&D in decarbonisation and establish collaboration mechanisms around concrete decarbonisation projects that foster early deployment mechanisms for green solutions
- Ensure that funding for R&D and implementation is well spread across cluster of maritime value chains and decarbonisation enablers
- Promote extensive knowledge exchange across the stakeholders of the cluster of the critical maritime value chains fuel, ship, operation
- Incentivise first movers in the field of decarbonisation across the ecosystem
- Avoid regulatory fragmentation on global level, for example across regions, sectors and the modes of transportation and instead push for global decarbonisation and energy transformation strategies
- Apply measures to support less developed nations in their decarbonisation efforts
- Ensure maximum clarity in respect to future regulation and programmes and consider an approved ‘green fuel’ list to “de-risk” investments
- Ensure that the IMO International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code) are enforced to mitigate the risk to ships, their crews and the environment, given the nature of the fuels involved
- Use the EU emissions trading system (ETS) for ships calling at EU ports as reference for a global mechanism but close gaps and impede double counting
- Avoid ETS fragmentation, as the EU and UK are building out their maritime ETS and China its land based ETS
- Set and gradually increase minimum blend requirements for zero-emission marine fuel in the spirit of the FuelEU maritime initiative
- Consider fleet renewal guidelines not obligations and help to ensure that financing is available
- Further the public debate on the security of using nuclear as one potential energy source for deep-sea shipping

Appendix 10: Initiator, authors, and contributors

Initiator

Nordic West Office is Helsinki-based think tank and global affairs consultancy, specialized in scenarios and strategic foresight. NWO helps companies to navigate the changing political, economic and technological environment by bringing together high-level international expertise in business, academia, politics, communications, and the legal field.

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End notes

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