DT4GS

Digital Twins for Green Shipping

D1.1: *Value-oriented Analysis in enabling Shipping Decarbonisation*

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Executive summary

The deliverable presents and describes a value-oriented analysis in enabling shipping decarbonization. This is achieved through framing the key decarbonization enablers as discussed in the scientific and industrial bibliography, its risks and opportunities, potential transition challenges and headwinds, stakeholders and a deep dive on decarbonization imperatives – regulation, financing (i.e., carbon credits, Green Taxes, etc) in the context of the latest EU disclosures, infrastructure and technology. Chapter 4 will unfold the Digital Twin context and how the project's planned Living Labs serve the scope of the project which is fuelled by the deployment of a digital twin model for green shipping. The purpose of the deliverable is to set the theoretical and operational framework around shipping decarbonization and digital twin, highlighting the value of digital twin models in shipping decarbonization. That shall be the foundation upon which the following project deliverables will build upon.

Within that context, the following types of digital twins will be built: a tanker oriented undertaken by EURONAV, a containership oriented carried out by DANAOS Shipping, a ROPAX one which is supervised by BALEARIA and finally STARBULK addressing bulk vessels.

Value Proposition Mapping is performed in Chapter 6, demonstrating the value added of the use of DT models results, through Identification and quantification of all enablers and challenges regarding energy efficiency Improvement and CO_2e reduction.

The innovation aspects that this report introduces is twofold:

- It establishes a link between the main decarbonization transition challenges and the cornerstone of the project, which is the digital twin, by elaborating on how the challenges may be incorporated into such a model and determine the operational implications at micro-level.
- Value proposition mapping method emphasizes on the value of each step of the digital twin model running for a variety of different users of shipping sector, isolating the less critical elements. In that regard, impactful value of the digital twin core services is directly elicited underpinning the user expectations.

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Table 1 Glossary of acronyms and terms.

Acronym / Term	Description
AI	Artificial Intelligence
DT	Digital Twin
LL	Living Lab
ML	Machine Learning
VA	Value Analysis
IoT	Internet of Things
KPI	Key Performance Indicator
ETS	Emission Trading Scheme
GHG	Greenhouse Gases
AER	Annual Efficiency Ratio
NB	Newbuild
TCO	Total Cost of Ownership
WASP	Wind-Assisted Propulsion
ERP	Enterprise Resource Planning
ECA	Emission Control Area
CAGR	Compound Annual Growth Rate
M/E	Main Engine
A/E	Auxiliary Engine
CAPEX	Capital Expenses
OPEX	Operational Expenses

1 Introduction

As digitalisation in the shipping industry has been maturing over the recent years, DT adoption will be dependent on establishing trusted and convincing DT application exemplars and ensuring that ship operators and other industry stakeholders can set up their own DTs based on their own business models, building their own confidential knowledge at reasonable cost. This requirement is at the heart of the DT4GS approach as illustrated in the figure below.

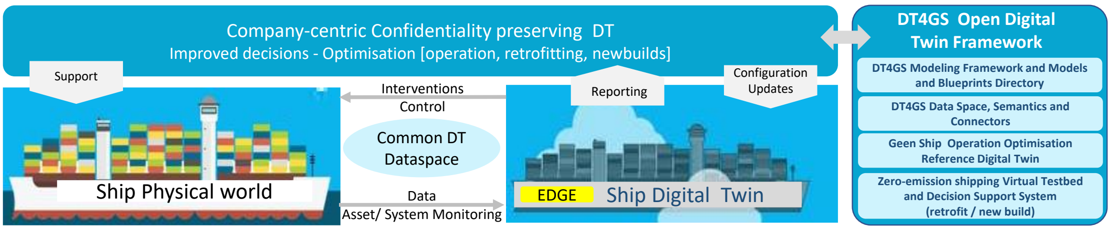

Figure 1 DT4GS approach

DT4GS will provide a virtual representation of ships and physical transport entities with a bi-directional communication links from sensing to actuation/control and data driven simulation and AI based decision support to shipping industry stakeholders. In DT4GS extra emphasis will be given to:

- DT applications onboard the ship utilising advanced IoT and edge computing infrastructure.
- Using AI/ML for accurate predictions and optimisation of ship parameters, both at design and operational stages.
- Creating a common point of reference which different stakeholders can access, utilise and adapt in line with their own internal business models, with respect to data ownership and security standards.

This document is linked to WP1 ''DT4GS Modelling Framework'' and focuses on delivering a value-oriented analysis on the use of Shipping Digital Twins for the decarbonisation of shipping by:

- innovative ship operation performance optimisation,
- simulation based planning and design of retrofitting with GS technologies and
- planning and designing Green Smart New-Builds (vessels).

Additionally, WP1 aims to deliver a set of KPIs to enable consistent evaluation of DT solutions employing strategic use cases and datasets drawn from the LLs.

The following DT4GS's LLs will build: a tanker-oriented DT undertaken by EURONAV, a containership-oriented DT carried out by DANAOS Shipping, a ROPAX DT which is supervised by BALEARIA and finally STARBULK DT will secure the LL of bulk vessels.

Chapter 4 will unfold the Digital Twin context and how the project's planned Living Labs serve the scope of the project which is fuelled by the deployment of a digital twin model for green shipping. The purpose of the deliverable is to set the theoretical and operational framework around shipping decarbonization and digital twin highlighting the value of digital twin models in shipping decarbonization. That shall be the foundation upon which the following project deliverables will build upon.

Value Proposition Mapping is performed in chapter 6, demonstrating the value added of the use of DT models results, through four dimensions: a) Identification and quantification of all enablers and challenges regarding value-oriented analysis and development of KPIs to monitor their performance, b) Provision of performance KPIs for Use Cases monitoring through LLs results (i.e. Energy Efficiency Improvement and CO2e reduction), c) Shipping community stakeholders from the supply and demand side of the DT4GS project and d) End user value proposition identifying the pains and gains of each value-added product/service examined by each LL.

The LLs performance tracking is a dynamic procedure which is not exhausted within the context of this deliverable and will be enriched through the project's work.

1.1 Mapping DT4GS Outputs

The purpose of this section is to map DT4GS Grant Agreement commitments, both within the formal Deliverable and Task description, against the current document.

Table 2 Adherence to DT4GS Grant Agreement deliverable and work description.

DT4GS GA Component Title	DT4GS GA Component Outline	Respective Document Chapter(s)	Justification
DELIVERABLE			
***D1.1* DT4GS Value-oriented Analysis in enabling Shipping Decarbonisation**	Value Oriented Analysis, LLs Scenarios, Transition Challenges, and high-level scenarios Requirements. This deliverable includes the outputs of T1.1.	*All*	*The deliverable provides macro-environment factors and analyses transition challenges, enablers and barriers as well as governance frameworks (e.g., sustainable finance) that are critical input elements for a shipping DT model. At micro-environment, it provides LLs overview coupled with user requirements and expectations together with data requirements. Last, it conducts a value-oriented analysis synthesizing the DT4GS ecosystem and market segments, emphasizing on value flows between users and providers and highlighting benefits per LL and per DT service provided.*
TASK			
ST1.1.1 DT4GS Living Labs Scenarios and	Scenarios and strategic case studies for the LLs, each LL will produce one (1) overarching scenario, and at a minimum two (2) case studies involving the	*Chapter 5*	*Chapter 5 presents DT4GS Living Labs: tanker, bulker, RoPax and container together with the scenarios and use cases which serve the purpose of scenarios. Voyage*

Strategic Case Studies	**DT4GS Core Services**, defining the user acceptance criteria, and delivering a reference guide for cooperation between the shipping stakeholder groups and the consortium partners.		*optimization, event recognition and predictive maintenance are amongst the use cases of phase 1 that are collectively tested in different operational environments (LLs) demonstrating key similarities and differences with a transferability capacity and to be emphasizing on lessons learned. There is a short description of Phase 2 as well, unfolding the most promising practices applied in a DT environment unlocking green shipping (carbon neutral fuels, green propulsion technologies, etc). DT4GS partners provided input also in – per LL – key requirements and data frameworks which will serve as DT model input (and expected output) driving the project's developments.*
ST1.1.2 Transition Challenges, Enabling Factors & DT4GS actors	Define the macro-environment enablers and challenges for DT4GS. Elicit methods, models and governance related to the economic viability of DT4GS, considering financial levers (i.e., carbon credits, Green Taxes, Transition Finance) in the context of the latest EU disclosures, and adoption strategies in line with the UN SDG's.	*Chapter 3*	*The macro-environment enablers and challenges are defined in Chapter 3. The key enablers of green shipping are described like low-carbon fuels, energy saving technologies, digitalization, regulation, and other market forces. Furthermore, green shipping barriers are outlined such as lack of supporting regulation, alternative fuels unavailability and lack of trusted data. Specific governance methods and models are also indicated that correspond to leverage factors like transition finance frameworks (such as EU Taxonomy), carbon taxes, sustainable financing, etc. These factors, although macro-economic, could be*

			further digested in a DT model to strengthen its simulation outputs and produce more informed decision-making. An indicative example could be the use of different scenarios of carbon pricing fed into a digital twin model.
ST1.1.3 High-level Requirements Specification for DT4GS.	Establish key requirements to drive project developments.	*Chapter 5*	Finally, a value-oriented analysis is conducted in Chapter 6 where user and stakeholder mapping and measurable guidance framework is provided which interrelates the transition challenges identified in Chapters 2 and 3 and the LLs with their shipping stakeholders. That framework secure that DT model is fed with both KPIs relevant to transition challenges / enabling factors and the LLs input parameters offering a holistic perspective of exogenous and intrinsic factors to be simulated. To enrich that scope, each Living Lab undergoes a value analysis in Chapter 6 indicating the pain and gains for each different scenario and use case.

1.2 Deliverable Overview and Report Structure

This deliverable frames the key shipping industry decarbonization perspectives, as discussed in the scientific and industrial bibliography, its risks and opportunities, potential transition challenges and enablers, stakeholders, as well as an in-depth survey of decarbonization imperatives – regulation, financing (i.e., carbon credits, Green Taxes, etc) in the context of the latest EU policies, infrastructures and technology.

The contribution of this report is to:

- establish a link between the main decarbonization transition challenges and the cornerstone of the project, which is the DT, by elaborating on how the challenges are addressed by the DT.
- present a Value proposition mapping method of the business value of the DT model for each shipping sector stakeholder.
- present key performance tracking KPIs which will be used to monitor the outcome of Use cases/Operational scenarios of the Living Labs.

This section of the document provides a description of the deliverable structure and an outline of the respective chapters and their content. The deliverable's chapters are the following:

- Chapter 1: It provides an overview of how the deliverable links to the work package and task requirements.
- Chapter 2: It surveys projects for clean and green waterborne transport.
- Chapter 3: It discusses initiatives, drivers and obstacles to ship decarbonisation.
- Chapter 4: It presents the concept of ship digital twin and its contribution to ship decarbonisation.
- Chapter 5: It introduces the Project's Living Labs, their high-level objectives and use cases.
- Chapter 6: It contains the Living Labs value analysis in terms of contribution to decarbonisation, KPIs etc.
- Chapter 7: It summarises the main takings and conclusions of this report
- Chapter 8: Annexes - They contain more details about the Living Labs scenarios and use cases.

2 Survey of Green and Clean Waterborne Transport Projects and Initiatives

Europe is traditionally a maritime shipping territory encompassing ocean shipping, coastal shipping and the use of the European inland waterways network. One of the challenges for EU shipping sector is how to ensure the sustainable performance of this system through the optimal use of energy sources and the mitigation of climate and environmental impacts. Considering that shipping is responsible for 90% of all international trade, over 75% of external EU trade and 40% of internal EU trade, there is high significance of this transport sector for the future of the EU economy.

Moreover, shipping decarbonisation and digitalization have always been a core focus policy area for European authorities tying in principle with the EU Green and Digital Transformation strategy. Digital tools applied to building, testing and operating vessels are enabling information and data sharing between the vessel, the infrastructure (Sea2Shore) and people facilitating decision-making towards low carbon economy. Therefore, digitalization could serve as a mean to achieve lower carbon impact in the shipping sector which currently accounts for 3% of global emissions.

Realizing this significance, the EU has put forward specific R&D funding engines to unfold its strategy towards developing a safe, secure and resource-efficient waterborne transport system. In the last years, the waterborne transport programmes have been dedicated to fund a number of innovative solutions in addressing the main challenges of the shipping sector Europe: infrastructure; energy efficient and zero emission vessels; innovative shipbuilding and complex value- added specialized vessels; safer and more efficient waterborne operations; and new and improved waterborne transport concepts.

AQUO (2012) project recognizes the underwater noise impact due to shipping, to prevent negative consequences to marine life. In that context, the final goal of **AQUO** project is to provide to policy makers practical guidelines regarding ship design (including propeller and cavitation noise), and solutions related to shipping control and regulation. **EU-CARGOEXPRESS** (2009) aim has been to prototype a ground-breaking innovative cargo vessel to meet the expectations of green transport and contributing to decongesting of Europe's roads. **ULYSSES** (2011) aimed at demonstrating the efficiency potential of the global fleet through a combination of ultra-slow speeds and complementary technologies. In this practical approach with timeless value **ULYSSES** focused on bulk carriers and tankers as these ship types produced 60% of the CO_2 from ocean-going vessels at that time. On the use of digital solutions for integrated logistics management, **SAIL** (2010) project aimed at developing an integrated ICT tool able to support logistic chain of goods flow and all business operations provided in the port and the dry port areas.

Staying on the navigational scope, **ARIADNA** (2009) attempted at developing a Volumetric Navigation System (VNS) with new traffic navigation solutions considering certain scenarios in which all the vehicles share information in order to be part of a collaborative navigation network. In same direction, **DOCKINGASSIST** (2011) developed a cost-effective location system, covering the complete port/harbour zone, to provide efficient and safe manoeuvring within the entire port area enhancing vessel trajectory, and providing constant monitoring for moored/docked vessels improving port traffic management, reducing operating expenses, CO_2 emissions and fuel usage. The need for an improved method for accurate and inexpensive deployment and retrieval of seabed sensors and equipment as addressed by the **AUTODROP** project (2010). **LINCOLN** (2016) presented three new concepts of added-value specialized vessels able to run requested services for several maritime sectors in the most effective, efficient, economic valuable and eco-friendly way. Those concepts have been serving like vessel platforms through dynamic simulation testing. **TRITON** (2013) focused on increasing the trustworthiness of on-board instrumentation used to report vessel information to the control organisms.

MINICHIP (2013) addressed the research gap in marine operations by developing mathematical formulations of marine shipping operations as a stochastic optimisation problem to minimise carbon footprint whilst optimising service level and cost with a use of decision support tool. Furthermore, focus has been shed on the engine capabilities and propulsion to gradually reduce the environmental impact from shipping. The **GASVESSEL** (2017) prove the techno-economic feasibility of a new CNG transport concept enabled by a novel patented Pressure Vessel manufacturing technology and a new conceptual ship design including safe on- and offloading solution. **RotorDEMO** (2017) enhances the complete propulsion system of a vessel by using wind as an auxiliary propulsion measure. The main objective of the **RotorDEMO** project is implementation of Norsepower Rotor Sail Solution in full scale on a RoPax vessel to boost sales of the solution. DEECON (2011) project created a modular, on-board, after-treatment unit that combines different sub-units, each of which is optimized to remove a specific primary pollutant.

Later projects have been addressing several aspects of green and digital shipping (EU CINEA, 2021):

<u>Infrastructure</u>:

- The Port of the future (PIXEL, PortForward, COREALIS, DocksTheFuture)
- Green airports and ports as multimodal hubs for sustainable and smart mobility (PIONEERS, MAGPIE)

<u>Innovative shipbuilding and value-added specialized vessels:</u>

- System modelling and lifecycle cost optimisation for waterborne assets (SHIPLYS, HOLISHIP)
- Development, production and use of high performance and lightweight materials for vessels and equipment (FIBRESHIP, RAMSSES)
- High value-added specialised vessel concepts enabling more efficient servicing of emerging coastal and offshore activities (LINCOLN, NEXUS)
- Complex and value-added specialised vessels (HYSEASIII, TrAM, NAVAIS)
- Improved Production and Maintenance Processes in Shipyards (Mari4_YARD, FIBRE4YEARDS, RESURGAM)

<u>New and improved waterborne transport concepts:</u>

- Preparing for the future innovative offshore economy (MARIBE)
- Delivering the sub-sea technologies for new services at sea (DexROV, BRIDGES)
- New and improved transport concepts in waterborne transport (GASVESSEL, NOVIMAR)
- Unmanned and autonomous survey activities at sea (ENDURUNS)
- The Autonomous Ship (AUTOSHIP)
- Moving freight by Water: Sustainable Infrastructure and Innovative Vessels (IWNET, NOVIMOVE, AEGIS, MOSES)

<u>Energy-efficient and zero emission vessels:</u>

- Towards the energy efficient and emission free vessel (E-FERRY, LeanShips, HERCULES-2)
- Promoting innovation in the Inland Waterways Transport (IWT) sector (PROMINENT)
- Innovations for energy efficiency and emission control in waterborne transport (AIRCOAT, HYMETHSHIP)
- InCo flagship on reduction of transport impact on air quality (SCIPPER)
- Ship emission control scenarios, marine environmental impact and mitigation (EMERGE)

- Retrofit Solutions and Next Generation Propulsion for Waterborne Transport (Nautilus, FASTWATER,
- GATERS, SeaTech)
- Structuring R&I towards zero emission waterborne transport (STEERER)
- Under water noise mitigation and environmental impact (SATURN)
- Improving impact and broadening stakeholder engagement in support of transport research and innovation (LASTING, PLATINA 3)
- Decarbonising long distance shipping (CHEK, ENGIMMONIA)

Safer and more efficient waterborne operations:

- Safer and more efficient waterborne operations through new technologies and smarter traffic management (EfficienSea2, LYNCEUS2MARKET)
- Response to oil spills and marine pollutions (GRACE)
- Safer waterborne transport and maritime operations (SEDNA)
- Marine Accident Response (LASHFIRE, SAFEPASS, FLARE, PALAEMON)
- Human Factors in Transport Safety (SAFEMODE)

3 Approaches to ship decarbonisation

Maritime transport emits 940 million tonnes of CO2 annually, accounting for circa 2.7% of the global CO2, an output of around 7% of SOx and 12.5% of NOx emissions (European Commission - 'Reducing emissions from the shipping sector'). Maritime shipping plays also a major role in European transport sector. It accounts for 75% of the EU's external trade and 36% of intra-EU trade flows by volume. Maritime emissions represented 13% of the EU's transport emissions in 2018. Shipping's global emissions are also expected to increase by up to 50% between now and 2050 (Transport and Environment, 2021). However, this contribution has slightly stabilized over the last 5 years however showing a similar trend for the next couple of years. Regulation is certainly underpinning this trend together with industry's realization about the need to decarbonise shipping (Figure 2).

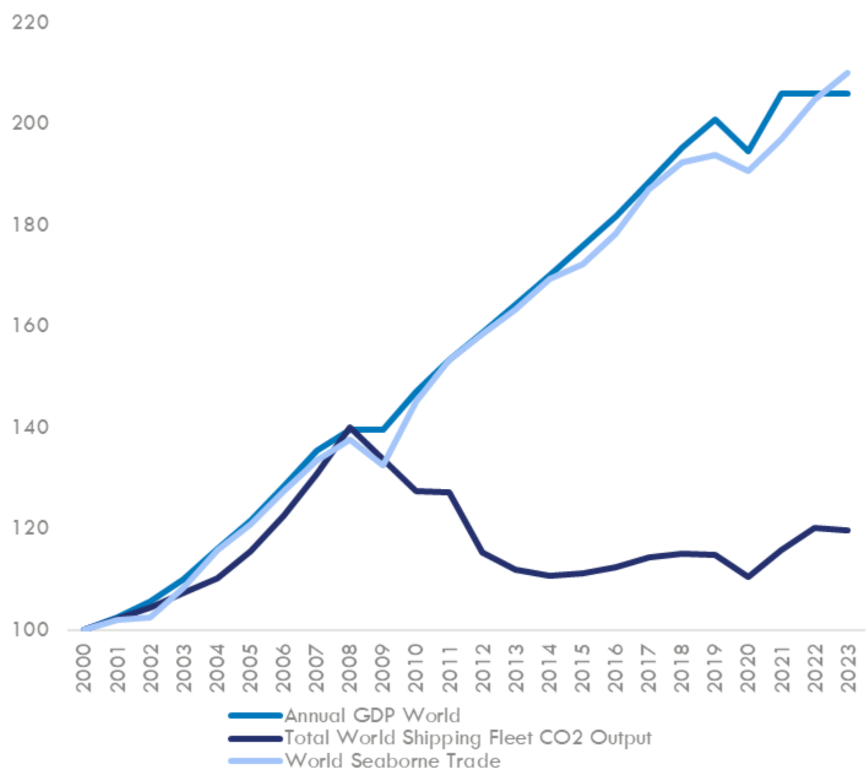

Figure 2 Shipping emissions vs. Global GDP and trade (Source: Euronav analysis)

Shipping finds itself in an odd juxtaposition between a perceived reluctance to take affirmative action on climate change and the actual planned reduction in GHG emissions. This reputation has been driven by the sector's absence from the Paris Agreement on climate change. However, a true picture of the environmental attributes of shipping emerges when it is compared against the other major transportation methods. Shipping is seven times more efficient than rail, sixteen times more than road transportation and a massive eighty-five times more efficient than air transport (IMO, 2009). For a global industry to emit just 2.7% of the world's carbon emissions, this is not only a very efficient process but the least impactful on the environment, particularly when taking into account the quantities and services it transports. For an economic region such as the European Union, shipping accounts for 80% of total exports and imports by volume, and some 50% by value. Shipping is the key transportation sector reflected in the International Chamber of Shipping's website (source: https://www.icsshipping.org/shipping-fact/shipping-and-world-trade-drivingprosperity/).

Since 2019, the total value of the annual world shipping trade had reached more than 14 trillion euros. Shipping's capacity to transfer goods and materials from where they are produced to where they are used or consumed underpins modern life (Bloomberg 1.1.21, International Chamber of Shipping).

Shipping segment size and emission generation are not always proportional. That applies for larger, ocean vessels. The greatest source of GHG emissions within shipping are from container ships, bulk carriers and oil tankers, as shown in Figure 2.

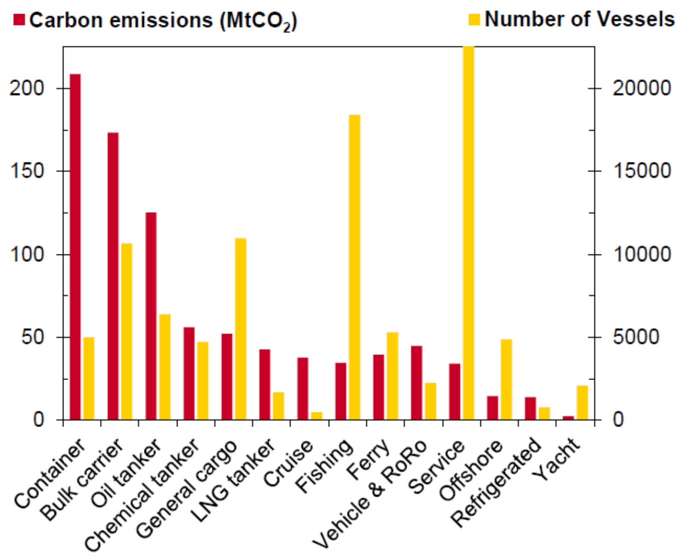

Figure 3 Number of ships and their carbon emissions, by category in 2017 (Source: Balcombe et al. 2019)

Recognizing the need to reduce emissions from shipping operations, the International Maritime Organization (IMO), the global shipping regulatory body, has established emission reduction pathways that are reviewed regularly. It is expected that next review round will be in the next 2-3 years. Currently IMO targets anticipate a reduction of 50% in the absolute emissions from shipping operations between 2008 and 2050. Moreover, the IMO has also set carbon intensity emissions as well where it is expected that global fleet's intensity will be reduced by 40% in 2030 and by 70% in 2050 both compared to 2008 reference baseline. In the figure below, the different trajectories under IMO targets with red line representing the official – to –date – emission reduction trajectory by the IMO.

Challenge for existing fleets is to reach the targets for 2030 the 2050. Many shipping players have already initiated that path: some have launched pilots although at small scale, important learnings are being collected across the industry. In many shipowners' strategies the route to 2030 could serve as an era of energy efficiency improvements stemming not only from retrofits but also from new technologies and digital transformation. Shipping digitalization enables informed decision making by operators, crews and ship managers based on quality data. This leads, in turn, into vast improvements in fuel and energy efficiency.

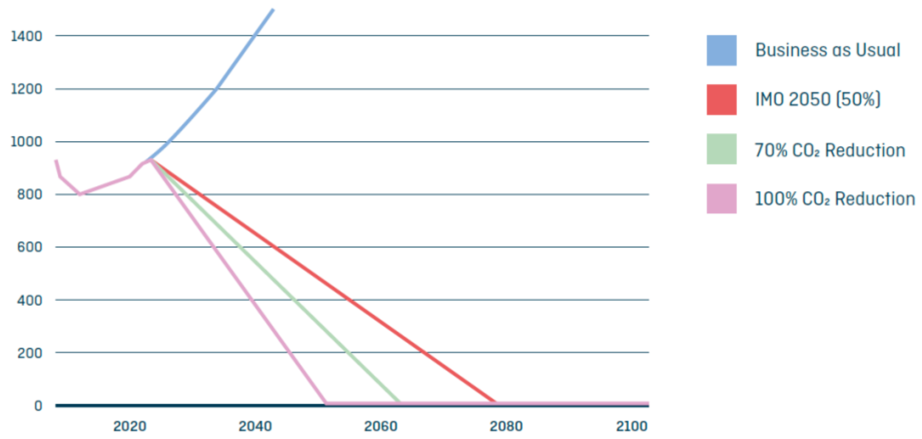

Figure 4 Global fleet's CO2 targets and trajectories under IMO targets (million tonnes of CO2) (Source: Poseidon Principles)

A key driver for shipping decarbonisation is fleet modernization. Transition strategies however entail difficult choices between newbuilds and retrofit options. Early adopters may face expensive future retrofits, while on the contrary, shipping players who wait for the fuel category killers may lose part of their customer segment who aim to be at the forefront of the climate agenda.

EU shipping could reduce a third of its emissions by 2050 by mainly leveraging its technical and operational energy efficiency. This can be achieved by installing energy saving devices such as wind-assisted propulsion or air lubrication, but also through operational measures such as optimizing voyage speed, or streamlining supply chain activities (e.g., so called Just-In-Time arrival). Among the sustainable fuels, green ammonia appears to be the most promising zero-emission fuel to decarbonise the EU-related shipping with green liquid hydrogen. To fully decarbonise by 2050, EU-related shipping needs to deploy green fuels as soon as possible. Below, Transport and Environment presents a high and low efficiency scenario regarding shipping decarbonisation pathways for EU shipping. In both cases, a mix of different measures is required to achieve the 2050 goal with fuels holding the lion's share.

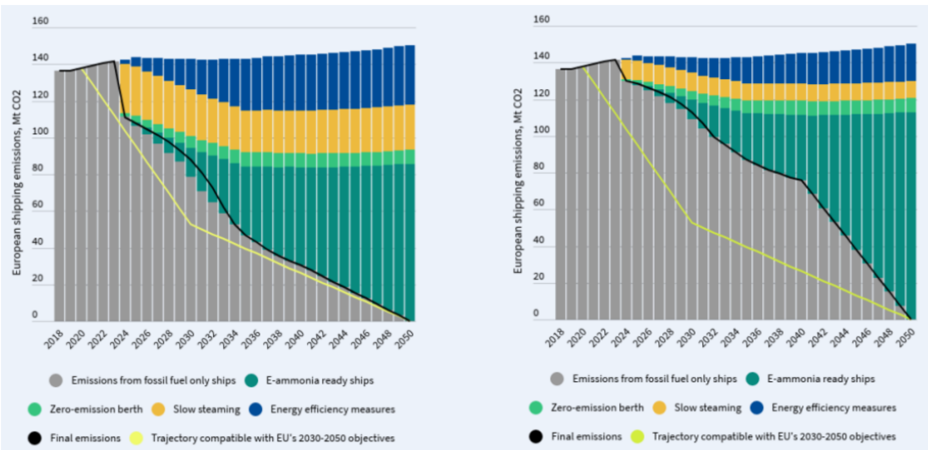

Figure 5 Decarbonisation pathways for EU shipping: high and low energy efficiency scenarios (Source: Transport and Environment 2021)

Shipping is at a crossroads so far as its decarbonisation journey is concerned. Firstly, shipping needs to show itself in a more favourable light and simplify the message. Shipping is the most efficient mean of transportation available in terms of GHG emissions. Yet, that often remains a hidden secret. Secondly, shipping needs to be a better corporate citizen. The recent COVID-19 induced crew change crisis, which is still not over and teaches shipping an inconvenient truth. Shipping's historical lack of transparency and poor governance counted against the sector when it needed political support and engagement. Thirdly, the shipping industry has a number of levers that it uses in driving carbon reduction. Examples such as voyage maximisation and the use of more efficient external paints will be important but relatively modest in the overall compliance with emission targets. Shipping fleets will need new fuels and possibly new power production technology to do the heavy lifting to support it.

Development and transition of a 90-billion-euro shipping fuel market is an attractive opportunity that shipping must not waste and will need if it aims to meet its decarbonisation objectives. Coherent and integrated regulation is to be welcomed and respected but needs to be applied universally, not at differentiated regional levels. Incentivised access for capital investment from the banking and capital markets requires a regulated framework already established, but which shipping in all forms should engage with as an equal partner.

3.1 Enablers

The environment and competitiveness are two perspectives where shipping companies try to pinpoint trade-offs over the recent years. This is because industry has identified several economic advantages in contributing and benefiting from the energy transition – by implementing more energy efficient technologies. Shippers demand and aim at operating more eco-efficient vessels same as charterers. On the other hand, insurers and investors will become risk adverse regarding stranded carbon assets (International Transport Forum, 2018).

Current levels of energy efficiency have not been driven by regulations, but by market status and bunker prices (Smith et al., 2016). There are also two different drivers in the market: some shipowners are addressing the necessity to reduce emissions as an additional cost that they must unwillingly bear while some other have proactively engaged in the development of greener performance. Regulations is an accelerator removing future uncertainty and de-risking investments to address environmental implications.

Understanding the environmental performance (e.g., fuel consumption, fuel burn by-products) of a ship is a data intensive process. However, most such data typically rely on service providers' or manufacturers' data and analysis which is carried out under specific conditions, and there is often a lack of transparency leading to significant uncertainty on possible energy savings when used in practice. Instrumentation installed on board does not offer the required sensitivity to provide accurate results. In addition, some calculations rely on measurement manually conducted by crew with unknown accuracy. Moreover, performance data may originate from studies that have no relevance or similarity to the actual operational usage and profile of a particular ship. To develop robust and accurate ship environmental and economic performance models, detailed ship technical/operational data are necessary. Performance models must also be ready to be customised and adapted to the actual specificities of individual ships and operating patterns, in order to enable real time operational optimisation, maintenance triggers and evaluating technological interventions (Aldous, 2015).

International Chamber of Shipping in its 2022 study about *Fueling the 4th Propulsion Revolution* suggests a set of ways to reduce emissions from shipping (Figure 5). There is energy efficiency, zero or low emission fuels, operational behaviour, and carbon capturing, amongst them (ICS, 2022). European Parliament focuses on the roles of regulation and cleaner fuels which will tackle the climate change impact from shipping (EPRS, 2020). Furthermore, ITF (2018) proposes technological, operational and alternative fuels and energy use on board as key levers to decarbonise shipping. They also identify the voluntary action taken by shippers to promote green shipping, investors divestments from stranded assets and the climate risks in ports and cities.

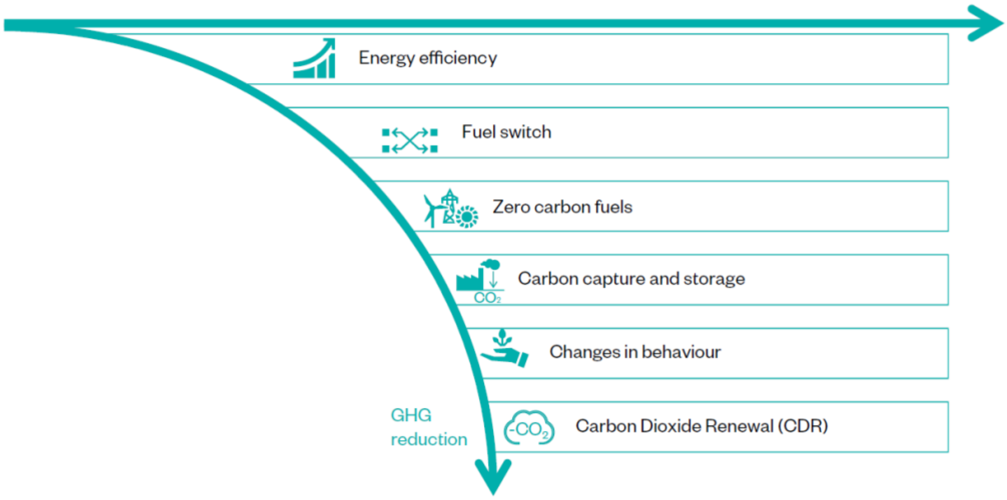

Figure 6 Six generic ways to reduce CO2 emissions (Source: World Energy Council, 2020)

There has been much focus in the literature on the trade-off between slow steaming to reduce voyage costs accordingly (lower fuel consumption and emissions) and the consequent extended voyage time resulting in lost revenue, as well as related machinery performance and emissions issues (Hountalas et al., 2014). In response to the oil crisis of the 1970s, optimum speed sensitivities given different revenue schedules were proposed. Additionally, several emission-reducing technologies (decarbonisation solutions), covering hull design, power and propulsion systems, alternative fuels, alternative energy sources, and operations have been proposed (Bouman et al, 2017).

3.1.1 Regulation

International shipping needs to align with IMO's GHG strategy and that is only possible through zero-emission fuels becoming the main fuel source by the mid-2030s, gradually phasing out current fossil fuels. However, a significant competitiveness gap is recorded between incumbent fossil fuels and alternative zero-emission options. This gap is the result of the existence of market barriers and failures, but mainly the lack of supply and demand, a lack of regulation on safety, as well as the price difference in the fuels. As a result, there is an urgent need for policy to bridge the competitiveness void and ensure shipping meets its decarbonisation ambition. One of the key drivers for shipping decarbonisation is regulations established by the IMO and the EU.

The maritime industry already takes actions to respond to the challenge of reducing its emissions. Serving 2015 Paris Agreement as a basis, IMO announced the goal of reducing GHG emissions by 50% by 2050 back in 2018 compared to emissions baseline of 2008. Besides regulations aiming at mitigating air pollutants such as sulphur dioxide and particulate matter, other measures targeting greenhouse gases are:

- EEDI (Energy Efficiency Design Index) for new ships. The goal of the EEDI is an improvement in average annual efficiency from 2015 to 2025.
- CII (Carbon Intensity Index) which provides ship operators with the pace by which they must reduce CO2 emissions annually to ensure compliance with regulations. The CII must be implemented within

each operator's Ship Energy Efficiency Management Plan (SEEMP). CII will be effective as of 2023 with a reporting kick off data in January 2024. CII index will be used to rate ships on a scale: A, B, C, D and E, from best to worst performing. This is shaped to drive improvements in vessel operations, e.g., by technology upgrades.
- EEXI (Energy Efficiency Existing Ship Index): this is also coming into force on 1 January 2023. The EEXI is applied to existing ships outside EEDI regulations. Emissions are defined per cargo tonne and mile.

The anticipated EEXI compliance based on the current global fleet status is (Bureau Veritas, 2021):

- Bulk: 60%
- Tankers: 70%
- Container ships: 30%
- Gas carriers: 55%
- LNG carriers (without steam turbines): 100%
- Cargo ships: 80%

IMO expects that EEXI, EEDI and CII will reduce the annual emissions of global maritime shipping by at least 25% vs. baseline (Richardson, 2021). In 2021 the Marine Environment Protection Committee (MEPC) of the IMO set new targets to reduce CO2 emissions per unit of transport work: a 40% reduction by 2030 a 40% decrease and 70% reduction by 2050 compared to 2008 emissions (IMO, 2021). The reduction path is designed by optimising operations, reducing speed, retrofitting vessels with energy-efficient technology and propulsion and gradually switching to lower or zero emission fuels.

As of 2010, the IMO revised International Convention for the Prevention of Pollution from Ships (MARPOL, Annex VI), aimed at a reduction in emissions of sulphur, nitrogen and particular matter (PM). It also introduced special emission control areas (ECAs) with emissions limits for those pollutants. Two ECAs were established in EU, the Baltic Sea and the North Sea. The revised MARPOL anticipated a reduction in the limit for SOx and PM in ECAs to 0.1 % from 1 January 2015. IMO also announced a global 'sulphur cap' of 0.5 % in all waters from 1 January 2020. It banned even the carriage of non-compliant fuels on board for ships without an exhaust cleaning system. The EU transposed the IMO SOx limits into Directive EU/2016/802. Use of marine fuels with a maximum 0.1 % sulphur content is mandatory in the EU ECAs from 2015. EU also set the same limit for ships calling at EU ports and a 0.5 % limit for all other EU waters from 1 January 2020.

The IMO also introduced reductions of nitrogen oxides (NOx), by setting limits for marine diesel engines on new-built ships. From January 2021, all ships use the mandatory standards or equivalent NOx emission reduction technologies to adhere to NOx emission levels. In 2016, the IMO incorporated Baltic Sea and North Sea to the existing NOx Emission Control Areas (Ricardo, 2022).

EU adopted a system for monitoring, reporting and verification of CO2 emissions from maritime transport ('MRV Regulation' 2015/757/EU), as a first step towards monitoring GHG emissions in EU. It mandates ships above 5,000 tonnes calling at ports in the European Economic Area (EEA) to collect and report their CO2 emission data, based on their fuel consumption. However, data collection under the global IMO DCS started in 2019 and thus, companies are obliged to report similar data twice.

The EU Emissions Trading Scheme operates on the basis of a cap-and-trade system. This means that the total GHG emissions emitted by the ETS parties are capped and there is a gradual reduction in the maximum amount of emissions per year at a specific pace. Participants must report their emissions annually and then surrender quotas purchased to meet their level of GHG emissions. The aim of the system is to reduce total emissions by 43% by 2030. European Commission in its continental carbon target framework considers increasing the GHG reduction target to -55 % by 2030 and integrate maritime sector into the EU ETS as of 2023. The shipowners participating into EU ETS must propose a monitoring plan which is built in accordance with the European Commission's monitoring and reporting regulation and be approved by an inspection body. Participants are required to report their emissions data which are verified by an accredited external verifier.

Below a combined map of past and upcoming IMO and EU shipping regulations is presented.

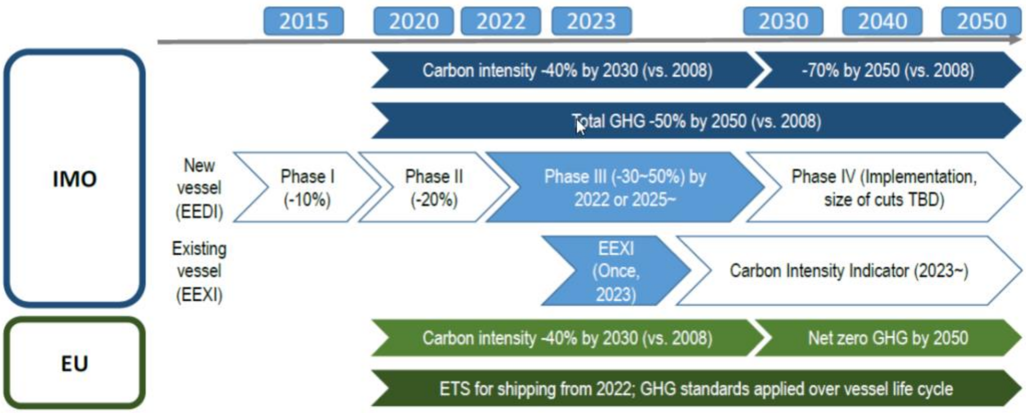

Figure 7 IMO and EU shipping regulations (Source: JP Morgan)

However, future potential market-based measures include carbon emissions taxes and levies, emissions trading systems and subsidies. They can foster decarbonisation and close the competitiveness gap by increasing the price of fossil fuels. The report asserts that to fully decarbonise shipping by 2050, the average carbon price should only need to be around USD 191/tonne CO_2 (Smith et al., 2019). The scenario assumes that carbon pricing would begin in the mid-2020s at a relatively low level and then rise more sharply through the 2030s and 2040s. The revenue generated by an economic measure such as carbon price is that it can be rechannelled to further support the energy transition of shipping, by for example subsidising the production and scaling of zero-emission fuels and technologies. The deployment of zero carbon fuel projects in developing countries could be promoted by this use of carbon revenues.

3.1.2 Voluntary market forces

Another driver is voluntary action driven by market players. There is a market segment which moves the energy transition at an accelerated pace either because of the embedded sustainability culture or upon request for climate neutral performance made by customers. There are many examples of shipowners launching emission reduction projects or directional ones. For instance, Euronav, a Belgian shipping company specialized in shipping oil, has entered in a joint venture together with DNV, LR (classification societies) and Hyundai Heavy Industries (shipyard) to accelerate the development of ammonia-fuelled vessels and relevant design standards (www.euronav.com). Many of Swedish leading companies, such as Volvo, IKEA and H&M have formulated targets to reduce their carbon footprint. From a different point of view, DT4GS R&D project is another initiative bringing together key actors of maritime shipping to support the development of digital twin models which can re-shape voyage optimization and shipping energy-efficiency. There are multiple examples in the industry where stakeholders create coalitions to test or demonstrate tangible technologies aiming at reducing industry's footprint once scaled up.

A range of other initiatives, such as the Clean Cargo Working Group (CCWG) and the Clean Shipping Project. The Clean Cargo Working Group (CCWG) has 45 members hold approximately 85% of the container volume. CCWG releases yearly environmental performance data of the member carriers verified by third parties which aims to help shippers benchmark their environmental performance and making logistics decisions. Smart Freight Centre established a group of industry stakeholders, experts, governments and others, called the Global Logistics Emissions Council (GLEC), in order to achieve harmonisation in emissions accounting. Large Swedish shippers have been driving the development of the Clean Shipping Index (CSI). The CSI is a tool that provides a rating to ships based on a range of environmental criteria to compare vessels' environmental performance. The United States Environmental Protection Agency (EPA) has developed a similar approach to assess shippers' environmental performance. SmartWay releases a clean shipping ranking each year to inform shippers and freight forwarders.

Decarbonisation efforts will have an impact on market drivers and vice versa. For instance, as new regulations kicking in supply/demand balance is expected to tighten. Average ship speed is expected to slow at a 0.8% CAGR in 2023-26E due to regulations compliance. As such, existing fleet will have to load more cargo in order to cope with the demand, leading, in turn, into increasing fleet utilization rate. Clarksons and UBS conclude that global fleet utilization rate to rise 1-2ppt in 2023-26E on the back of slower speeds and yard times required for retrofits so as to comply with EEXI/CII.

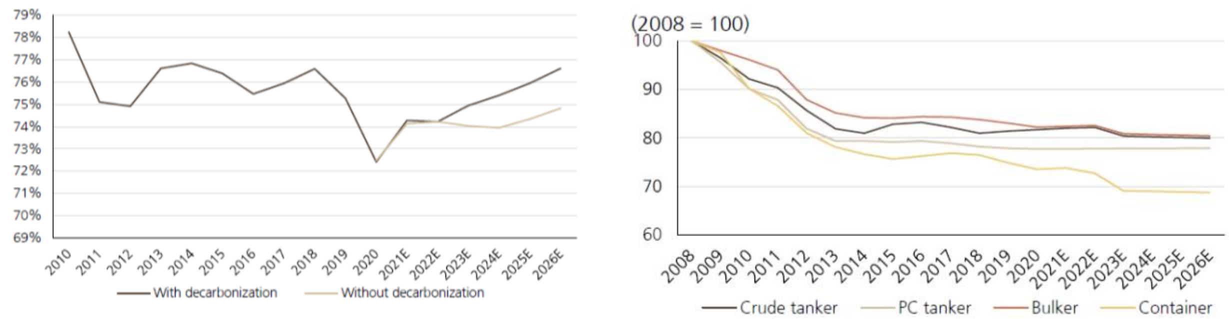

Figure 8 Global fleet utilization rates and average speed forecast by ship type (2008 = 100) Sources: Clarksons, UBS Estimates

3.1.3 Digitalization

The shipping industry in order to address high operational costs and fuel consumption together with other critical elements such as: safety and crew well-being has begun to use digital technology in their business. Digital technology relies on the ship-to-shore connectivity using hardware equipment on board vessels and sharing data and information to inform decision-making either on board or at shore. Tangible impacts from such disruptive strategies included financial savings and emission reductions. Such implications might not come directly from digitalisation, but they stem from the more informed decisions. On the downside, however, the inherent risk of digitalisation is the quality of data and controls used: lack of valid and accessible data. Hence, digitalisation should come with proper data validation and comparison with other sources of information I.e., noon reports.

Digitalisation is a mean to address decarbonisation. However, it is important to understand that savings through increased energy efficiency and lower energy usage through the use of new technologies might partly backfire as a result of the increased energy consumption of the new sensors and hardware on board. Increased digitalisation requires higher electricity demands. In the case that electricity is sourced from green or clean sources the additional energy demand does not impact the environment. This rebound effect may at times cause a loss of 10–30% benefits (Agarwala and Guduru, 2021).

There are numerous digital tools that have been developed and can be used in the shipping industry. Some examples of digital tools that can support decarbonisation are described below:

1. Digital twin: a digital tool that allows the availability of a digital replica of the ship, typically in real-time but not necessarily, shared with the operators on shore. In case of real-time monitoring, the ship and its machinery are visualized and tools ensuring that maintenance or optimization services are provided to the machinery to improve ship efficiency from different angles (Lind, et al. 2020).
2. Blockchain: digital ledger which unleashes fault-proof movement of cargo from one port to another ensuring faster loading and unloading activities (King Boison and Antwi-Boampong 2020).
3. Cloud technology: data computing and data storage to improve business agility. Together with Big Data analysis, the Cloud analyses great amount of data to provide a reality check of the ship condition (Di Silvestre et al. 2018).
4. 5G allows higher speed of transfer of data. This technology would allow easier and faster data transfer between ship to shore and between systems both from/to the ship and the port. As a result, there are some very important benefits recorded: faster reaction time, efficient material handling, video surveillance and remote control of cargo handling facilities (Agarwala and Guduru 2021).
5. Internet of Things (IoT) is a digital technology that uses machine to machine communication through digital signals. IoT allows remote and unmanned operations of machines thereby making the operation safer and efficient, reducing maintenance and fuel consumption (Plaza-Hernández, et al. 2021).
6. Edge Computing can assist in faster computing of navigation routes and initiate evasive actions against obstacles at sea without the help of Cloud and 5G technologies (Gakpo, et al. 2019). Such capacity would assist the deployment of ships independency and autonomy, transitioning them to "autonomous" vessels thereby rendering them more efficient, economical, and environmentally friendly. Using edge computing coupled with AI-driven analysis and modelling in the Cloud, real-time diagnosis and on-board predictions can be planned as well.
7. 3D printing: using digitised drawings of machinery parts, 3D printing systems enable the manufacture of these machinery parts on board the vessel. This would reduce the spares carried and ensure that defective machinery can be directly repaired or re-generated and made to operate efficiently (Kostidi and Nikitakos 2018).
8. Virtual Reality (VR) and Augmented Reality (AR) can be used as tools to reduce maintenance work, thereby reducing the energy use due to faulty machinery/ equipment. To add to this, if VR and AR are combined with digital twinning, the maintenance work can be completed while the ship is at passage. There has been a broad adoption of AR/VR technologies in terms of ship designing, construction, training, and maintenance (Chhabra and Rana 2020).

9. Drones either underwater (UUV) or in air (UAV) underpin surveying and analysis of the maritime space (i.e., hull) to assist decision making and awareness in a timely manner, either from the ship or from shore.

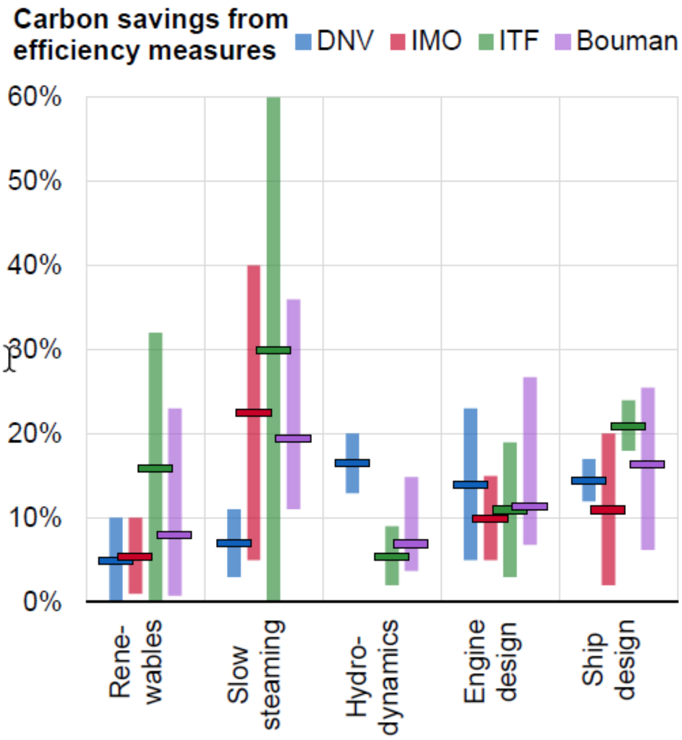

Figure 9 Ranges of GHG emissions reductions per different type of intervention. Light bars represent the range from each study (1st/3rd quartile from Bouman, min/max otherwise), and dark horizontal bars represent the median.

Sources: Bouman et al. (2017); ITF (2018); DNV GL (2017)

3.1.4 Confronting climate risks in ports and port-cities

Climate change has already started impacting exposed infrastructure, especially at ports and in port cities. Coastal zones are particularly vulnerable to sea-level rise and extreme weather conditions such as storms. Such extreme hazards can negatively impact the supply chains and the provision of goods and services through events such as flooding and coastal erosion. OECD (2015) estimates that South East Asia will be the mostly affected by sea level rise with highest impacts in India and other developing countries in the region. The monetary value of assets that are exposed to extreme water level has been estimated by Hanson et al. (2011). The quote that the value risk reaches USD 3,000 billion with the highest risk for assets located in Asia. Ports need to develop effective adaptation and mitigation strategies otherwise; lack of proactivity would have devastating implications for the global economy. Consequently, ports put in motion adaptation policies to climate change and invest in the protection of vulnerable infrastructure; As a logistics hub they live up to that by pressing shipping companies towards decarbonisation pathways through the use of incentives. Green berth allocation policies, green procurement and carbon pricing schemes have also been applied in some ports (ITF, 2018). Recognising their responsibility to contribute to the reduction of GHG emissions, fifty-five of the world's key ports have founded the World Ports

Climate Initiative, which has tried to develop port strategies to reduce GHG emissions and to facilitate best practice sharing (ICS, 2022).

3.1.5 Long Term Perspective

In order to comply with initial IMO strategy objective of at least 50% GHG reduction by 2050 on 2008 levels, and the Paris temperature goals, that is only possible with a switch to increased use of zero emission fuels as of 2030s and with rapid growth thereafter. Sustainable biofuels can be a growing part of the fuel mix, for example as part of blends, transitionally and before 2030, which could help to increase the timescale for the introduction of synthetic fuels (Baresic et al., 2018).

The transition towards net zero by 2050 will, at some point, require a full switch to zero carbon fuels. Medium- or short-term measures may, for some, include blend in of carbon neutral fuels, while most short-term measures constitute increased fuel and energy efficiency which is provided either by energy saving devises or operational measures, voyage optimization, etc.

The business models with adverse consequences for emissions, increases the need for global regulation and/or significant innovation. Both are likely to accelerate changes to how value is created in the industry. Till then, there are several technical and operational measures that could improve fuel consumption and support emissions reduction. Speed remains a key operational driver of emissions. Shipping digitalization with new technologies and sensors combined with big data analytics and machine learning helps tracking emissions and trigger actions to reduce vessels' fuel consumption.

The future of ship owning could be defined by large and standardised fleets of vessels that are offered as a premium product to the market (e.g., digital, circular and, eventually, decarbonised) but priced as a utility. These vessels could be built and operated using models that allow regular efficiency upgrades to be implemented without the need for additional investments from the asset owner.

3.2 Barriers

There is a range of market barriers that lead to a delay in adoption of low emission or zero emission technologies. They are reviewed below.

3.2.1 Production and availability of alternative fuels

In order to respond to the future demand of alternative fuels, sufficient development and adaptation of infrastructure as well as new production capabilities of alternative fuels need to be stimulated linked to each path dependence of the shipping sector. Examples of far-reaching adaptations that might be needed include the wider energy infrastructure and production capabilities related to advanced biofuels, but mainly on hydrogen, ammonia and other zero-carbon fuels like synthetic LNG and carbon capture facilities. Ships and ports would require the relevant facilities for bunkering provision.

3.2.2 Lack of supporting regulation: carbon tax

A negative externality is generated when an economic entity takes an action that has an impact on third party but does not bear the costs. For instance, pollution causes health issues in the long-term, where society undertakes the recovery costs without the economic entity bearing the cost of it. These costs are usually not borne entirely by the emitters and there are not any legal obligations for them to compensate those who are impacted, they have little or no economic incentive to reduce emissions.

Such, climate change impacts are not internalised in the price of maritime transport, in contrast for example to fuels for the road sector. Taxing fuels and / or emissions would be a way to internalise the externalities of carbon emissions. This lack of taxation is also impeding the adoption of alternative fuels: heavy fuel oil (HFO) for ships is not taxed but generates huge negative externalities, whereas some of the alternative energy sources (e.g., electricity) with much less of these externalities are actually taxed. This complicates a massive transition from HFO to alternative technologies and fuels generating a competitiveness gap between conventional and lower emission fuels. This would make lower or zero emission capable vessels a more attractive option vs. conventional ships. If accompanied by carbon pricing, or other measures, such as regulation, e.g., via low-fuel standards is expected to accelerate energy transition.

Carbon pricing would be a way to incorporate the costs of shipping's carbon emissions into shipowners' decision-making. A consequence resulting from negative externalities, carbon pricing would help to internalise them. So, carbon pricing would be one of the building blocks for achieving decarbonisation pathways. Lloyds Register and UMAS (2018) indicates that zero emission ships using biofuels only become competitive (compared with conventional vessels) when a carbon price of USD 250 per tonne of CO2 is introduced. Other fuel options, such as ammonia and hydrogen will only become competitive at a carbon price of approximately USD 500 per tonne is introduced. There are two forms a carbon tax might take:

i. Carbon tax where companies are taxed according to their carbon emissions generated;
ii. Emission trading scheme (e.g., EU ETS); a company holds emission rights with an option to pay more in order to acquire more rights from another company who is interested to sell theirs.

3.2.3 Sunk costs

As the average life of a vessel is approximately 20-30 years, whatever is delivered today will still be active by 2040. Therefore, some part of the global fleet will still run on fossil fuels or on no zero-emission by 2040, if not retrofitted. Decarbonisation depends on fleet renewal and its pace which in turn depends on the extent of scrappage of old vessels and the capacity to retrofit existing vessels. The potential for fleet renewal is larger if maritime trade and fleet is growing. As such there are market drivers that dictate decarbonisation speed (ITF, 2018).

Figures 10 and 11 below depict the past and present status of global newbuild order trend which has abruptly decelerated in 2022 and the shipyard capacity vs. Order backlog which indicates how shipyards

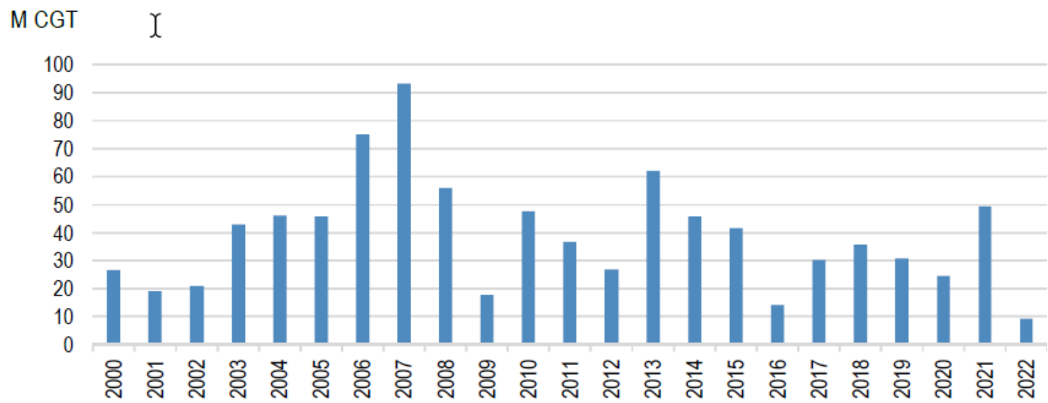

Figure 10 Global newbuild order trend. Source: Clarksons

can cope with the level of newbuild orders (or retrofit slots). These market drivers are also decarbonisation drivers because some key levers of decarbonisation (e.g., energy-efficiency technologies and fleet rejuvenation) require additional capacity by shipyards.

3.2.4 Diverging interests and split incentives

The entire edifice of international maritime trade is made up of building blocks that allocate the financial cost of (climate) inefficiencies. It usually emerges when stakeholders involved in a specific economic activity do not share same interests and priorities. For instance, charterers and ship owners time charter market, where the ship-owner provides a vessel, but the fuel costs are paid by the charterer as part of the operational costs. In a hypothetical case of slower steaming in order to either reduce bunkering costs or due to lower discharge terminal preparedness level, there are cost savings as of lower voyage speed that can be attributed to either shipowner or charterer. Similarly, the demurrage costs (demurrage = compensating the shipowner for the consequences of delay. Some of this delay is at port, the result of delays in the cargo operations, but most of it is at the anchorage, caused by the inefficiency of 'Steam Fast then Wait').

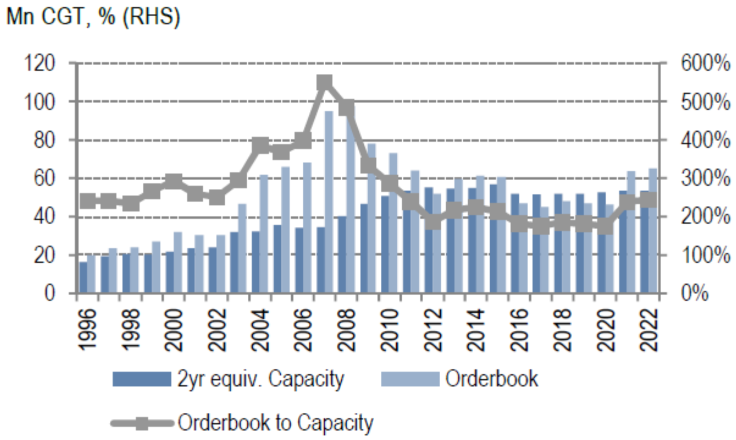

Figure 11 Global top 30 shipyards' capacity vs. Order backlog. Source: Clarksons

On the contrary, charterers may also decide to reward owners for their investments in clean technologies or engage in longer charter contracts to allow for a sufficient payback time for these technologies. The regulation is a driving force where charterers may pick more eco-efficient vessels in order to ensure regulatory compliance (e.g., CII) and bear lower expenses with regards to carbon emissions (e.g. EU ETS).

3.2.5 Lack of credible data

High quality data are a prerequisite to voyage and vessel optimisations, fuel safety and security and energy saving technologies. To ensure valuable outputs from digital platforms, data input must be of high-quality, standardized, valid, interoperable, and more transparent. Fuel consumption models and data must be accurate and informed. Technology can help support these decisions as optimisation and voyage speed variations have been seen to improve fuel reduction considerably.

There is an uneven playing field with regards to how companies are dealing with data in shipping. Noon reports include a huge range of data points, including average speed since the last noon report, propeller slip, engine RPM, weather and sea condition, distance. Because these reports are produced manually, often in accordance with individual shipping company, charterer, or ship management, the diversity and quality of their input can vary widely. Adding complexity to this is that much data can be unreliable, sometimes even "skewed" to protect commercial interests. This poses a challenge for anyone looking to optimize voyages, vessels, fuel, energy use, bunker and emissions. Therefore, a first step towards improving the accuracy of vessel performance could be i.e., to standardize noon reports. There are several entities currently working to standardize definition of terms which will also help in the future with data collection and sharing.

3.2.6 Market forces

Market barriers that already and will exist in this industry may slow the transition to zero-emission shipping and widen the competitiveness void between zero emission fuels and conventional alternatives. Those barriers need to be addressed by policy-makers which have enough power to steer the industry into the right direction. On the bright side, the shipping sector has numerous options to improve energy efficiency that lower emissions and costs through the reduction of fuel consumption. All in all, in the shipping industry, market barriers include business and financial risks, capital costs, limited access to capital and hidden costs (Fitzpatrick et al. 2019). In other words, these are economic obstacles faced by individual firms which can slow the uptake of decarbonisation technologies (Sorrell et al. 2004). Market failures pertaining to preventing the uptake of zero-emission technologies may occur because of diverging interests, lack of trusted data, lack of regulation, sunk costs, etc. The consequence of both market barriers and failures is the slow adoption of zero-emission technologies, decelerating the transition and risking the industry to low regulation compliance and lack of access to green funding. This means that, as part of addressing the competitiveness gap, any future policy design in shipping should consider and address these market features, where possible.

3.3 Sustainable financing

The shipping industry is governed by small, medium and a few large sized shipowners. The highly volatile nature of the industry has led to a market practice where shipowners try to sell their vessels at a premium to their purchase prices. The nature of this asset game disincentivises large-scale fleet rejuvenation and discourages more innovative thinking. These market dynamics have led to the creation of the risk of gradually stranded assets when the shipping industry needs to incorporate a carbon price. Traditional strategies centre around regulatory compliance, customers or maker expectations and securing seamless access to financing and capital. There is low appetite for breakthrough innovation, new business models and possible expansion of market size. Still, shipping industry is preparing for the transition towards zero emissions shipping. Hence, today's opportunities regard dual fuel solutions where future retrofit packages are integrated so as to allow a switch when a lower carbon fuel alternative becomes commercially available, at scale, and with a competitive price.

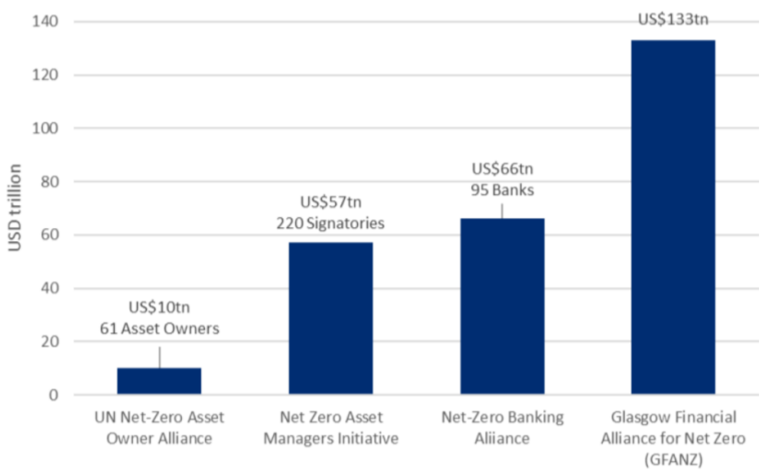

Figure 12 Net Zero Initiatives across financial markets

Sources: www.gfanzero.com; www.netzeroassetmanagers.org; www.unepfi.org/net-zero-banking/; www.unepfi.org/net-zero-alliance

3.3.1 Climate risk is financial risk

Banks are using analytical tools to assess climate alignment and track sustainability performance of their shipping portfolio, in order to make better lending decisions. This is of paramount importance as commercial banks are the largest source of financing for the shipping industry. There is a significant opportunity for the finance community to catalyse the global energy transformation and de-risk future investments (ICS, 2022).

Many banks are setting the scene ensuring that their shipping finance portfolios have net-zero emissions by 2050 or at least there are somehow climate aligned. This led to the creation of the Poseidon Principles – a framework to assess and integrate climate considerations into banks' lending decisions so as to encourage and support decarbonisation in the shipping industry. Signatory banks are expected to gradually align their portfolio towards companies achieving a 50% reduction in emissions by 2050 in line with IMO 2050 strategy. Investors begin to measure the performance of financial institutions and central banks are further regulating financial system imposing green investment ratios for national banks. The shipping industry involves very complex value chains of upstream and downstream activities and together with long-lifespan of shipping assets means that decarbonising the sector will be a capital-intensive exercise.

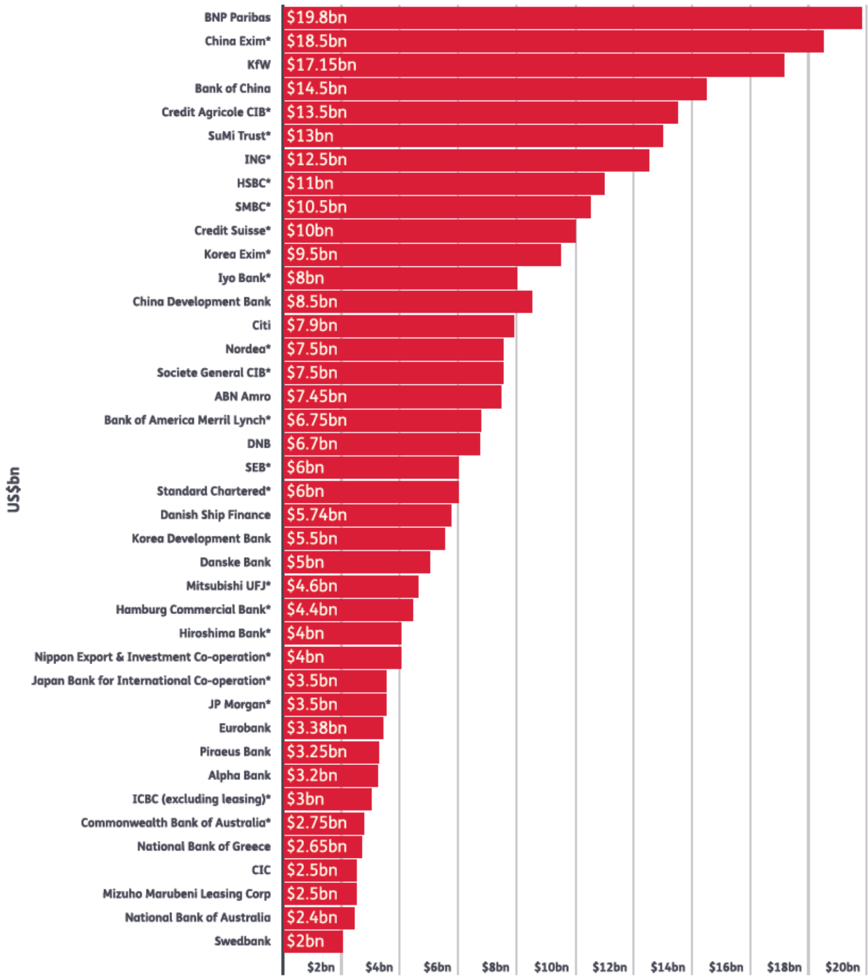

Figure 13 Top 40 banks in global shipping finance (2021). Source: Petrofin Research, August 22

Figure 14 Top 40 banks lending to global shipping finance (2007-2021). Source: Petrofin Research, August 22

For instance, shipping companies will need financing to build new vessels powered by alternative fuels. There are the cost spreads between conventional, fossil fuels and their zero emission alternatives, such as green ammonia, which are high, and green fuels are expected to remain expensive for a long time. Capital intensity is also recorded on the fact that manufacturers will need to design new engines; port operators and fuel suppliers to build bunkering and logistics infrastructure; and energy companies to invest heavily in producing renewables at scale making sure that there are infrastructural links between production and consumption locations for those new types of fuels.

According to Standard Chartered estimates, investments of up to USD1.5 trillion are needed to halve shipping's carbon emissions by 2050. Other forecasts suggest the industry may need to step up to USD2.4 trillion to achieve net-zero emissions by 2050, in the net-zero 2050 scenario. Taking into account the magnitude of capital required to decarbonise shipping, the finance sector is expected to heavily dictate the pace towards zero emission shipping.

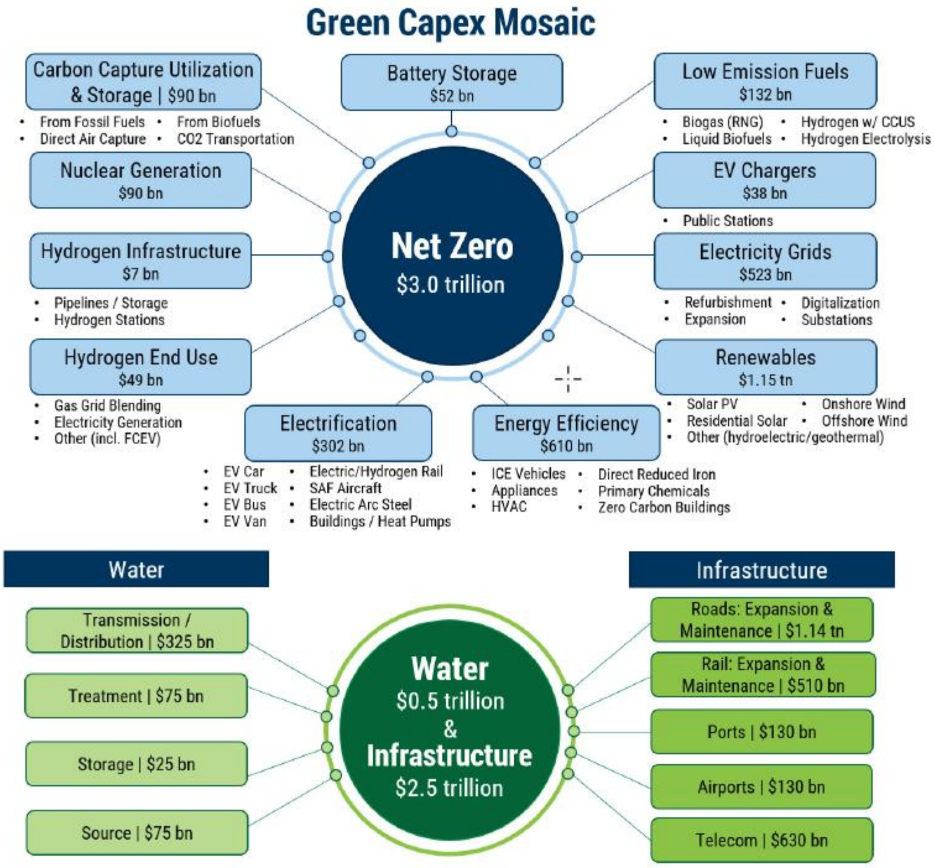

Figure 15 Level of investments and technology mix required to decarbonise the blue economy sectors

Source: McKinsey, OECD and Goldman Sachs Global investment

3.3.2 EU financing initiatives

As shown in the figures above, EU has strong participation into shipping financing. To help financial institutions flow the resources to the right economic activities, EU has developed a regulation aiming to define ‘green’ economic activities which is called ‘Green Taxonomy’. It aims at enabling organisations and investment companies to understand which activities are defined as environmentally friendly, and to mobilise more capital to finance greener economic activities. The ones who should report are financial market participants offering financial products in the EU, large organisations that are already required to provide reporting under the Non-Financial Reporting Directive and EU Member States when establishing public measures, standards or labels for green financial products or green bonds. To comply with the taxonomy, the economic activities of organisations must contribute to one of six environmental objectives and not undermine the other environmental objectives. EU Green Taxonomy is a step towards harmonisation of the classification of green activities, aligns organisations of financial markets in Europe with the efforts to align with the Paris Agreement and supports legislative initiatives in terms of reporting turnover, capital and operational expenses (European Parliament, 2020).

3.3.3 Public Finance

There are public subsidies, either regional or national or governmental, to shipping could be targeted to stimulate decarbonisation. Usually, public financing to private sector is prohibited by Competitiveness Laws however, temporary governmental support to secure market transitions under a scope of common interest may be released. Such subsidies could then help shipping to build the critical mass to move shipping to a zero-emission pathway. For instance, favourable tax provisions for shipping could be leveraged to decarbonise the sector, in form of tonnage taxes, a tax that uses fleet size rather than corporate income as a tax base. Countries could also consider defining decarbonisation as one of the conditions for tonnage taxes. For instance, electric ships would be helped with exemptions from electricity taxes, similar as those provided in relation to onshore power supply for ships.

Some of state-owned organizations are active in ship finance: Norway's Government Pension Fund Global announced that they will introduce environmental requirements for their participations in the shipping sector (ITF, 2018).

CO2 emissions could also serve as a criterion of the public procurement of shipping services. Although this might mainly regarding domestic shipping services, decarbonisation practices in domestic shipping activities might provide spill overs for internationally operating fleets and unlock a new playing field for piloting and scaling-up zero-emission technologies and infrastructure.

Port-based incentives are also provided in some cases fostering the reduction of shipping's carbon emissions. Ports are already offering incentives (e.g., lower fees) for ships with higher environmental performance (ITF, 2018b). Most of these port fee reductions are targeting on reducing local air pollutants. The uptake of electric ships could benefit from reductions on port fees, particularly if applied in many ports and if the reduction is substantial. The public sector can also stimulate investments by the private sector e.g., create favourable conditions for instruments such as "Green Bonds" that unleash new finance opportunities towards green shipping.

4 Digital twins in shipping

This chapter discusses the concept of Digital twin and its value proposition for shipping industry decarbonisation. Recent advancements in artificial intelligence, sensors, machine learning, and the Internet of Things are moving digital twin technology beyond the concept stage to where it is emerging as an invaluable took to aid the shipping industry decarbonisation. In this chapter we outline the technology's value proposition in areas such as voyage optimisation, ship maintenance and operations, environmental impact and sustainability.

Three business drivers justify the need for digital twins: creating a shared source of asset (i.e. vessel) data that can serve as a single source of 'truth'; supporting investment decision making; and accelerating continuous process optimization[1].

4.1 How a digital twin is constructed

A digital twin can be used across each stage of a vessel's life cycle, from testing what if scenario in financing, ship designs, to reduce human error, to ship building, commissioning operations and decommissioning. Various ship models are integrated into the digital twin and when populated with actual ship data make the digital twin a true replica of the physical ship.

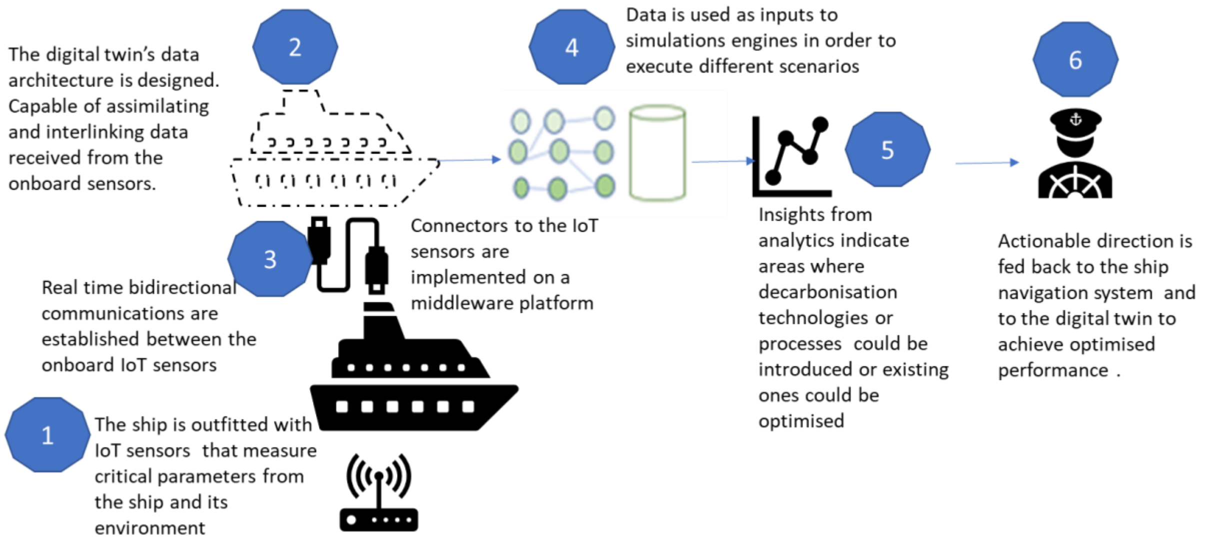

Figure 16 Digital twin construction and operation lifecycle.

As Figure 16 illustrates, a digital twin model is essentially, an interlinking (knowledge graph) of various types of ship models that are populated by data that correspond to ship designs, operational data and even data from the ship's environment. In the ship's operational phase, such data are collected by Internet of Things (IoT) sensors installed onboard the ship. The ship's models populated with data are used to analyse, predict and control the ship's behaviour using an ensemble of simulation and machine learning techniques. The ultimate objective is to optimise some of the ship's operating parameters with the aim of reducing the ship's environmental footprint.

Various optimisation areas can be explored such as the ship's navigation and routing as well as keeping the ship in optimal operating condition that minimises fuel consumption, via preventive maintenance.

[1] How digital twin technology is transforming supply chains | EY - Global

The business value of a ship's digital twin is therefore many-fold and addresses the needs and business models of multiple stakeholders. Moreover, as business priorities are constantly evolving over the life cycle of a ship, a digital twin that remains up to date can support an agile approach to decision-making and management.

4.2 How a ship digital twin is used

As explained in the previous section, a digital twin is a digital replica of the physical ship and can be used to perform analyses and answer 'what if' questions in a manner that is impossible (or prohibitively expensive) to carry out on the real ship. The initial digital twin model (base model) is a 'normalised' ship model, where normalised means that it consists of the ships design and operational configuration data as specified by the ship's designers and constructors (shipyard, subsystem manufacturers etc).

The data sets of the digital twin consist of nominal data and values obtained from manufacturers data sheets, public data repositories etc. The base model will be used as the 'ground truth' to validate any machine learning predictions, source of simulation data and as comparison point for subsequent more elaborate and specific data models (e.g., digital twins).

4.2.1 Simulations/'what if' scenarios

To simulate 'what if' scenarios, a model is required which operates on input parameters to calculate output parameters. Each set of input parameters can represent a hypothetical ('what if') scenario.

MODEL: this is a ship (or ship subsystem's) physical model, i.e., a model containing the mechanical interactions or energy exchanges between the ship subsystems and/or the environment.

INPUT parameters: the independent (e.g., ship performance related) variables.

OUTPUT parameters: The variable we want to understand e.g., ship speed under different operating scenarios.

Variables can easily be introduced into performance models to build scenarios that can provide responsive solutions to changing regulations. To test for example compliance with various emissions regulations.

4.2.2 Assess Energy savings from a decarbonisation solution

Simulations can also be used with available real performance data, to assess the effectiveness of a decarbonisation solution, without actually fitting the solution on the ship.

Required models:

- A digital twin of the ship before the decarbonisation solution (BEFORE-TWIN)
- A blackbox ship performance model (BLACKBOX-PERFORMANCE-MODEL)
- A digital twin (or several) of the ship with the decarbonisation solution installed (AFTER-TWINS)

STEPS:

- Train the BLACKBOX-PERFORMANCE-MODEL using the BEFORE-TWIN
- Predict the energy consumption/emissions/etc using as input data from the AFTER-TWIN(s) to match conditions and to compare equal with equal.

Compare the predicted consumption/emission with the actual to estimate any savings.

4.3 Building the Digital Twin

Before building the DT model, it is important to set the framework in which the model will be built and deployed. DT models consist of co-dependent and real-time interacting physical assets and digital representations. These simulation platforms require significant amount of data in order to optimize the operational environment (ship building or shipping operations) and therefore a Digital Twin Framework to replicate the real-life activities as accurately as possible. Main applications of DT may be navigation management, route optimisation and hull/propeller optimisation, integrated machinery performance, etc. The DT of a vessel is a complex virtual model of a vessel, and its main application is having better prediction of the vessel's performance (i.e., bunker consumption) given her current physical condition and external factors.

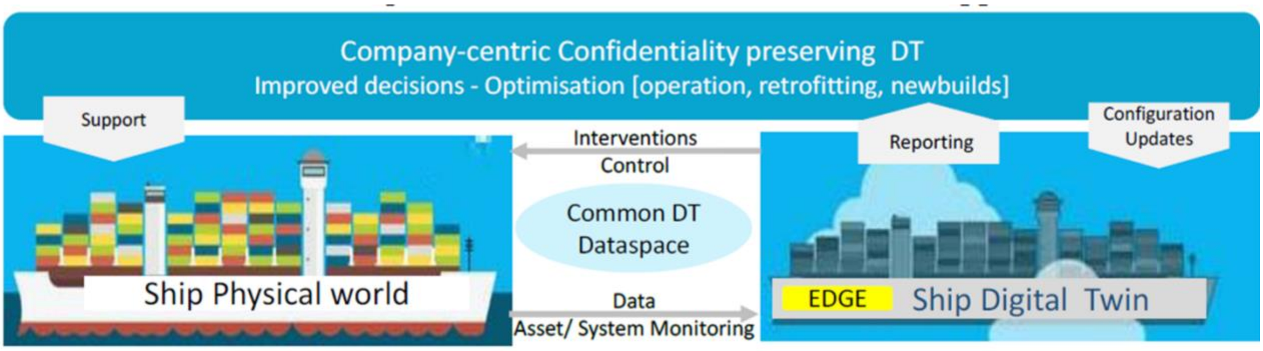

Figure 17 DT4GS Approach to ship digital twinning

4.3.1 DT Challenges

Building comprehensive digital twins of ships requires vessel data (e.g., cargo tanks data, fuel containment specifications, main and auxiliary engine specifications, etc), voyage data (speed, RPM, type of fuel, bunker consumption) and external data (weather and environmental conditions). Moreover, other information is also useful to increase the model's output accuracy (regulatory constraints – technical or emissions, carbon prices/taxes, etc.) which should be converted in digestible format (input) to be able the DT to process it. And this is exactly the scope of this deliverable: to set the macro-environment enablers and challenges providing the initial project perspective in terms of governance related to economic viability of DT model (carbon taxes, transition finance, regulations, etc) and discuss in what way these factors are also actors under a digital twin model. After analysing such factors, the Living Labs have been presented with a break down on use cases (e.g., voyage optimization) and operational scenarios serving the use cases, data requirements (vessel, voyage, external), expected outcomes and user value-added.

Of course, there will be many challenges during the processes of DT models creation, training, validation, on-board implementation and "establishment" as decision making tools. However, taking into consideration the enablers of shipping decarbonization, coming from multiple different sectors, it is of the utmost importance to deal with the majority of challenges through an efficient collaboration between the supply (i.e., market) and the demand (i.e., user segments) sides. Both sides have as common objective the decarbonization of shipping industry, each one for different reasons, through energy efficiency improvements (i.e., MWh/year or MWh) and GHG emissions reduction (i.e. CO_2 emissions reduction). As already mentioned, this common target derives both from market/commercial needs but also from global regulations, so the outcome of the DT4GS project can be proven really meaningful and applicable not only for shipping companies which provide their LLs, but for the broader shipping sector.

5 DT4GS Living Labs

5.1 Methodological approach

According to the Project's description of work the four participating shipping companies (Euronav, DANAOS, Baleària and StarBulk) will develop and test DT applications that correspond to each phase of the project, namely

1. Phase 1: Design and deployment of Operational Optimization DT (M1-M20)
2. Phase 2: Use of DT4GS for Selecting / Planning Shipping Decarbonization Retrofitting Solutions (2030 horizon) (M16-M28)
3. Phase 3: DT4GS enabled zero emission (2050 horizon): New Build Planner (M22-M32)

Such applications will be used to simulate different operational approaches and new technologies that could be applied on board real vessels (i.e., they will be tested inside the Project's Living Labs).

5.1.1. Phase 1 (M1- M20) - Design and deployment of Operational Optimisation DT

This Phase will include two global (generic) use cases that will be customised by each Living Lab and will be further adapted during the process of training and validation of the digital twin models.

Voyage Optimization

Voyage optimization can be considered as a solution for improving the operation of the vessel and leading to a better efficiency, mainly by means of reducing the fuel oil consumption of the vessel and therefore her environmental footprint. In fact, with voyage optimization the route and speed profiles for any sea passage are optimized, of course taking into consideration operational constraints and the current weather conditions. The concept is based on a dynamic routing where the calculations are real-time and can be adapted by the user (i.e., the Master) according to operational needs and his point of view. In this project, the idea is to include all the following aspects of voyage optimization: Route planning, Weather routing, Speed optimization, Consumption optimization, Just In Time Arrival (JIT), Bunkering optimization and Trim Optimization, depending on the Living Lab requests.

Event recognition for Predictive Maintenance

One of the most important factors to consider when discussing the operational optimisation of a vessel and her performance is the ship hull and propeller fouling. During a vessel's operation there is some degree of fouling, resulting in lower or higher increases in resistance (i.e., frictional) and power requirement. In that way, the fuel consumption of the vessel increases and therefore the fuel costs and the GHG emissions. Except for the aforementioned, the more fouling a ship has, the more challenging is for her to achieve the design and charter party speeds and also the CII ratings, leading many times to failures and then to commercial uncompetitiveness. In addition to the commercial considerations, a ship may also become unsafe when navigating in adverse conditions (Liu et al., 2021), which is the most important reason for taking measures since it could lead to catastrophic failures, such as grounding and collision accidents. In order to avoid the aforementioned and have an energy efficient vessel the proper hull maintenance and fouling management should be adopted.

Counter measures that could be taken to ensure the normal operation and health condition of equipment and mechanical systems, include:

- reactive maintenance by replacing/repairing failed components;
- planned preventive time-based maintenance;
- condition-based maintenance based on regular inspection;
- condition-based predictive maintenance based on continuous monitoring.

From the above maintenance strategies only the first one, that of reactive maintenance, cannot be applied within the fouling management. In fact, planned preventive time-based maintenance includes the dry-docking activities every three or five years and the third schema of condition-based maintenance based on regular inspection means that a diver inspects the ship's condition, which requires a logistics arrangement, and the results are heavily dependent on the diver's experience and report (US Navy, 2006). There is also condition-based predictive maintenance based on continuous monitoring that has started to gain more and more attention. As a matter of fact, ISO has developed a standard (ISO 19030) on measuring the changes in hull and propeller performance (ISO 19030, 2016). This enables the operators to better detect the need for hull and propeller maintenance, repair and retrofit. Examining the different maintenance schemes, it is understood that the optimal pathway is the minimum amount of work necessary to ensure the ship provides the optimal level of speed, fuel and emission performance to ensure it is competitive on the market. Thus, the ship owner and/or operator must figure out the optimal maintenance frequency (Liu et al., 2021).

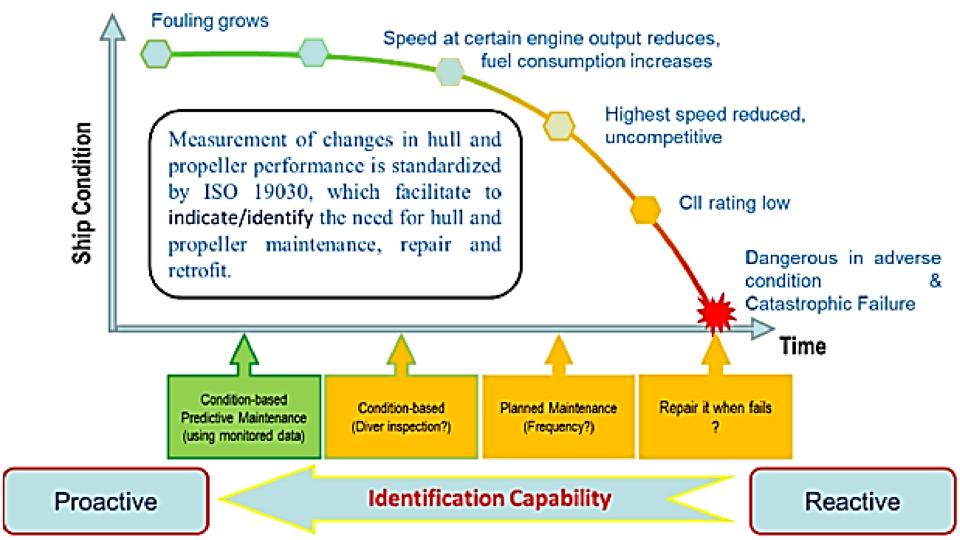

Figure 18 Ship condition degradation and alternative maintenance schemas

5.1.2 Phase 2 Selecting / Planning Shipping Decarbonisation Retrofitting Solutions (2030 horizon)

Some of the areas to be investigated/evaluated by Living Labs during Phase 2 are:

1. Carbon-neutral fuels: The target is the development of digital twins of the power generation plant, containment system and fuel supply system. The deployment of these DTs will enable simulations of the vessel responses in actual voyages with regards to engine response, consumptions (daily rate and total), boil-off rates and power demands for the fuel supply. After the generation of an adequate number of design variants each of them can be assessed by simulation and a multi-objective decision making and design selection based on the deriving Pareto fronts can be conducted with the use of utility functions.

2. Energy production/conversion: The development of DTs for the energy production and conversion process of fuel cells, generators and coupled steam turbines can further enhance the ship system DT and widen the global design space creating design modularity, scalability and flexibility. Also, a composite photovoltaic (PV) surface model and its application including energy storage will be investigated with the bidirectional link onboard energy optimization and possible HVAC technologies.

3. Energy storage: DTs of batteries and supercapacitors coupled in the global DT will enable the improvement of excess energy/power production and smoothening of the power demand during peak and transient conditions.

4. Thermal energy recovery/conversion: DTs covering combined cycle arrangements, heat recovery, Organic Rankine Cycle waste heat recover etc., can enable the ship system simulation to drive further down energy demands. The overall energy reduction can lead into the sizing of smaller machinery components and thus help to reduce the building and thus acquisition cost proportionally.

5. Green propulsion technologies: DTs of wind-assisted power saving technologies (wings, sails, rotors, kites etc.) coupled with corresponding vessel hydrodynamic models, and shaft generators on the main engine interact with the global DT through a holistic context considering the total route energy optimization. The routing and speed optimization is critical here in order to identify routes where the wind assisted technology will have the maximum produced thrust leading to considerable savings. Since this will be a holistic and integrated approach on the global DT, the vessel's lines, propeller and appendices design as well as machinery configurations (e.g., use of shaft generator) will be adjusted to the technology and the resulting optimal routes, speeds and corresponding environmental conditions.

5.1.3 Phase 3 (M22- M32) - DT4GS enabled zero emission 2050 New Build Planner

Some of the applications to be investigated/evaluated by the Living Labs during Phase 3 are:

- Leveraging on the experience and operational data gained from low or zero carbon NBs the further trained DTs can be used for the lifecycle optimization of carbon free designs at optimized production scales and with minimized cost.
- Autonomous green ships: The already developed DTs will carry knowledge of the green propulsion technologies so a further enhancement should be the elaboration of the autonomous features.
- Intelligent shipbuilding covering all aspects of ship's lifetime, such as design, production, management.

5.2 Expected outcomes of Living Labs

The expected outcome of all shipping companies, as already stated in the Proposal and Grant Agreement documents of the project, is to achieve reduction of CO_2 emissions, by developing and deploying real-time configurable DTs split into three different phases: for ship and fleet operational performance optimization (up to 20% CO_2 emissions reduction - 2026 horizon), for selecting/planning shipping decarbonization retrofitting solutions (55% CO_2 emissions reduction - 2030 horizon) and finally for zero emission new build planner (2050 horizon). In fact, the living labs would like to achieve the optimum performance combined with the best retrofits selections - or best design in case of new buildings - in order to reduce the fuel oil consumption and energy requirements on board the vessel and therefore minimize the produced CO_2 emissions.

5.3 Data Sources for the Digital Twins

The Digital Twins either relying of the Living Labs Vessels or on the different artificial operational environments the different operations simulations will be built based on various data sources. The major source will be the vessels but also some data from the office IT infrastructure will be needed, as well as external data from internet services. Below, there is a brief presentation of the data requirements for this project, split into five different types.

i. General information, drawings (e.g., Sea Trials Report, M/E and DGs Shop Tests and NOx Technical Files, etc.) particulars and the like required to "define" the DT
ii. Data from office core systems that will facilitate the creation of the vessel digital schema, for example a tree structure describing vessel assets/machinery. Possible sources of such information may be the ERP system used for spare parts requisition/handling.
iii. Available past data to be used as basis for model development and evaluation. High-frequency past data will be used for data-driven models training.
iv. Real time data to be used to feed the DT model inputs and display as Digital Shadow
v. External data from the internet, especially weather data.

In the below figure the most important parameters required are listed.

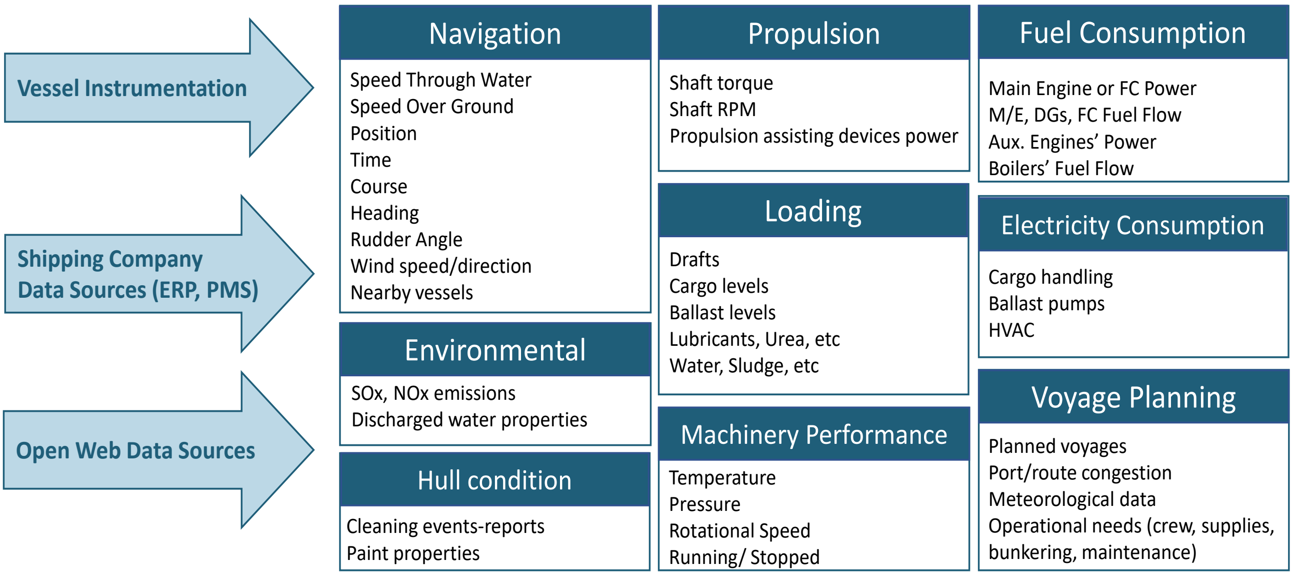

Figure 19 Data required for the formulation of digital twin

6 Value Proposition Mapping

6.3 User and stakeholder mapping - methodology

The chapter presents a value proposition mapping with regards to the WP1.1. objectives. The value proposition mapping process is as follows:

- **Identify all enablers and challenges with regards to value-oriented analysis and provide metrics to monitor their performance during DT4GS project**

  Regulations, green finance, shipping technologies and resources like fuels, energy saving devices and digital equipment, do perform in a certain way and are designed to serve the industry's scope. The objective of this step is to develop specific monitoring KPIs for each different lever which would serve as an input-output in the digital twin simulation process.

- **Formulate relevant performance tracking KPIs from LLs and propose correspondence matrix with data-converted enablers/challenges**

  Present key performance tracking KPIs which will be used to monitor the outcome of Use cases/Operational scenarios from a purpose driven point of view. For instance, we will not refer to organizational KPIs which mirror the organizational excellence of each Use Case as this is part of WP1. However, we refer to the actual value added (e.g., carbon emissions saved) as the key performance tracking KPIs for the Use Cases.

- **Build a user segment matrix and associated KPIs with each different segment**

  At this stage, a user segment building block is described in order to understand the supply side of DT4GS and the (end) user levels; the latter are the ones who can be mostly benefited by the DT model.

- **Build end-user-oriented value proposition matrices (products/services vs. Gains vs. Pains)**

  A model which decomposes the LLs into different product proposition will be created and for each value-added product / service proposition, the pains and gains will be identified for the end user. The pains and gains are combinations of weaknesses/threats and strengths/opportunities respectively.

6.4 Value Proposition Tracking of DT4GS ecosystem

The beauty of a digital twin model is that not only does it incorporate an array of vessel, performance, and other operational data but it can also process other type of data with a direct or indirect impact on a Use Case. Such data regard enabling factors or decelerators of shipping decarbonisation which are then converted in quantifiable components that can be read by a specific algorithm. Below (Figure 20) is a summary of key enabling factors, challenges and governance models that characterize the shipping transition:

	Transition Component	Example	KPI1	KPI2	KPI3	KPI4	KPI5
Enablers	Technical regulation	EEXI/CII	GHG	CO2	AER	EEOI	
	Voluntary market forces		GHG	CO2	% fleet utilization	NB price	second-hand price EUR
	Digitalization		GHG	CO2	bunker consumption		
	Energy efficiency		GHG	CO2	AER	CAPEX	OPEX
	Low/Zero-emission Fuels		GHG	CO2	AER	TCO	
Headwinds	Lack of regulation	Carbon tax	EUR/CO2	EUR/GHG			
	Production and availability of alternative fuels		Tonnes	EUR/tonne			
	Sunk costs		EUR	Yrs			
	Lack of trusted data		% error				
Sustainable Financing		EU Taxonomy	Turnover	OPEX	CAPEX		

Figure 20 Transition challenges and enablers in quantifiable format (KPIs)

The components in the figure above represent the challenges and enabling factors that have a direct or indirect impact on the ship design and operations. The work is directional, and the list is non-exhaustive, and one can develop more granular KPI assumptions. The KPIs above serve as input and / or output and once quantified can be used in DT model services.

- The effectiveness of technical regulations is assessed against compliance under specific carbon criteria either in terms of carbon emissions or carbon intensity. Annual Efficiency Ratio (AER) is an indicator developed in the course of Poseidon Principles as an effort to better understand the actual carbon intensity of voyages. It combines fuel consumption and emission factors divided by the summer deadweight capacity (DTW) x (ballast + laden) distance covered. EEOI is a similar indicator only taking into account the actual cargo load instead of vessel capacity.
- The decarbonisation speed is dedicated by market dynamics such as fleet utilisation, supply and demand factors, newbuild prices and second-hand prices next to the emissions performance. The former is related to the materials prices (e.g., iron), the available slot at shipyards for retrofits or NBs construction, etc.
- Digitalization in principle assumes on board sensors connectivity which provide several data; one of that key data is fuel consumption, which is then translated into voyage emissions.
- Energy efficiency, on the other side, does rely most on CAPEX and OPEX of energy-saving devices or relevant technologies who might have longer payback periods. Fuel consumption reduction is the overarching target which will drive investability. GHG but also exclusively CO_2 emissions are always key and secondary KPIs at the same time.

- Low or zero-emission fuels are still in early stage; however, many shipping companies are examining the TCO (total cost of ownership) which combines different perspectives (fuel price, retrofit CAPEX, extra OPEX for training etc, carbon pricing, etc). Therefore, it is a complicated exercise which will impact GHG emissions, carbon intensity (AER) and a holistic total cost of ownership.
- With regards to headwinds, a) lack of regulations such as carbon tax – monetizing externalities putting a price tag on a tonne of CO2 or GHG, b) production of availability for alternative fuel types which is translated into volume availability interpreted into fuel cost/price, c) sunk costs, which refers to investments already made and cannot be recovered like NBs running on fuels that will dominate the industry for next 20 years and finally d) understanding the quality potential of data and their error constraints.

The main Value Indicators related to the three phases of the project are as per Table 3 :

Table 3 DT4GS for ship/fleet performance optimisation

Optimisation areas	**Navigation Management**	**Integrated Machinery performance management and remote control**	**Integrated ship energy production, distribution, recovery and management**	**Digital Twin for Ship Hull and loading**	**JIT arrivals**	**Life Cycle Assessment Management**
Efficiency improvement	3-8%	3-8%	5-15%	3-10%	3-10%	3-10%
Average CO2e Reduction	5%	5%	10%	5%	5%	5%

Source: DT4GS Grant Agreement

There are two different KPIs that will be used to measure the performance of the possible different use cases: energy efficiency improvement (=MWh/year or MWh) and GHG (= CO2e reduction).

Table 4 Decision-Support System planning, design and simulation of ships for retrofitting green shipping technologies

Technologies to be monitored	**Decarbonised fuels: H2, NH3, methanol**	**Fuel Cells [PEMFC, MCFC and SOFC]**	**Energy storage [Battery, supercapacitors]**	**Integration (PV) system into a ship power grid**	**Wind-assist system Flettner Rotor**
KPIs	Efficiency	power capacity	power capacity	Capacity	Capacity
	Cost	lifetime of the FC stack	size	Lifetime	safety
	Emissions	carbon absorption	costs	Costs	Costs
		costs	lifetime		

Source: DT4GS Grant Agreement

On a more technical angle, different use cases entail different technologies to be simulated under a DT model. In that regard, Table 4 presents several KPIs per different low-carbon technology:

- Fuels – energy efficiency (MWh), cost (EUR) and emissions (CO_2e)
- Fuel cells – power capacity (MW), life-time of fuel cell stack (years), carbon capture potential (%) and cost (EUR) of implementation
- Energy storage – power capacity (MW), size (m^3 or m^2), costs (EUR) and lifetime (years)
- Integration of PV system into ship's power grid – capacity (MW), lifetime (years) and costs (EUR)
- WASP – Flettner rotor – capacity (MW), safety (fatal incidents/Lost Time Injuries/LTI frequency rate/ Total Recordable Cases/TRC frequency rate/people-hours), costs (EUR)

A user community around the DT4GS outputs is presented which will drive usage across as many customer segments as possible. The user community consists of the supply side, which is expected to build and provide DT solutions such as consultancies, DT integration, DT services, Open Libraries and other decarbonisation related directional guidance using the DT tools. End users – on their side – will leverage on the material expertise using the solution to tackle their ambitions.

For instance, **regulatory authorities** will benefit from the use of DT model outputs by understanding ship design and ship operational parameters, transition potential, cost structures, technical and technological perspectives of vessels (fuel containment systems, pipelines, cargo tanks, engine specifications) which would lead to the development of safety policies and procedures together with new training skills. The regulation pathways could tie with the KPIs identified in Table 3 . Which will enable authorities to map their regulatory performance and compliance by the industry. In, more or less, same path, **classification societies** are interested in working with industry and regulators in order to devise technological standards around ship design, support regulation development and the design and implementation of technical solutions, improving methods for new vessel design, manufacturing and operation incorporating non-polluting systems and autonomous technologies covering all aspects of asset lifecycle and integration with smart green supply chains. DT model is a brilliant tool to inform their expertise regarding ship design (hull, engines, cargo tanks, ballast water treatment systems, etc.).

On the academic side, DT further fuels the research and development efforts on ship design science, advancing research, refreshing knowledge and helping that sector to thrive and offer back to society and industry as well. Also, the DT4GS Decarbonisation knowledge Hub should provide a trusted observatory of key decarbonisation solutions which is another value drop for **universities and researchers**. **Shipowners and ship operators** achieving, in the short term, full ship operational efficiency optimisations and producing improved evidence-based new digitized SEEMP (Ship Energy Efficiency Management Plans). Also, ship owners, managers and operators may capitalise on the DT potential to increase ship efficiencies to constantly reduce CO_2e, and to support sound investment decisions - retrofit/newbuilds - in the longer term. **Port authorities** can be benefited by enjoy Virtual Testbed and Decision Support System, creating a collective capability of the waterborne industry to harmonise efforts and increase synergies between DT applications. Finally, ship operators and ship crew can reap the benefits of a next-generation user led solution for total ship operational optimisation based on DT technology capable of adaptation according to ship type and increasing ship automation, thus delivering superior cost effectiveness.

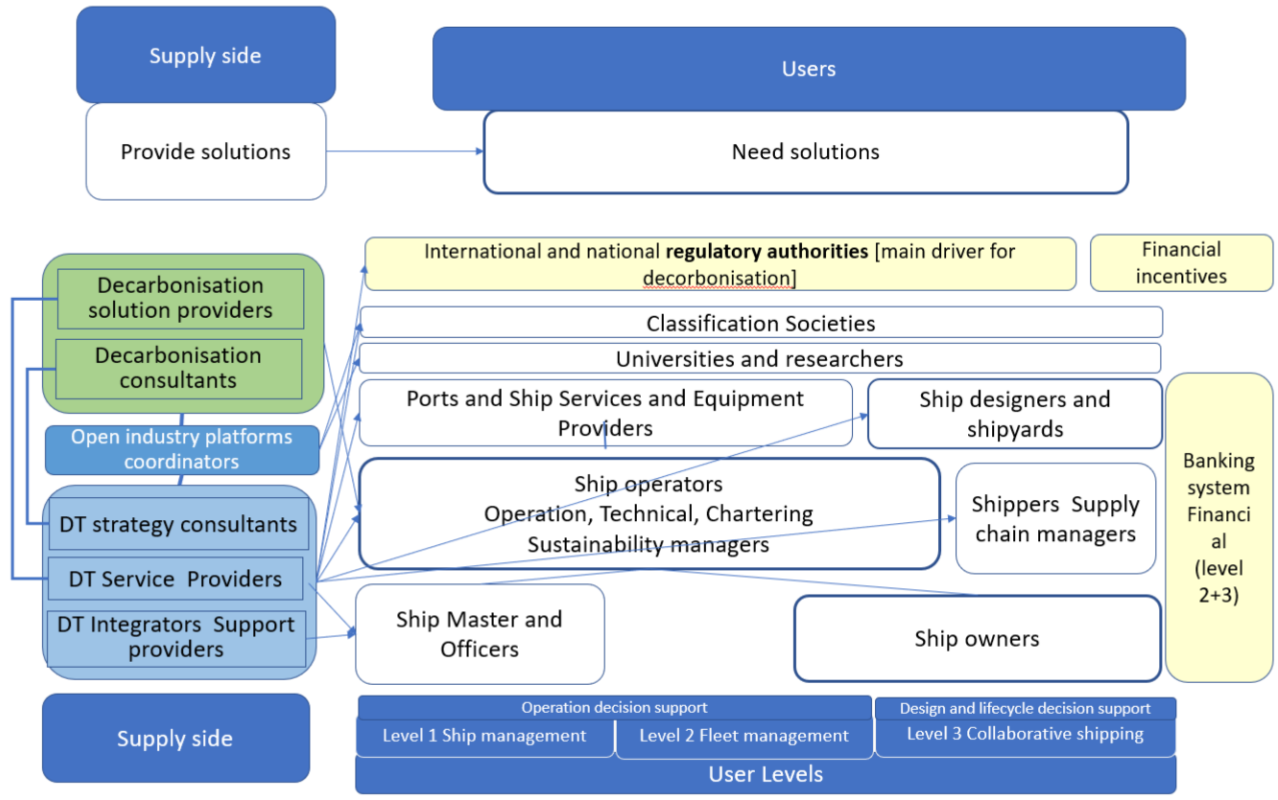

Figure 21 Market overview – DT stakeholders

Source: DT4GS Grant Agreement

Living Labs are integral DT4GS building blocks as they will be organized and performed to enable demonstration and testing of the DT model into various operational environments on totally different equipment, tankers, bulkers and container vessels. The main goal is to maximise sustainable adoption of the DT4GS energy efficiency innovations across the fleets of the participating ship owners. DT4GS is designed as an innovation ecosystem, for the systematic exploration, experimentation and evaluation of innovative ideas, scenarios, concepts and related technological artefacts in real life use cases and a real-world shipping DT deployment at sufficient scale to demonstrate implementation. This way convincing exemplars of actual DTs working and producing measurable benefits will be established early in the project and will be used to engage a growing number of users across all industry to incentivise use beyond the project lifetime.

In order to tap into the full potential of each Living Lab, we are going to use the Value Proposition Canvas (VPC), an innovative model to identify and emphasize on the value proposition of a specific service or solution or product to its tailored end-users, and not general users or public audience. The particularity of VPC is that it breaks down each product or solution into specific jobs undertaken by a specific interested party which has gains and pains impacting the end-user. Our analysis is LL-centralized: we identify the end user which is expected to be mostly benefited by the application of DT models and services through LLs (chapter 4) and we will map their value proposition adopting their interests and point of views.

VPC is a mapping tool which – as mentioned – provides an X-ray to the product / solution based on who is providing the solution, what additional value and benefits that solution brings to specific end-users and what discrepancies is that solution tackling. In parallel, the end-users carry out specific tasks which emerge specific gains and pains that are addressed by the product offered by the solution provider.

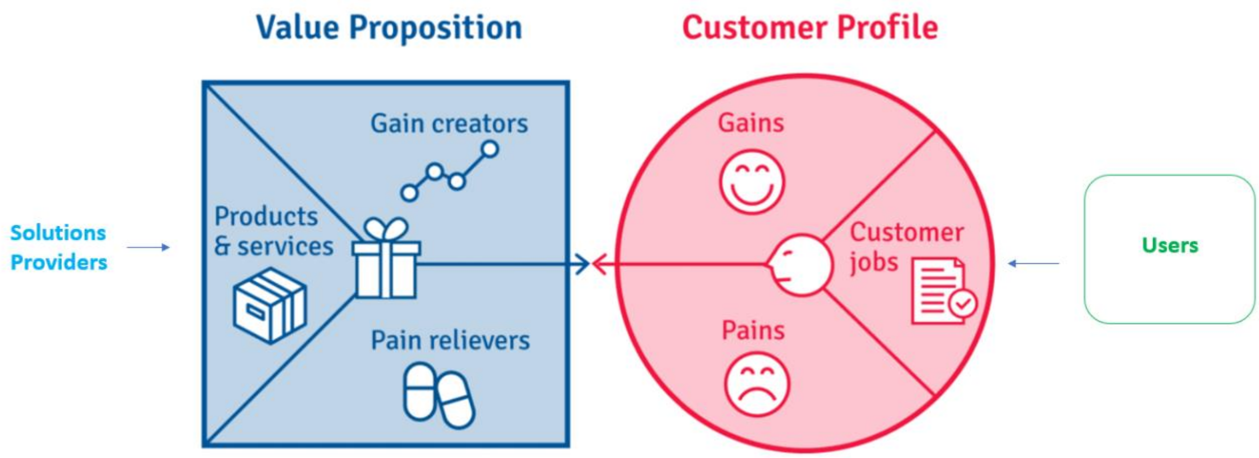

Figure 22 Value Proposition Canvas

The following tables present the results of the value analysis for each Living Lab.

Table 5 Tanker Living Lab Value Analysis

Jobs (= essential tasks to be done – related to theme)	Pains	Gains
Voyage optimization;	• Sub-optimal routing – increased fuel consumption • Less visibility on weather conditions; less predictability • Disrupted supply; not streamlined service • Data acquisition challenges	• Minimum consumption route, leading to the minimum CO2 emissions route • Fastest route • Best Time Charter Equivalent (TCE) route
Event recognition – predictive maintenance – Hull degradation	• Low predictability on hull degradation; lack of monitoring capacity • More expensive hull cleaning • Higher bunker consumption	• On-time hull cleaning decision making • Optimal hull maintenance process with lower costs • Better compliance with CP contracts

Table 6 Container Living Lab value analysis

Jobs (= essential tasks to be done – related to theme)	Pains	Gains
Voyage optimization;	• Multiple opportunities still untapped • Data acquisition; complexity	• Enabling control sensing and vessel actuation • Improvements on fuel consumption

Event Recognition for predictive maintenance and safety	• Crew safety level undermined • Window for cargo loss mitigation • Data quality	• Exploitation of different technologies (IoT, AI, other DANAOS technologies) to increase data validity • Better safety monitoring for people and containers • Better event recognition and analytics • Better data synchronization

Table 7 ROPAX Living Lab value analysis

Jobs (= essential tasks to be done – related to theme)	Pains	Gains
Voyage optimization; Trim optimization	• Data collection from third party (weather data) • Lack of data visualization	• Fuel consumption optimization • Informed decision-making on board • Better CII monitoring and optimization
Event Recognition for Predictive Maintenance: Event Recognition for Hull Degradation and Predictive & Preventive Maintenance	• Lack of user-friendly tool • Need to solid historical data	• Optimization of under-water cleaning • Improving fuel consumption • Detect systems failure in timely manner

Table 8 Bulk Living Lab Value Analysis

Jobs (= essential tasks to be done – related to theme)	Pains	Gains
Event Recognition for Predictive Maintenance Monitor & Measure sea growths development in underwater body	Accumulation of sea growth leading to: • significant drop in vessel's performance • reduce vessel speed, • Increase in vessel fuel consumption and emissions • Increase the accrual of cleaning costs	• Better monitoring and visualisation of sea growth • Cleanliness of cargo holds optimized
Cleanliness optimization of cargo holds	• Potential delays, • off-hire and charter party disputes • cargo contamination and infestation • cargo damage claims from cargo receivers.	• Recognition and analysis of the dirtiness status • Continuous monitoring throw-out the process • Continuous calibration • Reduces the number of staff members involved in cleaning operations • lower cost

6.5 Reference Guidance for DT4GS market

As described before, a DT4GS ecosystems is composed of:

- The DT solution providers which are responsible for the development of digital twin solutions and services as a mean to accelerate green shipping performance;
- The DT potential (end) users which are the ones leveraging the solution elements to create additional value on their service provision and/or performance
- The products or services developed by the solution providers which unlock operational solutions for potential users; such products might include data pools, shipping optimization tools, deployment support services, decarbonisation solutions and more;
- The value drops which are reflected mainly by the positive impact of gains generated by the users' tasks, as analyzed in the previous chapter; such value-added concerns measurable impact of the execution of DT solutions or products that could be mobilized by end users to deliver large scale impact on the broader shipping community

For example, there are several use cases in the course of LLs that use some of the DT services developed by the project providers. The use cases are operational models executed primarily by the end users and they unlock untapped value which serves the end users expectations or requirements. Below, the matrix summarizes the solutions and services to be generated in the DT4GS ecosystem, the direct stakeholders (solution providers and end users) and the expected value-added for the end users. The below landscape serves as synthesis of the previous analysis carried out in that chapter mapping out demand-side stakeholders and market segments, supply side stakeholders, and pains and gains of LLs use cases.

Table 9 DT4GS solution elements and value-oriented mapping

SOLUTIONS/ PRODUCTS	PROVIDER	END USERS	EXPECTED VALUE
Open Digital Twin [DT4GS] Infrastructure	KNT	• DT Service & Integration Support providers • Open Industry platforms managers • Solution providers for decarbonisation	• Informed decision-making • Standardization • Time savings during DT developments • Green shipping learning services (transferability) • Cross-community collaboration
Modelling, Analysis, Simulation, and Optimisation Tools	KNT	• DT Service & Integration Support providers • Open Industry platforms managers • Solution providers for decarbonisation • Academia and Research institutes • Classification societies • Shipyards	• Open simulation frameworks and configuration • Large-scale simulations of onboard systems (e.g., energy management) • Ship performance control, optimization, adaptability and responsiveness • Vessel life-cycle simulation development (e.g., through Functional Mock-Up units)
DT4GS (Green Shipping) Dataspace	FINC	Ship operators (Operations, ship management, charterers)	• Alignment with International Data Spaces • Shipping and Ship IoT development

DT4GS Model Blueprints and Open Model Library	DAN TUD	All user groups	• Ship design and performance model consolidation • Facilitation of autonomous vessel design • Development of new modelling frameworks
Modelling and Benchmarking of Green Fuels	CEA	• Solution providers for decarbonisation • Academia and Research institutes • Classification societies • Ship owners • Ship operators	• CO_2, CII, GHG estimations and forecast • Testing of duel-fuel and/or fuel blends • Determination of energy recovery potential (vs. Engines vs. Fuels) • Energy storage studies
Edge modelling and control models	IBM	• Ship owners • Ship operators • Masters and officers	• Ship performance automation with AI technologies • On-board infrastructure to facilitate on-board activities execution • Cloud based infrastructure
Green shipping collaboration models with port and supply chains	VAL VLTN	• Supply chain managers • Shippers and forwarders • Ports and relevant services	• Models for Just In Time or virtual arrival; port call process optimization and readiness • Green energy supply at ports
Fleet & company specific DT configuration	DAN	Ship operators (Operations, ship management, charterers)	• Data collection, cloud-type infrastructure services provision • Support integration of DT4GS Infrastructure services
Green shipping Operational Optimisation - DT Reference Application	DAN KNT	Ship operators (Operations, ship management, charterers)	• Reference guidance for LL testing • Continuous deployment solutions (automation, etc.)
Intelligent Decarbonisation solutions	FINC KNT CEA	• Ship owners • Ship operators • Classification societies • Shipyards	• Knowledge hub • Reference guidance for LL testing

7 Conclusions

This report contains a value-oriented analysis of digital twin-based ship decarbonisation. This work realises the first project objective, namely to guide the specification of high-level requirements for the project's research and development activities including

a) Relevant scenarios and strategic case studies;

b) policy /regulatory issues;

c) alignment of industry stakeholders with key GHG reduction strategies and solutions;

d) key transitioning challenges and enabling factors, and policy and standardisation roadmaps.

The main conclusions drawn from this report are as follows:

- The decarbonisation of the shipping industry is a multifaceted issue that involves policy, business, financial and technological domains and their interplays.
- Decarbonisation will require synergetic actions across the industry's stakeholders
- Decarbonisation technologies are mainly at the emergent phase, meaning that they need to be further analysed and understood in real settings and contexts
- The digital twin approach allows experimentation with decarbonisation technologies and with understanding their actual potential, in a more flexible and lower cost manner compared with conventional approaches.
- Additionally, digital twins can serve for raising awareness about decarbonisation issues, best practices and emerging solutions, amongst the industry stakeholders.

Regarding the DT4GS Project this report has established the framework (policy, business and technology) upon which research and development will be conducted. In particular, the report has identified digital twin related decarbonisation strategies that will be pursued by the Project's Living Labs.

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Annex I – Living Labs Phase 1 Use Cases and Scenarios

Annex I contains the detailed description of the use cases and scenarios of the Project's living labs.

Living Lab I – Tanker Centric Digital Twin (EURONAV)

- Voyage Optimization (Global Use Case) – Multi-objective approach

According to tanker centric living lab the voyage optimization use case should be a multi-objective approach, not concluding to just one potential routing but different ones according to different criteria taken into account. An idea of the application to perform the aforementioned could be to have the following structure:

- Input: The input should include the basic voyage information, i.e. the route characteristics, such as the departure, destination & via points and estimated time of arrival (ETA) to the destination. Also, some other parameters could be filled by the user, but considered as optional, in order to optimize the output of the model and reflect reality. These voyage parameters could be the draft, charter party speed, maximum fuel oil consumption due to bad weather, fuel oil type used and its price. Regarding the maximum fuel oil consumption due to bad weather it could be set in case of severe weather conditions as a restriction in order not to optimize the voyage duration at the expense of fuel oil consumption. Of course, the current and immediate future weather data should be used as automated input, without the need of user to set them manually.
- Process: The Voyage Optimization Digital Twin, consisting of models, algorithms or any other computational method that would be considered appropriate for extracting the most valid results. The above model will be trained by the vessel's high frequency data and external meteorological & oceanographic data in order to simulate vessel's operation and extract the results explained in the below section.
- Output: The result of the Voyage Optimization model should be multidimensional, meaning that the a multi-objective approach should be followed as aforementioned in order to define different potential routes. These different but still optimal routes could be the following:
    - Minimum consumption route, leading to the minimum CO_2 emissions route
    - Fastest route
    - Best Time Charter Equivalent (TCE) route

Regarding the third route, it should be taken into account that it is a more holistic approach, considering not only that specific passage, but the overall voyage execution. The TCE is a measure used to calculate the average daily revenue performance of a vessel. To be more specific, it is calculated by taking voyage revenues, subtracting voyage expense, including canal, bunker and port costs, and then dividing the total by the round-trip voyage duration in days. Since it includes costs that do not depend on the shipping company directly, additional inputs coming from the ports and other passages of the voyage will be required and might be difficult to be included at the early stage of the project. For this reason, a simplified TCE optimization (i.e. TCE maximization for the overall voyage) without going into the complexities could be approached at the beginning an then be further developed.

- Event Recognition for Predictive Maintenance: Event Recognition for Hull Degradation (Specific Use Case)

The event recognition for predictive maintenance in Euronav's case is concentrated to the Hull Degradation. In fact, the idea is to create an easy-to-use tool that could predict the hull and propeller fouling effectively and provide a decision on whether an underwater cleaning should be performed before or during a voyage in order to reduce to the greatest extent the fuel oil consumption and therefore the CO2 emissions. The idea behind the application/tool is to be based on the existing fouling of the vessel, the current speed & consumption relationship/tables and the "over"- consumption at different speed values. The latter could be measured using the ISO19030 method, which is a method for measuring changes in hull and propeller performance and calculating a set of basic performance indicators. In fact, the ISO 19030 series consists of three parts:

1. ISO 19030-1 outlines general principles for how to measure changes in hull and propeller performance and defines a set of performance indicators for hull and propeller maintenance, repair and retrofit activities.
2. ISO 19030-2 defines the default method for measuring changes in hull and propeller performance and for calculating the performance indicators. It also provides guidance on the expected accuracy of each performance indicator.
3. ISO 19030-3 outlines alternatives to the default method. Some will result in lower overall accuracy but increase applicability of the standard. Others may result in same or higher overall accuracy but include elements which are not yet broadly used in commercial shipping.

After having set the basis, which will be the core of the model, the input to the latter will be the next "potential" voyage of the vessel, including basic information such as the destination point, a via point, the charter party speed, the voyage duration and the fuel oil price per ton of the used fuel.

Finally, the output of the model will be a decision on hull and propeller cleaning before or during the next voyage, considering of course various operational parameters. Regarding the latter, it is worth mentioning that Euronav's vessels are cleaned mainly during Ballast mode so there will be no delay when cargo is transferred. Furthermore, when a vessel is under voyage charter the fuel costs are paid by the shipping company – owner and in case of ballast condition a laycan (laydays and cancelling date) has to be followed in order the vessel not to arrive too late and be rejected by the charterers. However, in case the vessel is cleaned before or during the ballast voyage she can increase her speed and therefore the fuel oil consumption in order to arrive in time, but then after loading she will have a profit – less fuel oil consumption – in laden condition. On the other hand, if the vessel is under time charter, she is hired for a specific period of time and the fuel costs, port charges, cargo handling costs, commissions and a daily hire fee are all paid by the charterer. In time charter contracts there is a typical speed and consumption warranty set by the owners who guarantee that the vessel will maintain during the whole currency of this charterparty under good weather conditions. In case of underperformance there can be a compensation to the charterparty so it would be better to clean the vessel and "lose" some time and money for this process rather than not reaching the guarantee values of speed and consumption. In conclusion, the aforementioned operational parameters together with the underwater inspection, hull cleaning and fuel costs should play a major role on defining the model's decision.

Living Lab II – Containership Centric Digital Twin (DANAOS)

- **Global Use Case: Voyage Optimization (optimize a route given a set of constraints)**

DANAOS specified vessel technical details (Deadweight, Displacement, Main Engine(M/E) Auxiliary Engine(A/E) type, Propeller type, NOx technical files, SFOC curves, etc.), provided shop trial reports and outlined the data acquisition system architecture (Figures: 6, 7) of a containership-centric Living Lab (LL). They also provided a snapshot of the actual data (features, granularity, format) acquired from the vessel that will be utilized as a testbed in the context of Phase1 of the LLs in order to employ a preliminary operational digital-shadow of the ship that will eventually enable control sensing and actuation on the vessel (Headquarters (HQ) – EDGE communication).

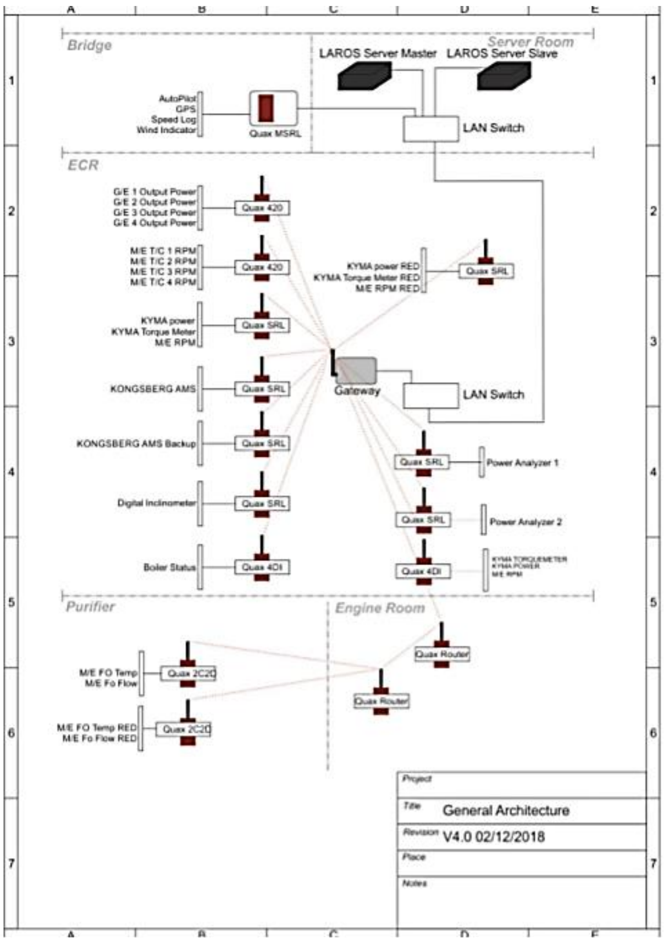


Figure 23 Sensor suite generic architecture

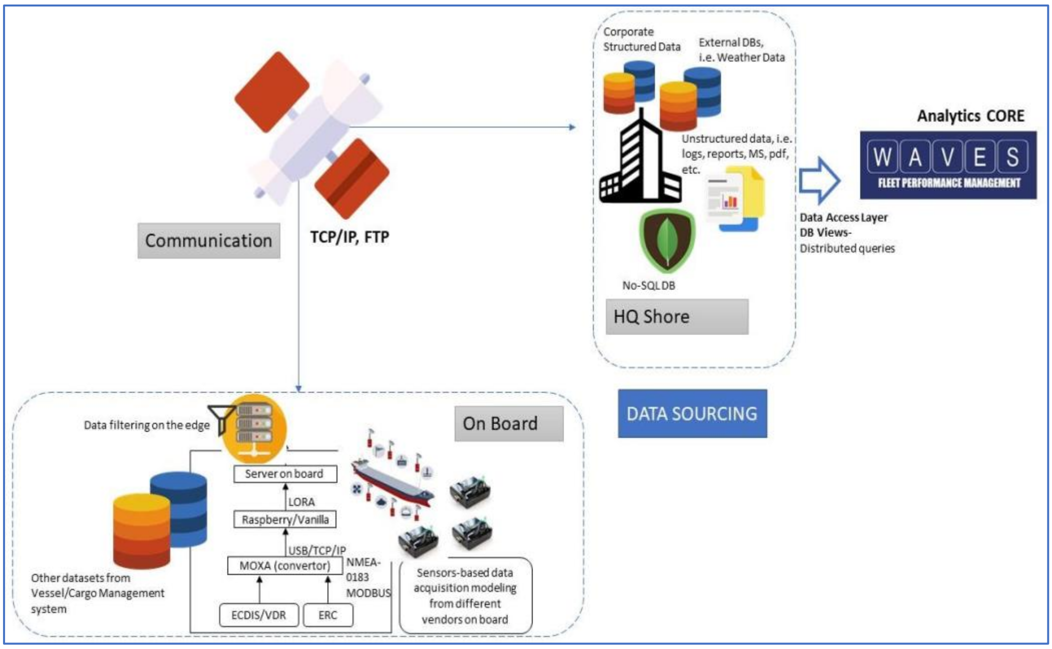


Figure 24 Data Acquisition System & Data Analytics Module (HQ-EDGE comm.)

With the participation of the other LL partners the global use case of Voyage Optimization was defined. More specifically DANAOS focus on the global use case of Navigational Management will revolve around the following pillars, entailing namely:

- Weather routing,
- Speed/Trim optimization,
- JIT arrivals,
- Bunkering Optimization
- Cargo Handling

Navigational management-optimization corresponds to Phase1 of operational optimization, enabling the transfer of Digital Twins (DTs) across the LLs.

- **Specific Use Case: Event Recognition for predictive maintenance and safety (identification of hull degradation/biofouling/corrosion, prevention-identification of parametric roll for cargo loss and crew safety)**

As a specific use case DANAOS proposed Event Recognition for predictive maintenance and safety (identification of hull degradation/biofouling/corrosion, prevention of parametric roll for cargo loss and crew safety).

With the utilization and exploitation of Internet of Things (IoT), Internet of Robotic Things (IoRT) and Artificial Intelligence (AI) advancements and technologies DANAOS aims to employ data driven models for predictive-preventive maintenance and event recognition purposes. The aforementioned concepts and use cases are inextricably linked and can be incorporated in the broader theoretical backbone of a Life Cycle Assessment (**LCA**) framework. LCA will facilitate in the transition to Phase3 of the LLs concerning either retrofitting solutions (ORC M/E, Applied Coating, PV instalments) for existing container-ships or new build assessment (*Financial assessment-projection of proposed solutions, OPEX-CAPEX, Net Present Value NPV, Investment Analysis, Environmental impact, Compliance with new regulations e.g. CII*) .

Furthermore, DANAOS demonstrated the existing data analytics toolkit (*WAVES*) as well as a prototype application for emission monitoring, event recognition, statistical/causal analysis and visualization (*ARTeMIS*) that will expedite the employment of the initial digital replica of the en-route vessel (core functionality demonstrated in Figures 8, 9) as well as the utilization and exploitation of simulation models developed in the context of DT4GS.

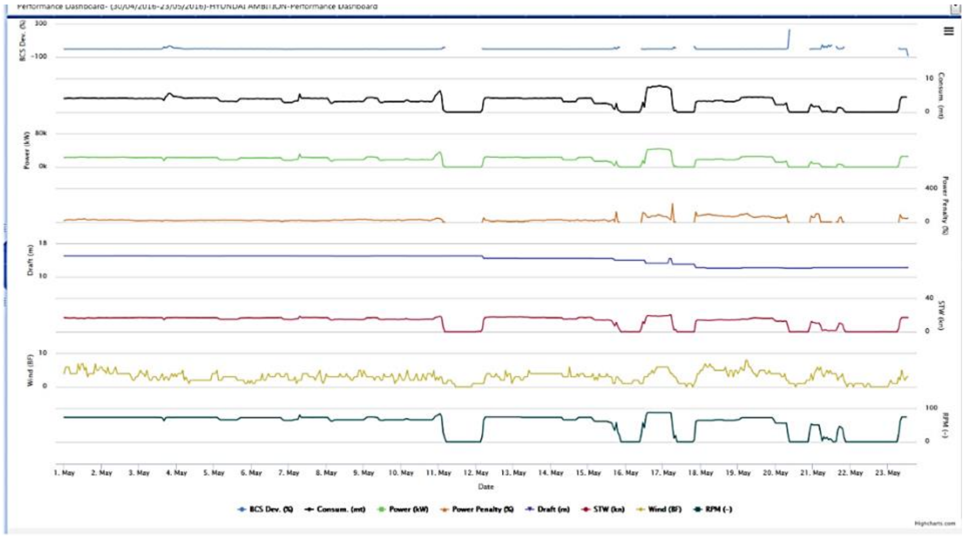


Figure 25 WAVES Vessel Performance Dashboard

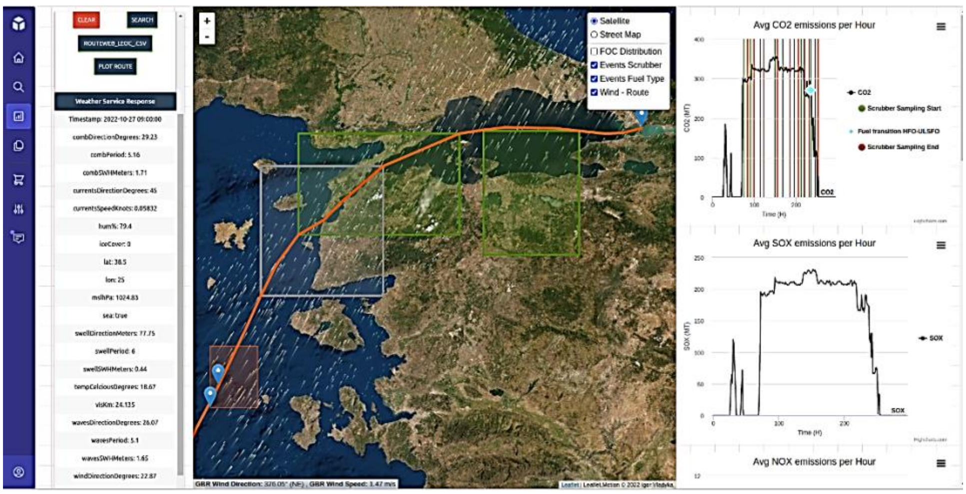


Figure 26 ARTeMIS main GUI

Finally, an office server was provided, that will synchronize with the newest operational data acquired from the vessel, incorporating a No-SQL database scheme for faster indexing. The provision of a centralized office server hosting operational data from the LLs is the first step towards the employment of an operational optimization cross-reference DT.

Living Lab III – RoPax Centric Digital Twin (BALEÀRIA)

- **Voyage optimization (incl. Route Planning, Weather routing, Speed optimization, JIT arrivals, Bunkering Optimization, etc) + Trim optimization (Global Use Case) – Multi-objective approach**

According to RO-PAX centric living lab the voyage optimization use case must be a multi-objective approach, not concluding to just one potential routing or operational optimization but different ones according to different criteria taken into account.

An idea of the application to perform the aforementioned could be to have the following structure:

- Input:
  The input should include all variables available, such as: Consumptions, ME's Power, Heading, Depth, Weather Conditions, SOG, Rudder Angle, Inclinometer, Drafts, Emissions, ETA, safety, overall cost, etc. Also, weather data must be obtained from a third party and integrated to the models. All inputs must be automated, without the need of user to set them manually.
- Process:
  The Voyage Optimization Digital Twin, consisting of models, algorithms or any other computational method that would be considered appropriate for extracting the most valid results. The above model will be trained by the vessel's high frequency data and external meteorological & oceanographic data in order to simulate vessel's operation and extract the results explained in the below section. This Voyage Optimization DT must include models, algorithms, etc for calculating: Route planning, Weather routing, Speed optimization, Consumption optimization, JIT (Just In Time information), Bunkering optimization (Cross info related to CII, EU ETS, Fuel EU, Fuel prices, etc.), Trim Optimization, etc.
- Output:

  The result of the Voyage Optimization model should be multidimensional, meaning that a multi-objective approach should be followed as aforementioned in order to define different potential routes, information and operational optimizations. These different but still operational optimizations could be the following (with weather conditions):
    - Minimum consumption route, leading to the minimum CO_2 emissions route.
    - Fastest route.
    - Route planning (consumption, time, etc) due to a fixed speed.
    - Route planning (speed, time, etc) due to a fixed consumption.
    - JIT: automated ETA update.
    - Dynamic Trim optimization.
    - CII of that trip and it's rating: A, B, C, D or E (and be able to calculate annual accumulate CII and rating).
    - Operational parameters (speed, ME's load, consumptions, etc) for Best CII.
    - Bunkering/Fuel optimization: Due to the possibility of using different fuels (HFO, VLSFO, MGO, LNG…), it should give you the before operational optimizations simulations comparing them to the use of different fuels, taking into account the economical part (fuel prices, EU ETS costs and FUEL EU sanctions). For this it will be necessary to have: Fuel prices (in each port and how it would take the bunker -truck, bunker vessel…-), EUA price (for EU ETS), etc.

As we understand, the models should compare historical data and new data generated (real time data) to create models, algorithms, etc, that may calculate the Voyage Optimization specified before in real time, before a departure and simulating future/past voyages; so Captains (and onshore people) can have an advice of this optimization, and can make decisions in real time, check past voyages and plan next voyages.

These models must be shown in a simple and visual tool, that gives Captains an easy decision tool. For this, it must have a color legend similar to traffic lights that warn of the performance of the optimization (red=bad, yellow=middle, green=good).

For example, for dynamic trim optimization, it must have something like this (ABB-OCTOPUS):

Figure 27 Dynamic Trim Optimization ABB-OCTOPUS

- **Event Recognition for Predictive Maintenance: Event Recognition for Hull Degradation and Predictive & Preventive Maintenance (Specific Use Case)**

The event recognition for predictive maintenance in BALEÀRIA's case is concentrated to the Hull Degradation and Predictive & preventive maintenance.

(a) Hull Degradation:

The idea is to create an easy-to-use tool that could predict the hull and propeller fouling effectively and provide a decision on whether an underwater cleaning should be performed in order to reduce to the greatest extent the fuel oil consumption and therefore the CO_2 emissions. The idea behind the application/tool is to be based on the existing fouling of the vessel, the current speed & consumption relationship/tables and the "over"- consumption at different speed values.

This model must advise when it is worthy to do the underwater cleaning if the vessel still operating in the same way as latest voyages, considering of course various operational parameters and advisory of the economic losses.

For this it will be necessary to have: Fuel prices (in each port and how it would take the bunker -truck, bunker vessel…-), and an estimation of drydock for cleaning hull costs.

As we understand, the models should compare historical data and new data generated (real time data) to create models, algorithms, etc, that may calculate the Hull degradation (overconsumption, decision maker tool, economic losses, etc).

(b) Predictive & preventive maintenance:

In this section, the idea is to create an easy-to-use tool that could detect which Systems and Equipment onboard are not working properly (high consumption, near to a failure, needed to do maintenance, needed to calibrate, etc.) in real time.

For this, it must be defined different KPI's and select for them high and low alarms, but also must be able to detect abnormal trends.

For example, if the models detect an abnormal increase in consumption of main engines, the tool should give an alarm of what is happening, even if it does not reach the high alarm.

As we understand, the models should compare historical data and new data generated (real time data) to create models, algorithms, etc, that may calculate the KPI's that detect that Systems and Equipment onboard are not working properly (high consumption, near to a failure, needed to do maintenance, etc.) in real time.

Living Lab IV – Bulker Centric Digital Twin (STAR BULK)

- **Monitor & Measure sea growths development in underwater body (Global Use Case)**

According to bulker centric living lab we have a strong interest to explore Hull Biofouling as a global use case supported by e – robotics for the hull inspection.

Sea Growth is a threat to the efficient performance of the vessels causing problems in their functioning. The accumulation of sea growth over time leads to inefficient sailing performance, through increased resistance, leading to higher fuel consumption and increased GHG emissions. Transport can be delayed if cleaning is not scheduled properly or PSC will maybe find a biosecurity issue. Either the biofouling or the methods of its removal can cause hull damage.

The increased drag from fouling will reduce the service speed when the engine uses the same power. Fouling increases both the quantity of fuel consumed, and the emissions produced, and a clean ship can sail faster, using less power and producing fewer emissions.

At the same time, global regulations regarding GHG and vessels' performance become stricter.

An anti-fouling system is the first line of defence against biofouling but minimizing establishment through ship cleaning is also essential.

In that case we aim to develop and field demonstration of rapid automated inspection for hull biofouling assessment. This will be achieved with the deployment of underwater robotics carrying image analysis algorithms for sea growth evaluation. Measuring and tracking biofouling levels can lead to an optimization of the hull cleaning schedule and maximize coating performance.

The robot will be used for underwater inspection in order to check the condition of AFS and the amount and position of biofouling accumulation on the hull and in niche areas.

Its capability will be:

- Mapping of the hull and navigation based on pre-defined path – pattern recognition.
- Quantification of Biofouling level
- Autonomous mapping and reporting of biofouling

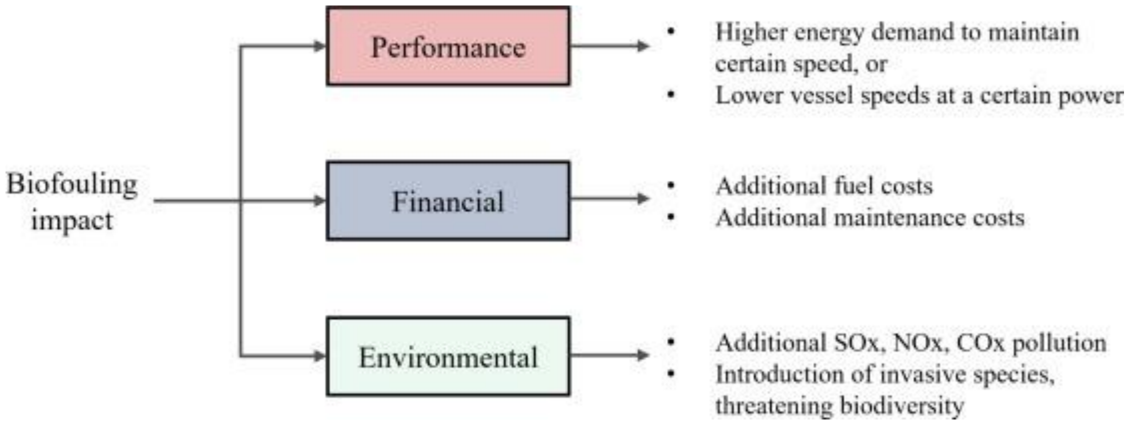


Figure 28 Biofouling impact to maritime ecosystem

- **Cargo Hull Optimization (Specific Use Case)**

Starbulk's specific use case is concentrated to cleanliness optimization of cargo holds.

After carriage of the bulk cargoes, cleaning is a necessary procedure for cargo holds and essential especially before the freighting of new cargo. Required careful planning and preparation to maintain cargo quality as is and to avoid any delays/ off-hires and charter party disputes which may arise as well.

Cargo contamination and infestation, leading to cargo damage claims from cargo receivers.

It becomes understood that a thorough cargo hold cleaning is vital for the whole transport operation to run smoothly. This is why personnel onboard and onshore, involved in cargo holds preparation should be familiar with the whole range of issues surrounding the cleaning of holds.

Up to now cleaning is a difficult and costly task, performed by crew which need equipment and hours.

We will use an innovative cleaning procedure which will has as a result to a fast, safe and accurate operation. It will be supported by robotic technologies and will have the following advantages:

- Recognition and analysis of the dirtiness status
- Continuous monitoring throw-out the process
- Continuous calibration
- Reduces the number of staff members involved in cleaning operations
- Lower cost

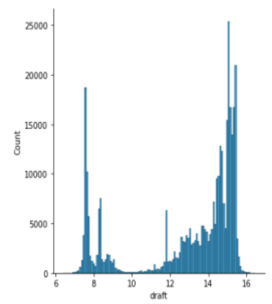
Annex II: LL Questionnaire & Use Case Summary

Living Lab I – Tanker Centric Digital Twin

Questionnaire fields for LL definition & Phase 1 "Generic" Use Cases		
Please fill in below constant values for the vessel you will consider as a Living Lab. In case you would like to include more than one vessel or extra information that you consider useful, please feel free to add fields and/or data.		
Input Data – Control variables	**Description**	**Measurement Unit**
Vessel Name	Alex	
Vessel Type	Tanker/VLCC	
Vessel Capacity (DWT, TU, etc.)	299,446	**tonnes (S.DWT)**
Vessel Age	6	**years**
Fuel Type for ME, AEs & Boilers	LFO/VLSFO & MGO	
Propeller type	Fixed pitch	**Fixed/Controllable Pitch**
Typical voyage/Route		
- Departure Port	South Africa	**Port Name(s)**
- Arrival Port	China	**Port Name(s)**
Average speed Ballast (indicative - charter party speed)	10	**knots**
Average speed Laden (indicative - charter party speed)	13.5	**knots**
Historic Data Availability	Yes	**Yes/No**
Period of Historic Data Availability	19 months for high frequency data	**months/years**
Last DD	19/02/2021	**Date**
Last Underwater Inspection	22/11/2021	**Date**
Last Hull Cleaning	19/02/2021 @ DD // Sea Chest Gratings, Propeller Blade, PBCF @ 22/11/2021	**Date**
Applied coating (e.g. premium coating, silicone) (Optional - for Hull Degradation)	Hempaguard X7 (both hull & propeller)	
Hull Surface Preparation (e.g. full blasting / spot blasting) (Optional - for Hull Degradation)	Boottop: Hydro Blasting 50% Vertical Sides: Hydro Blasting 100% Flat Bottom: Hydro Blasting 100%	

Use Cases - Phase 1 (As per proposal & WP4 monthly meeting 13/07/20202)		
Please fill in at least one (1) Use Case. In case you have more than four (4) Use Cases to propose please feel free to include them.	**Use Case 1**	**Use Case 2**
Use Case	***Voyage optimization (incl. Route Planning, Weather routing, Speed optimization, JIT arrivals, Bunkering Optimization)***	***Event recognition for predictive maintenance, safety etc. (underwater inspections, hull cleanings, etc.)***
Short Description **(e.g. how you define the use case, which purposes are served, a tool you would like to be included for a better vessel operation, any requirements/restrictions etc.)**	For the voyage optimization method, the following three elements are needed: Basic Voyage Information (departure, destination, sailing constraints, ETA, safety, etc.), Ship Performance (speed and consumption relationship, ship motions, etc.) and Weather data. The above three elements will be the inputs of the voyage optimization algorithms in order to provide the ship optimal routes regarding ETA, Minimum Fuel Consumption, Ship Safety (e.g. Master's point of view). For example, a model for choosing direction and power/speed according to weather forecast and currents could be used for achieving the minimum fuel consumption for a specific voyage with the constraint of JIT arrival. In addition, the voyage optimization should always take into account the compliance with the CII/POSPRI/other limits.	The condition of hull & propeller should be monitored according to the Speed & Consumption table outcomes in order to predict when and where an underwater inspection and/or cleaning should be done to preserve the optimal condition of hull&propeller. Also, the condition before and after hull cleaning should be compared in order to determine the hull cleaning effect on ship fuel oil consumption. The model could also provide a perspective on arranging the proper docking time by calculating the energy efficiency losses caused by hull and propeller fouling. Idea for a specific tool: According to the results of existing fouling and over-consumption a useful tool could be created as per below. The tool could take as input the data for the next voyage of the vessel (e.g. days, fuel oil price/tonne, etc.) and "decide" whether the vessel should have a hull cleaning or not, taking into consideration of course the off-hire for the underwater cleaning in comparison to the gain in fuel. In case a vessel is in laden condition the bottom and vertical sides cannot be cleaned due to the high draft and also the charterer should approve a cleaning of the boottop. On the other hand, when the vessel is in ballast condition the bottom and vertical sides can be cleaned. It is worth mentioning that the "over"-consumption should be evaluated from a basis/reference line. The latter could be according to ISO19030 the line right after the last DD. Finally, the ''over''-consumption could be also estimated depending on different speeds.
Input Data **(potential inputs you think suitable for the model)**	- Use of high frequency data - GPS Data: Longitude, Latitude, Heading, Slip, Speed Over Ground - Speed log data: Speed Through Water (Longitudinal), Longitudinal/Transverse Water Speed - Anemometer data: Relative Wind Direction, Wind Speed - Water Depth - Rudder Angle & ROT - Draft Aft & Fwd - Inclinometer X & Y (Pitch & Roll) - M/E RPM - M/E Shaft Power - M/E FO instant flow (?) - Engine/Shaft Power Limitation (EEXI Regulation) (If applicable) - CII/POSPRI Limits	- GPS Data: Longitude, Latitude, Heading, Slip, Speed Over Ground - Speed log data: Speed Through Water (Longitudinal), Longitudinal/Transverse Water Speed - M/E RPM - M/E Shaft Power - M/E FO Consumption per day - Last Underwater inspection & Outcomes - Last Hull/Propeller Cleaning - Speed & Consumption Tables to be constructed according to available data
Available Sensors **(choose from WP4 excel list which ones could be used)**	All the above potential input data are taken from available sensors on board except for the Engine/Shaft Power Limitation (EEXI Regulation) and the CII/POSPRI (etc.) limits that will be "constant" inputs-values in order to monitor compliance constantly.	All the above potential input data are taken from available sensors on board, except for the Underwater inspection outcomes, Last Hull/Propeller cleaning dates and Speed&Consumption tables according to the latest historical data (3-4 months).
Expected outcome	***CO2 emission reduction (t-CO2)***	***Energy Saved (%)***

Living Lab II – Containership Centric Digital Twin

Questionnaire fields for LL definition & Phase 1 "Generic" Use Cases		
Please fill in below constant values for the vessel you will consider as a Living Lab. In case you would like to include more than one vessel or extra information that you consider useful, please feel free to add fields and/or data.		
Input Data – Control variables	**Description**	**Measurement Unit**
Vessel Name	EXPRESS ATHENS	
Vessel Type	CONTAINERSHIP	
Vessel Capacity (DWT, TU, etc.)	14.022 m / 78243.0 mt	
Fuel Type for ME, AEs & Boilers	HSFO / LSMGO	
Propeller type	Nakashima Propeller Co. 1650 kW (2213 HP)	**Fixed/Controllable Pitch**
Typical voyage/Route		
- Departure Port	NHAVA SHEVA	**Port Name(s)**
- Arrival Port	MUNDRA	**Port Name(s)**
Average speed Ballast (indicative - charter party speed)	14	**knots**
Average speed Laden (indicative - charter party speed)	12	**knots**
Voyage Duration (ON AVG) - Operational profile (<u>% or days</u> Ballast, Laden, Idle, Loading, Discharging, Bunkering, Off-hire/Service)	NHAVA SHEVA - MUNDRA - 1 day, On AVG: 3 days  balast_days = len(data[(data['draft'] >= 6) & (data['draft'] <= 10)]) perc_balast = np.round((balast_days / len(data)) * 100) ladden_days = len(data[(data['draft'] >= 11)]) perc_ladden = np.round((ladden_days / len(data)) * 100) print("% OF BALAST DAYS ON A SIZE OF {} OBSERVATIONS (8 MONTHS): {} %\n" "% OF LADDEN DAYS ON A SIZE OF {} OBSERVATIONS (8 MONTHS): {} %".format(len(data), perc_balast, len(data),perc_l % OF BALAST DAYS ON A SIZE OF 352857 OBSERVATIONS (8 MONTHS): 21.0 % % OF LADDEN DAYS ON A SIZE OF 352857 OBSERVATIONS (8 MONTHS): 79.0 %	**% or days**
Historic Data Availability	Yes	**Yes/No**
Period of Historic Data Availability	from 2018 and onwards	**months/years**

Use Cases - Phase 1 (As per proposal & WP4 monthly meeting 13/07/20202)			
Please fill in at least one (1) Use Case. In case you have more than four (4) Use Cases to propose please feel free to include them.	**Use Case 1**	**Use Case 2**	
Use Case	***Voyage optimization (incl. Route Planning, Weather routing, Speed optimization, JIT arrivals, Bunkering Optimization)***	***Event recognition for predictive maintenance, safety etc. (underwater inspections, hull cleanings, etc.)***	
Short Description **(e.g. how you define the use case, which purposes are served, a tool you would like to be included for a better vessel operation, any requirements/restrictions etc.)**	Optimize a given route given a set of constraints (emissions, safety, overall cost, arrival time etc.)	Utilization of IoT, IoRT and AI advancements and technologies to employ data driven models for predictive maintenance event recognition purposes	
Input **Data** **(potential inputs you think suitable for the model)**	M/EFOConsumption TransverseGroundSpeed Draft Mid InclinometerYzc InclinometerXzc M/ERPM POWER + Weather data acquired from External Services (NOOA)	InclinometerXmax InclinometerXmin InclinometerXzc InclinometerYmax InclinometerYmin InclinometerYzc VesselHeading CommandedRudderLimit Latitude Longitude TrackDegreesMagnetic M/ERPM_AMS RudderAngle SpeedOverGround M/ETorque TrackDegreesTrue WindAngle WindSpeed CommandedRudderAngle CommandedOffHeadingLimit CommandedHeadingToSteer OrderedRudderAngle LongitudinalWaterSpeed TransverseWaterSpeed LongitudinalGroundSpeed TransverseGroundSpeed SternTransverseWaterSpeed SternTransverseGroundSpeed CurrentDirectionTrue CurrentSpeed HeadingTrue SpeedOverWater TotalTurnsQuaxLastReset ShopTestRPM LRMargin M/EPowerTheoretical M/EPowerPenalty MidDraftGages Pitching Rolling SL_SOG SpeedTheoretical	M/EFOTotalVolume M/EFOFlow G/EFOTotalVolume G/EFOFlow TotalRevolutLastReset RPM_Indicator M/EScavengeAirPressure M/E_T/C1ExhGasOutTemp M/E_T/C2ExhGasOutTemp M/E_T/C3ExhGasOutTemp T/C1LOOutTemp T/C2LOInPres T/C2LOOutTemp T/C3LOInPres T/C3LOOutTemp MainBRG&PCOOutTemp CrossheadBRGOilInTemp M/EThrustBRGTemp Cyl1-6ExhGasOutTemp Cyl2ExhGasOutTemp Cyl3ExhGasOutTemp Cyl4ExhGasOutTemp Cyl5ExhGasOutTemp Cyl6ExhGasOutTemp Cyl7ExhGasOutTemp Cyl8ExhGasOutTemp Cyl9ExhGasOutTemp Cyl10ExhGasOutTemp Cyl11ExhGasOutTemp Cyl12ExhGasOutTemp AlarmRegister M/EPowerMPS M/EFOTempViscosity G/EFOTempViscosity M/EPower STW Current M/ETorqueLEMAG M/ERPM DraftMid(S) DraftMid(P) AbsoluteRudderAngle

		Slip(STW) TrueWindSpeed TrueWindAngle TrueWindSpeedCorrected WaveEffect WindBF WindEffect SFOCNormal SFOCCutOut Density LCV C3 T/C3RPM T/C2RPM T/C1RPM G/EFOTemperature M/EFOTemperature DraftAft DraftFore	M/ERPMTheoretical SpeedTheoreticalInitial SlipInitial Dslip WeatherHumidity WeatherSigHeight WeatherSwellDirection WeatherSwellHeight WeatherSwellPeriod WeatherTemperature WeatherWaterTemperature WeatherWindDirection WeatherWindSpeed
Available Sensors (choose from WP4 excel list which ones could be used)	M/EFOConsumption TransverseGroundSpeed Draft Mid InclinometerYzc InclinometerXzc M/ERPM POWER	A broad range of available sensors will be used (see above list).	

Living Lab III – ROPAX Centric Digital Twin

These routes are an important segment of the EU shipping industry and have the added benefit of helping to raise awareness of the potential for green shipping in the general population since they provide passenger services. For example, decarbonizing the Baltic ferry routes could result in CO_2 emission savings of more than 600,000 tonnes annually[42]. The decarbonization of ferries may require a specialized type of CfD program compared to other shipping segments. In some respects, the decarbonization of regional ferries is an easier undertaking than for intercontinental cargo routes. The relatively shorter journeys taken by ferries mean a wider range of zero-emission technologies are available, while the higher margins and proximity to the end customer mean more costs can be passed through as green premiums. Despite these lower operational costs (OPEX), in switching to SZEFs, ferries are expected to face higher capital costs (CAPEX) as a proportion of total switching costs. Therefore, ferries may need a CfD program based on total cost of ownership rather than fuel costs alone.

Questionnaire fields for LL definition & Phase 1 "Generic" Use Cases		
Please fill in below constant values for the vessel you will consider as a Living Lab. In case you would like to include more than one vessel or extra information that you consider useful, please feel free to add fields and/or data.		
Input Data – Control variables	**Description**	**Measurement Unit**
Vessel Name	MARIE CURIE (MAC) or SICILIA (SIC)	
Vessel Type	RO-PAX	
Vessel Capacity (DWT, TU, etc.)	28.658 / 24.409	
Vessel Age	2019 / 2002	**years**
Fuel Type for ME, AEs & Boilers	ME = Dual Fuel (VLSFO/MGO/LNG) AE = MGO (MARIE CURIE has 1 AE Dual Fuel = VLSFO/MGO/LNG) Boiler = MGO	
Propeller type	CCP (Controllable Pitch Propeller)	**Fixed/Controllable Pitch**
Typical voyage/Route		
- Departure Port	MAC (Huelva) / SIC (Málaga)	**Port Name(s)**
- Arrival Port	MAC (Las Palmas) / SIC (Melilla)	**Port Name(s)**
- Via	MAC (Tenerife)	**Port Name(s)**
Historic Data Availability	Yes (need to check quality of data)	**Yes/No**
Period of Historic Data Availability	12 months?	**months/years**
Last DD	MAC (03/01/2021) / SIC (06/07/2020)	**Date**
Last Underwater Inspection	MAC (05/06/2022) / SIC (07/11/2021)	**Date**
Last Hull Cleaning	MAC (03/01/2021) / SIC (06/07/2020)	**Date**
Applied coating (e.g. premium coating, silicone) (Optional - for Hull Degradation)	MAC (Silicone: Sigma Ecofleet 530) / SIC (Silicone: Sigmaglide 1290)	
Hull Surface Preparation (e.g. full blasting / spot blasting) (Optional - for Hull Degradation)	MAC (¿?) / SIC (Touch up)	

Use Cases - Phase 1 (As per proposal & WP4 monthly meeting 13/07/20202)			
Please fill in at least one (1) Use Case. In case you have more than four (4) Use Cases to propose please feel free to include them.	**Use Case 1**	**Use Case 2**	**Use Case 3**
Use Case	***Trim optimization***	***Voyage optimization (incl. Route Planning, Weather routing, Speed optimization, JIT arrivals, Bunkering Optimization)***	***Event recognition for predictive maintenance, safety etc. (underwater inspections, hull cleanings, etc.)***
Short Description (e.g. how you define the use case, which purposes are served, a tool you would like to be included for a better vessel operation, any requirements/restrictions etc.)	For this Use Case, we need to have monitored the following data: Drafts, SOG, Consumptions, ME's power, Weather conditions, etc. We will need to compare historical data and new data generated (real time data) to create an Algorithm that may calculate the real time OPTIMAL TRIM taking into account the rest of real time variables. It will need a Tool to calculate Optimal Trim (Historical Voyages data) in every moment (real time), and compare it with the Actual Trim of the vessel (indication also with colors). It will be necessary to integrate to a Weather conditions data base (historic and real time), because onboard we only have an anemometer.	For this Use Case, we need to have monitored the following data: Consumptions, ME's Power, Heading, Depth, Weather Conditions, SOG, Rudder Angle, Inclinometer, Drafts, etc. The Voyage Optimization must include: Route planning Weather routing, Speed optimization, Consumption optimization, JIT, Bunkering optimization (Cross info related to CII, EU ETS, Fuel EU, Fuel prices), etc. We will need to compare historical data and new data generated (real time data) to create Algorithms that may calculate the Voyage Optimization specified before in real time, and before a departure, so Captains (and onshore people) can have an advice of this optimization, and can make decisions in real time, and plan next voyages. It will need a Tool to calculate Voyage Optimization in real time, and before a departure, and compare them with the Historical Voyages data. It will be necessary to integrate to a Weather conditions data base (historic and real time), because onboard we only have an anemometer.	For this Use Case, we need to have monitored the following data: Consumptions, ME's Power, Heading, Depth, Weather Conditions, SOG, Rudder Angle, Inclinometer, Drafts, Automation data, etc. (all data available) The Event recognition for predictive maintenance, safety etc. must include: Hull degradation, Predictive & preventive maintenance. We will need to compare historical data and new data generated (real time data) to create Algorithms that may calculate the Hull degradation, and KPI's that detect that Systems and Equipment onboard are not working properly (high consumption, near to a failure, needed to do maintenance, ...) in real time. It will need a Tool to calculate Hull degradation, Predictive & preventive maintenance,... in real time, and compare them with the Historical Voyages data. It will be necessary to integrate to a Weather conditions data base (historic and real time), because onboard we only have an anemometer.
Input Data (potential inputs you think suitable for the model)	Drafts, SOG, Consumptions, ME's power, Weather conditions, Trim, Inclinometer, …	Consumptions, ME's Power, Heading, Depth, Weather Conditions, SOG, Rudder Angle, Inclinometer, Drafts, …	Consumptions, ME's Power, Heading, Depth, Weather Conditions, SOG, Rudder Angle, Inclinometer, Drafts, Automation data, …
Available Sensors (choose from WP4 excel list which ones could be used)	• Draft - Port Bow, Starboard Bow & Starboard Aft • ME/AE/PF Flowmeters (Inlet/Outlet) - Consumption & Temperature • Torquemeter - RPM, Power & Torque • Wind - True Wind (° & kn) & Relative Wind (° & kn) • STW • GPS - SOG, UTC time, latitude, Longitude • Inclinometer - Heel, roll, pitch & yaw angle, surge, sway & heave acceleration • Trim (Calculation) • Weather conditions (Needed external data!)	• ME/AE/PF Flowmeters (Inlet/Outlet) - Consumption & Temperature • Torquemeter - RPM, Power & Torque • Heading • Depth • Wind - True Wind (° & kn) & Relative Wind (° & kn) • STW • GPS - SOG, UTC time, latitude, Longitude • Rudder Angle • Inclinometer - Heel, roll, pitch & yaw angle, surge, sway & heave acceleration • Draft - Port Bow, Starboard Bow & Starboard Aft • Trim (Calculation) • Weather conditions (Needed external data!)	• ME/AE/PF Flowmeters (Inlet/Outlet) - Consumption & Temperature • Torquemeter - RPM, Power & Torque • Heading • Depth • Wind - True Wind (° & kn) & Relative Wind (° & kn) • STW • GPS - SOG, UTC time, latitude, Longitude • Rudder Angle • Inclinometer - Heel, roll, pitch & yaw angle, surge, sway & heave acceleration • Draft - Port Bow, Starboard Bow & Starboard Aft • Trim (Calculation) • Automation Integration (miscellaneous data) • Weather conditions (Needed external data!) • ¿increase Automation data integration? • ¿Vibrational sensors?
Expected outcome	***Energy Saved (%)***	***Energy Saved (%)***	***Energy Saved (%)***
Indicative value of expected outcome (Optional)	***approx. 1-5***	***approx. 1-5***	***approx. 1-5***

Living Lab IV – Star Bulk Centric Digital Twin

Questionnaire fields for LL definition & Phase 1 "Generic" Use Cases		
Please fill in below constant values for the vessel you will consider as a Living Lab. In case you would like to include more than one vessel or extra information that you consider useful, please feel free to add fileds and/or data.		
Input Data – Control variables	**Description**	**Measurement Unit**
Vessel Name	STAR ELIZABETH/ MAHARAJ	
Vessel Type	STAR ELIZABETH: KAMSARMAX/MAHARAJ: NEWCASTLEMAX	
Vessel Capacity (DWT, TU, etc.)	STAR ELIZABETH: 82.403/ MAHARAJ: 209.472	**DWT(mt)**
Vessel Age	STAR ELIZABETH:1 / MAHARAJ: 7	**years**
Fuel Type for ME, AEs & Boilers	BOTH: HSFO	
Propeller type	BOTH: FIXED PITCH	**Fixed/Controllable Pitch**
Typical voyage/Route	BOTH: WORLDWIDE	
- Departure Port	PORT HEDLAND OR TUBARAO	**Port Name(s)**
- Arrival Port	SHANGHAI	**Port Name(s)**
Average speed Ballast (indicative - charter party speed)	BOTH: INDICATIVE: 11.0	**knots**
Average speed Laden (indicative - charter party speed)	BOTH: INDICATIVE: 10.5	**knots**
Last DD	Maharaj: 04Sep19	**Date**
Last Underwater Inspection	Maharaj: 27Feb22	**Date**
Last Hull Cleaning	Maharaj: 27Feb22	**Date**
Applied coating (e.g. premium coating, silicone) (Optional - for Hull Degradation)	BOTH: PREMIUM COATING	
Hull Surface Preparation (e.g. full blasting / spot blasting) (Optional - for Hull Degradation)	BOTH: SPOT BLASTING	

Use Cases - Phase 1 (As per proposal & WP4 monthly meeting 13/07/20202)	
Please fill in at least one (1) Use Case. In case you have more than four (4) Use Cases to propose please feel free to include them.	**Use Case 1**
Use Case	***Event recognition for predictive maintenance, safety etc. (underwater inspections, hull cleanings, etc.)***
Short Description **(e.g. how you define the use case, which purposes are served, a tool you would like to be included for a better vessel operation, any requirements/restrictions etc.)**	Voyage Optimization
Input Data **(potential inputs you think suitable for the model)**	Noon Report Data
Available Sensors **(choose from WP4 excel list which ones could be used)**	N/A
Expected outcome	Energy Saved (%) & Cons diff t/24h