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Green and Sustainable Maritime Shipping for Climate Change and Disaster Mitigation

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ABSTRACT

Climate change implications have various domains of effects, each with a varying degree of significance and onset. The intensifying pattern of extreme weather temperatures, hurricanes, flooding, drought, and forest fires has arisen credible concerns to the field of Disaster Management. As impacts continue to increase in severity and frequency, the level of upkeep is becoming more challenging and increasingly overwhelming. All prescribed natural events have a track record of thousands of years which renders the basis for highlighted contrasts to be pattern-based in a comparative analysis. It has been scientifically debated that emissions of Green House Gases (GHGs) contribute negatively to increasing atmospheric temperatures which corresponds to a diverse range of climate-induced impacts. These impacts are consequential towards equilibriums of natural eco systems as well as livelihoods in urban developments. By this token, measures to reduce emissions and capture of atmospheric GHGs could drag accelerating rates of climate change which subsequently leads to mitigation of natural disasters. A common pitfall to green and sustainable shifts is the cancellation effect due to technological limitations or unacknowledged factors. These unintended gaps can be exploited by the concept of Lifecycle Assessment which constitute holistic evaluation of entire value chains to ensure credible net outcomes of contemplated solutions. Herewith, the value of this crossover research is mutually constructive to all fields by way of symbiosis. Wherein, decarbonizing maritime shipping lie at a unique interposition between prescribed domains in a relationship that is further validated by the reversal of concept known as balancing loop complex. Currently, the maritime sector is championed by the International Maritime Organization which is targeting to achieve absolute-zero emission point by having irreducible emissions neutralized via natural, industrial, and/or socioeconomic solutions. Challenges to this outlook are manifested in advancement of technology; regulatory enablement; accessibility of business drivers and incentives. To this end, sustainable financing as a growing incentive combines three success elements predominantly known as Environmental, Social, and Governance (ESG). As such, a successful achievement of this interwoven scope has direct and indirect feeds to the overarching climate strategy sat forth by the United Nations. This strategy is categorized in 17 clusters referred to as Sustainable Development Goals (SDGs).

1. Introduction.

1.1. World view

This research stems from a pragmatic world view with a supplemental support by a post-positivism. The reasoning for the hybrid approach is that decarbonizing the maritime is largely a practical and technical-centered domain. However, in the universe of compliance, incentives and drivers as well as various climatic subsequences, there can be few issues of theoretical basis due to low maturity in applications and data collection. It also seems appropriate to use a post-positivism in the realms of social responsibility as well as socioeconomic developments as they pertain to SDGs.

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1.2. Background

In December 2010, Parties of United Nations Framework Convention on Climate Change (UNFCCC) recognized that global warming must not exceed the temperatures experienced before the industrial revolution by more than 2° C. This parameter is critical to maintain as exceeding it results in significant eco changes whose reversal is unforeseeable. As such, this long-term goal requires global GHG emissions to be reduced by at least 50% below 1990 levels by 2050 (EU Commission, 2013, p.7).

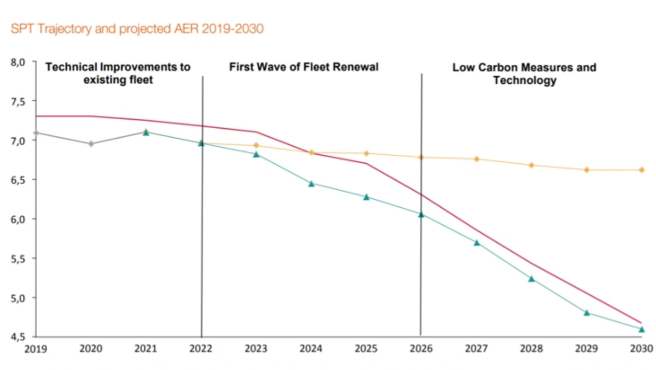
Post IMO's regulation to curb GHG emissions, rates have fluctuated within stable boundaries with ranges represented in the table below:

Emitted gas/ annual rate	2012	2014	2018
Carbon Dioxide (mt)	848	836	929
Nitro's Oxide (mt)	19.7	18.6	20.2
Sulphur oxide (mt)	10.8	10.1	11.4
Methane (kt)	59	76	148

Source: Author.

While the plateau in emissions may appear to discount efforts exerted in controlling emissions, the growth of voyage-based data has grown at a net rate of approximately 6% from 2012 to 2018. The reasoning of using voyage-based data as basis is to counterproof the reduction in number of vessels vs. amounts of emissions which could indicate an increase in emissions per vessel. According to prescribed, though shipping vessels have reduced in number they have grown in size and are being allocated more consistently.

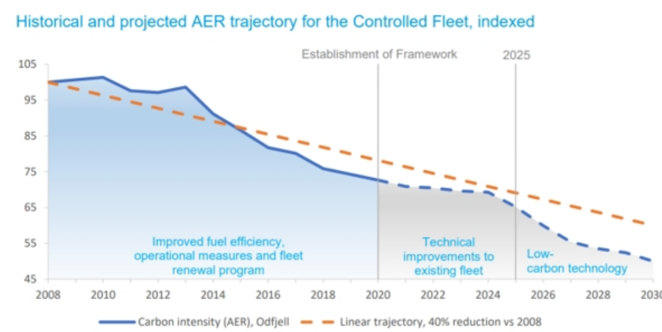
There are more GHG gases emitted from the shipping industries but the focus here is allocated towards most prominent GHGs as they impact climate change by measures of volume and potency. From a comparative analytical angle, methane is the sole gas that has seen a significant increase at more than twice the amount over the subject duration of 2012-2018. Methane is a very potent and dangerous GHG gas which warrants root-cause identification of this increase as will be explored later in this research (IMO, 2020).



Source: Hapag-Lloyd, 2021, p.10.

From a regulatory and benchmarking standpoint, the Average Efficiency Ratio (AER) and the Efficiency Operational Indicator (EEOI) are metrics that are used to gauge the efficiency factor. These metrics are further elaborated in Operational Efficiency and International Regulatory and Compliance sections. Below table illustrates historical standings of Odfjell which shows a gradual but progressive increase as time progresses.

As such, future projections will have similar basis with measurement tools such as EEOI and AER as well as others such as in larger and more inclusive schemes such as carbon accounting. Monitoring and disclosure of such data indirectly assist with IMO's goal achievement where scientific trajectories are compared to current standings across time and pre-set milestones. Therefore, below gap highlights grounds to be covered with considerations towards severity and delay as a measure posing an accumulative effect. Below table materializes IMO's carbon reduction benchmarks 40% by 2030 and 70% by 2050 in AER-based measurement.



Source: Odfjell, 2020, p.9.

1.3. Research opportunity.

1.3.1. Purpose Statement.

The context and intent of this paper is to support the global maritime green shift with an all-encompassing lens towards better alternatives. These initiations are aimed at restoring balance to various natural systems and thereby achieving an influx that reduces the negative impacts generated by the state of imbalance. By reducing emission, climate change will either plateau or start to revert to normalcy as theorized across multiple complexes. A plateau in the trajectory of extreme weather events is likely to reduce incurred consequences, transpiring as a meaningful approach to disaster mitigation. However, the journey towards the green shift is full of challenges which requires a set of guiding principles that can be listed as follows:

- Emission reduction potential
- Sustainability of energy sources
- Environmental safety
- Economic feasibility
- Reliability of technology

The overall purpose of this research, therefore, is to overlap these interrelated fields and conceal gaps via symbiosis resulting in a mutually strengthening relationship. In specific, the

Historic AER levels for the Controlled Fleet

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
AER	11,78	11,86	11,94	11,50	11,44	11,62	10,74	10,20	9,63	9,44	8,94	8,75

Source: Odfjell, 2020, p.8.

field of disaster management benefits from discoveries in climate change and can act as advocatory reinforcer to regulations concerning industrial practices from the perspective of population and infrastructural safety. Industries and businesses in return can benefits from understanding particular implications surrounding climate change and take steps that exceed measures of regulatory compliance.

1.3.2. Research Questions.

Question 1. What is the maturity ranking of alternative fuel pathways and how can current platforms be adjusted to accommodate their limitations?

Question 2. What hindrances are posed by the network of support domains subliminally responsible for overall pathway feasibility?

Question 3. What is the achievable level of greenhouse influx from contemplated alternatives and what are the inadvertent mid-term consequences resulting from this shift?

Question 4. What are the performance indicators that quantify decarbonization initiatives towards climate change and what is the optimum solution to achieving a state of carbon neutrality?

1.3.3. Research Methodology.

This research uses mixed methods where a quantitative approach will be largely dedicated for technical and operational domains of shipping vessels; while the qualitative approach will be predominantly dedicated for advancement of regulations, enablers, and future research. The purpose of this mixed method design is to anchor the topic to palpable metrics and parameters as they pertain to industrious settings, while maintaining a social and accountability approaches towards the cause. The use of mixed methods warrants a credible cross-over between remotely associable disciplines which transcends as the purpose of this research.

2. Literature Review.

2.1. Climate change.

According to NOAA (2020), the last decade (2011-2020) recorded the warmest global surface temperature of +0.82°C (+1.48°F) in comparison to the decade preceding it (2001–2010) that recorded +0.62°C (+1.12°F). These markers culminate into an average temperature increase at a rate of 0.08°C (0.14°F) per decade since 1880. As the industrial revolution continued its exponential expansion, the rate has doubled during the 1981 decade reaching to +0.18°C (+0.32°F) (para. 3-4).

Going on unchecked, contemporary trends and demand support a further increase which will accelerate climate changes and its consequential effects. This compels robust and innovative schemes of accountability and governance to support responsible and conscious growth of industries. Climate change is multifaceted encompassing many ecological disbalances, but the focus of this paper is oriented towards global warming and extreme weather events as effects of GHG emissions. Increase in earth temperature is the root cause to arising symptoms such as sea-level rise, water shortage, increased threat of forest fires, and drought. Efforts are ongoing to cap temperature increase to +2°C, largely empowered by the Paris Climate Agreement. However, Bates (2021), summarizes the predicament as

"... if global warming exceeds the target—2 degrees Celsius (3.6 degrees Fahrenheit)—the risk of ice shelves around the ice sheet's perimeter melting would increase significantly and their collapse would trigger rapid Antarctic melting. That would result in at least 0.07 inches of global average sea-level rise a year in 2060 and beyond" (para.2).

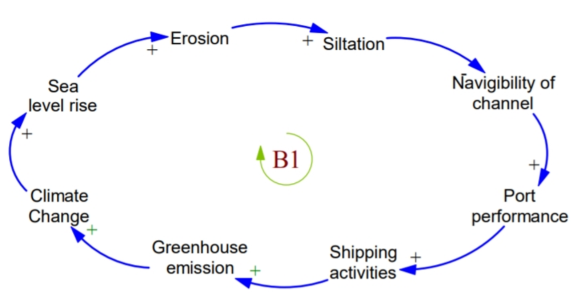
Additionally, ocean acidification is a phenomenon that is exacerbated by the amount of CO2 dissolution in oceans. Ocean acidification entails multiple adverse effect but most relevantly to GHGs, a large-scale CO2 dissolution challenges the survivability of oceanic ecosystems. Coral reefs, seaweed, and associated organisms contribute greatly to carbon sequestration and their extinction adversely impacts CO2's *lifetime in the atmosphere*. Kinsey and Hopley (2003), estimates the sequestration capacity of coral reefs to be 111 million tonnes a year (para.1). The impact of prolonged *lifetime in the atmosphere* is estimated at 4% to 9%; thus significantly upscaling CO2's Global Warming Potential (GWP).

GHGs contribute to global warming by absorbing the sun's energy and radiating a portion of it back to earth. In states of natural equilibrium, much of sun's energy would deflect back to space; however, these gases and particulates obstruct the pathway and retain a proportional amount of energy. The temperature of the earth, therefore, is largely dependent on a balance complex between incoming energy from the sun and corresponding deflection of sun energy towards space (Bird, 2005, para.1). There are about eight identified greenhouse gases, some of which are categorized based on functional similarities. According to U.S. Environmental Protection Agency (2020), the inventory conducted of greenhouse gases from data accumulated from 1990-2014 indicates there are 6,870 million metric tons of carbon dioxide equivalents. These make up of these gases are as follows: Carbon Dioxide (82%), Methane (10%), Nitrous Oxide (5%), Fluorinated Gases (3%). Aforementioned gases are produced from the following sectors along with their respective bearings: Electricity (30%), Transportation (26%), Industry (21%), Commercial and Residential (12%), Agriculture (9%). These suspended gases and particulates can be assumed as a backlog of waste awaiting recycling and processing. Such phenomenon warrants considerations of *lifetime in the atmosphere,* a measurement of the time required until assimilation. Carbon Dioxide being the lead influencer cannot be anointed a fixed lifetime value due to the complexity of responsible ecosystems in their various forms. The remaining gases have atmospheric lifetime as follows: Methane 12.4 years, Nitrous Oxide of 121 years, Fluorinated Gases range from few weeks to thousands of years (U.S. Environmental Protection Agency, 2020b).

This sets the ground for the inevitability of green technologies and initiatives as measures of sustaining livelihood as we know it. In supplementation, industrial carbon capture and storage technologies are being increasingly popularized to complement already-compromised natural ecosystems. The scope of this paper is focused on green technology for shipping vessels being the largest emission contributor amongst other types and classifications of vessels accounting for 80% of global trade by volume and 70% by value. Though Maritime shipping is responsible for less than 3% of the world's emissions, the trajectory of letting this industry unchecked is expected to grow by 50-250% by 2050. Thus, IMO has targeted emissions reductions at 40% by 2030 and 70% by 2050 (Climate Bonds Initiative, 2020). This lends green and sustainable technology as crucial measures of climate change actions as the industry trends towards exponential growth.

2.2. The balancing loop.

The term "balancing loop" refers to the circulatory perspective where the effects of emissions are linked directly to the impact on efficiency. As climate impacts have been linked to intensifying weather events, all measures of efficiency are jeopardized by rough seas and elongated voyages as a result of weather routing (sailing around storms). This should not negate the various green initiatives in decarbonizing shipping as too little too late; to the contrary, it further essentiates the drive while simultaneously mitigates the impact. Extreme weather events impact shipping activities in areas of safety, efficiency, and global economics. More on operational efficiency and weather routing in later sections. Below graph illustrates how GHGs contribute various factors that can impede on desired performance.



Source: Sarwar, 2006, p.26.

The maritime pertinence to natural disasters extends beyond issues of mere global warming. While many of these systems are diversely tied to one another in the grand ecosystem, a compartmentalization is warranted from a disaster management perspective. Some of the most relevant subsequent effects of global warming are sea level rise, erosion, and siltation. These effects indirectly impact the maritime transport through backwater effect which can be described as changes in tidal flow from the movements of ships (Alam 2003, p.13). Erosion is further compounded by increased water salinity by way of destroying mangrove plants in forest areas rendering soil to be loose and destabilized (Hossain, 2001). The deposition resulting from soil displaced by erosions is transferred to a different area, altering water depths and thereby impacting the navigability of water channels and pathways. In extreme cases this alteration translates as limitations in the number and sizes of passing ships through restricted channels (Sarwar, 2006, p.27).

On the economic front, the maritime shipping sector is not immune from impacts of natural disasters. The main correspondence affecting shipping is increased costs as result of incurred delays and increased insurance premiums. More weather-related delays ensue longer service time and higher risks and such inevitably drives the costs higher. Also, depending on the status of global trade, prolonged shipping times could decrease number of available allocations which raises costs via supply vs. demand pricing strategy. Parallelly, increase in insurance premiums is already taking effect due to the increased risks associated with deep-sea extreme weather events (Shipping and Freight Resource, 2020).

2.3. Sustainable sourcing and economic circularity

Acaroglu (2018), explains the utility of system thinking and a lifecycle approach as necessary means to sustain a regenerative ecosystem. The expedience that green and sustainable products provide in their tank-to-wake could be overshadowed by preceding processes collectively known as well-to-tank. Consistency in these two fundamental parts of the value chain is critical towards overall scoring and solution viability. Acaroglu continues to identify elements of the lifecycle as:

1. Extraction of material
2. Design and administration
3. Manufacturing
4. Packaging and transport
5. Use (operation)
6. End of life (disposal/recycling)

The Maritime industry relies heavily on steel and a combination of green manufacturing and eco-efficient products can be a framed bias if other lifecycle elements are not in equilibrium. Material sourcing makes up most of the upstream window of analysis. There are various entities that examine sustainable sourcing of materials and the World Steel Association champions this role for steel. World Steel Association (2012), approximates climate change impact to be 1.8 tons of Carbon Dioxide per metric ton of crude steel (p.4). The study averages inputs from 1900 to 2011 with a weighted focus towards the last decade 2000-2011 which shows the most significant growth in demand and production. Out of the total 1,518 tonnes of steel produced 4.8% is consumed by other transport which maritime shipping dominates. Steel production in 2020 has grown to reach 1,878 and the consumption percentage has shown fluctuations over the decade from 2010-2020 but remains within the territory of aforementioned parameters. The steel demand by in large is expected to continue to grow as it supports various sectors such as construction, manufacturing industries, and other uses. Additionally, steelmaking is responsible for producing Sulphur Oxide and Nitrous Oxide. Other domains of environmental impact correlating to sustainability are water usage and compromised air quality resulting from emitted dust and particulates (World Steel Association, 2012, p.16). Sources of energy used in steelmaking is another critical component which varies by technology used. The gap of required energy expenditure between lowest and highest technological maturity is estimated at 50%. Energy expenditure in making steel continues to drop driven by profitability as energy cost count of 20-40% of steelmaking cost.

Therefore, the discussion around sustainable sourcing is rendered integral. The energy expended in the extraction and transportation of steel is deterministic towards the quality of produced steel which corresponds to *lifetime at use* and recyclability at end of life. The concept of circularity puts a considerable and wide lens focus on the lifetime which is an aspect of durability and deliberate recycling. Steel is one of the most recyclable materials in the globe thanks to its magnetic property which makes the sorting process less challenging compared to other types of materials. Shipping vessels are comprised of about 98% steel, the equivalent of 600,000 tons of steel. This renders the shipping industry as highly circular in terms of potential with the vacuum lying at accountability. Maersk Line (n.d.), highlights the significance of a cradle-to-cradle approach through the product passport initiative which does not only ensure economic circularity but the safety and effectiveness of steel recycling. Streams aiding maximization on utilization of steel include light-weighting, durability, efficiency, substitution, eco-design, industrial symbiosis, and leasing/renting. The domains surrounding the viability of such transformation are based on technical, social, and organizational innovations throughout the value chain (European Commission, 2014, n.p.). Moreover, Ellen MacArthur Foundation. (2013), defines a circular economy as "an economy that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility value at all times, distinguishing between technical and biological cycles." This leap is very different from a linear economy which in this context corresponds to lack of accountability over acquisition of raw materials. Shipping vessels operational life ranges between 20 to 30 years which is on the higher end of durability in comparison to other products. The referenced accountability constitutes maintenance of quality and standards of raw materials across several lifetimes to befit original purpose or degrade to the immediate lower tier. Steel being one of the most practical materials to use is responsible for the manufacturing of wind turbines, a sector that is contributing towards the green and sustainable shift. Wind turbine construction is currently exploring opportunities in sourcing steel recycled from ships, rendering a high potential for credible lifecycle assessment.From an advantageous outlook, effects of climate change namely ice melting is opening positive possibilities by enabling shipping through the Northwest Passage (NWP). CBC News (2006), compares the distance of shipping route between Europe (London) and Asia (Tokyo) where through the Panama Canal is 23,000 km, while NWP shortens the distance to only 16,000 km. This 7,000 km saving is likely to lend meaningful reductions in transport time, emissions, and fuel consumption. Having that said, the opening of NWP does not only serve existing commercial opportunities but extends to enable abandoned ones in the Arctic.

2.4. *Iatrogenics of Green shifts.*

The green shift has demonstrated that it has inadvertent consequences, some are mid-term others are long-term. Herewith, these consequences are ought to be metricized and accounted for in order to ensure credible scoring. Without such accountability many promises of the green shift will be subject to being highjacked. In parallel to lifecycle assessment thinking, many iatrogenics can be concealed in phases other than operation which frequently serve as the selling pitch; rather, they lie in pre and post operation phases such as manufacturing, logistics, and disposal. However, an acknowledgement of the state of advancement could render various transitional inadvertencies as justifiable, having time factored in as an essential element of development.

A major pitfall to the green shift is the indirect impact of alternative fuels. For example, Hydrogen shows a promising 80-100% reduction in GHG emissions. However, a careful look into the hydrogen lifecycle and other indirect means of environmental impact could nullify such promise. Hydrogen can be produced via multiple pathways but for the sake of framing practical and relevant solutions, analyses were constrained to the below

Green Hydrogen is produced by electrolysis where the combination of power (electricity) and water in a device referred to as electrolyzer produces hydrogen and oxygen. The source of the power plays a major role to outcome of the lifecycle assessment, where the reliance on conventional power generation comes close to defining the process of iatrogenic. Transportation, administration and storage processes can also be nullifiers towards the desired offset i.e. a diesel truck transporting hydrogen.

Blue Hydrogen, on the other hand, is a green but not a sustainable process. It is produced by separating hydrogen from natural gas through a reforming process yielding products of Hydrogen and Carbon Dioxide. This model stores the carbon byproduct either by reintroducing it to the reserve from which natural gas was extracted, or through alternative ground storage. Either way the carbon emissions are mitigated but other issues surrounding plant power generation and sustainability of fossil resources remain contemplative (Petrofac, n.d.).

A common element for both types of hydrogen is their tank-to-wake is projected to have zero GHG emissions. Although that hydrogen leaks have low GWP estimated at a ratio of 1:4.3

to that of Carbon Dioxide; there are few studies suggesting that Hydrogen leaks could have indirect negative consequences, as known as, secondary GHGs (Department for Business, Energy and Industrial Strategy, 2018, p.3-4). Hydrogen leaks into the atmosphere increases the lifetime of some direct greenhouse gases such as methane which is a more prominent gas than Carbon Dioxide.

Another highly relevant potential undoing of the green shift is attributed to carbon emissions measured throughout the entire lifecycle of Lithium-Ion (LI) batteries. In the maritime shipping sector Lithium-ion batteries are deemed applicable to hybrid auxiliary systems practically and fuel cell technology provisionally. Though much of the literature around the carbon footprint of LI batteries is largely developed by car manufacturers, the variables to their maritime applications are deemed as negligible as will be elaborated later in the research. Ronalder et. al. (2018), mentions:

"The process of battery manufacturing like many other types of technology is at a linear intercourse towards wide-spread maturity and full sustainability. Just to build each car battery—weighing upwards of 500 kilograms (1,100 pounds) in size for sport-utility vehicles—would emit up to 74% more C02 than producing an efficient conventional car if it's made in a factory powered by fossil fuels in a place like Germany, according to Berylls' findings" (para.6).

This comparison is subject to variables in the sourcing of raw materials and differentials in manufacturing processes. Once these batteries are in operation the major determinant revolves around the source of power. Places like France which largely depends on nuclear power will have definitive differences in the lifecycle assessment from places like Germany where there is heavy reliance on coal as power-generating fuel (Ronalder, 2008, para.11). This undoing is relative to the setback of diesel engines in automotive efficiency which to the context of maritime may not be as harmful as currently scaled but can be enough to negate the objective of the shift. Assessment tools and scopes are multivariate in support of the comparative analysis between Internal Combustion Engines (ICE) and fully electric powertrains. In one case as suggested by Melin (2019),

"... results are also widely different with a climate impact ranging from 39-kg CO2e/kWh to 196-kg CO2e/kWh. If an electric vehicle is using a 40-kWh battery its embedded emissions from manufacturing would then be equivalent to the CO2 emissions caused by driving a diesel car with a fuel consumption of 5 liter per 100 km in between 11,800 km and 89,400 km before the electric car even has driven one meter. While the lower range might not be significant the latter would mean an electric car would have a positive climate impact first after seven years for the European average drive" (p.2).

To further reemphasize the variability factor in this specific example and for the entire section, higher maturity and collective viability will equilibrate parallel to the advancement of technology and increased reliance on green and sustainable energy. Through these interrelated domains of developments may produce negative impacts in the short to medium terms, their long-term relationship looks to be mutually benefiting.

Moreover, The International Council on Clean Transportation (2018), estimates the remainder capacity of contemporary car batteries to be around 75%–80% upon their retirement from their first life. This range renders them highly applicable for other domains such as grid power storage. From a LCA perspective this life-prolonging solution estimated at additional 10 years could enhance the value chain to very promising scores. There are many prospective alternative usages that require very minimal processing as opposed to energy-intensive recycling processes (p.7).

Last but not least, on areas of potential iatrogenics is the increased emissions of other GHGs as a result of the disproportionate focus on Carbon Dioxide. Carbon Dioxide received most of the concern with regards to global warming and for good reasons, but as alternative fuel pathways are being explored more harm can be had by increased emissions of other GHGs. Other GHGs such as Methane account for much less volume but has exponential Global Warming Potential (GWP). Below table illustrates the proportions of GWP using CO2 as a baseline:

Pollutant	100-year	20-year
Carbon Dioxide (CO2)	1	1
Methane (CH4)	36	87
Nitrous Oxide (N2O)	298	268
Black Carbon (BC)	900	3200

Source: Comer and Osipova, 2021, p.2.

As a contextual linkage to the maritime industries, Liquified Natural Gas (LNG) is presumably a greener fuel but is responsible for considerable methane emissions. Ewing (2020), references The Intergovernmental Panel on Climate Change report indicating a 30% increase in LNG usage which resulted in 150% increase in methane emissions between 2012 and 2018 (para.4). Methane slips occur in bunkering, refueling, and combustion processes. Though there are various technologies to curb this slip, it remains a challenging, but foreseeable developments in engine and logistical technology are projected to reduce it by at least 90% (para.10). The International Transportation Council on Clean Transportation produced a formula that account for a well-to-wake global warming potential across time and potency of GHG gases with figures as listed in below table:

Fuel type	Engine type	Well-to-wake (g/g fuel)					
		EF_{WTW}				CEF_{WTW}	
		CO_2	CH_4	N_2O	BC	CO_2e100	CO_2e20
HFO	SSD	3.545	0.00404	0.00018	0.00019	3.915	4.553
	MSD	3.545	0.00404	0.00017	0.00049	4.182	5.510
VLSFO	SSD	3.734	0.00453	0.00019	0.00019	4.124	4.787
	MSD	3.734	0.00453	0.00018	0.00049	4.391	5.744
MGO	SSD	3.782	0.00466	0.00019	0.00004	4.043	4.367
	MSD	3.782	0.00466	0.00018	0.00026	4.237	5.068
LNG	LNG-Otto-MS	3.280	0.05336	0.00014	0.00002	5.259	8.023
	LNG-Otto-MS + crankcase	3.280	0.05977	0.00014	0.00002	5.490	8.580
	LNG-Otto-SS	3.280	0.03499	0.00014	0.00002	4.600	6.427
	LNG-Otto-SS + crankcase	3.280	0.04175	0.00014	0.00002	4.844	7.015
	LNG-Diesel	3.280	0.01958	0.00023	0.00001	4.063	5.077
	LBSI	3.280	0.04438	0.00014	0.00002	4.936	7.242
	LBSI + crankcase	3.280	0.05079	0.00014	0.00002	5.167	7.799
	Steam Turbine	3.280	0.01824	0.00008	0.00002	3.978	4.952

Source: Comer and Osipova, 2021, p.4.

This puts Heavy Fuel Oil (HFO) and Very Low Sulphur Fuel Oil (VLSFO) at an advantage of reduced emissions at varying rates compared to LNG.

2.5. Data collection.

Quantitative data are primarily sourced from The American Bureau of Shipping (ABS), The International Council on Clean Transportation (ICCT) and the Det Norske Veritas (DNV). Research from aforementioned institutions serve as a foundation for maritime-related data and associated interpretations. Odfjell data and strategy is used throughout as a comparable real-life application of IMO's goals. The National Oceanic and Atmospheric Agency (NOAA) is a primary source for climate change data and contextual analysis.

On the qualitative front, International Maritime Organization (IMO) is the primary source of legal and regulatory matters, while the United Nations (UN) serves as a prominent body for sustainable goals and green shift enablement. The book of Corporate social responsibility in the maritime industry the prominent reference for public disclosures and transparency. Morgan Stanley and Climate Initiative Bond and instrumental resources of sustainable financing and green taxonomy.

2.6. Data analysis.

Data analysis uses chronological and comparative data analyses for prospective alternative fuel pathways. This domain that is largely quantitative benefits from current position vs. future trajectories in emission and sustainability standings; current capabilities vs. proposed capabilities across various limiting or empowering factors; as well as a determination of practicality from an analytical lens examining power output, reliability, efficiency, range of operation, and practicality of refueling solutions.

On the other hand, the qualitative part analyzes nested, interdependent solutions such as in green financing and economic circularity which is largely driven by social responsibility and market-based incentives. In this realm there exist indicators such as qualification criteria for green financing rewarded by lower interest rates under prominent conditions such as emissions public disclosure. These sets of indicators act as a skeleton for the viability of these nested solutions, but deeper analyses of case studies reveal potencies, limitations, and areas of improvements. Quantitative indicators can be misleading in the absence of situational interpretations which can avail manipulations, inaccuracies, and exceptions.

The iterative parts of this research predominantly expressed in economic circularity, the balancing loop, and eco-balances, and incurred disaster risk using systematic analyses to recurse cause to effect and back to cause. This cyclical approach is at the core purpose of this research deconstructing large, momentous problems into smaller sets of actionable initiatives with the aim of reconstructing a reflective positive outcome. Climate change is complex issue with many interdependencies where the disturbance of simple elements could lead to an emphatic cascading effect.

2.7. Efficiency streams.

2.7.1. Efficiency overview.

As the viability of green technology and fuels is challenged by preset missions and required capabilities, efficiency in design and operation are rendered as critical enablers. As a general principle, the larger shipping vessels are, the more efficient they become due to the plateau of energy expenditure per extra volume/mass of cargo; however, hindrances to sizes are constrained by size of passing canals and ports capacities. From a performance efficiency standpoint, IMO and UN Sustainable Development Goals (n.d.) has listed the following domains along with their GHG reduction potential as follows:

- Concept, speed and capability (2-50%)
- Power and propulsion systems (5-15%)
- Energy Management (1-10%)
- Fleet Management, logistics and incentives (5-50%)
- Voyage optimization (1-10%)
- Green and renewable fuels
  - Full electric (50-90%)
  - Bio-LNG/LPG (35%)
  - Biofuel 3^{rd} generation (90%)
  - Hydrogen and other synthetic fuels (80-100%) (p.1).

2.7.2. Technical efficiency.

As measured by Energy Efficiency Design Index (EEDI) can be defined as measures of exhausting all opportunities to maximize performance and minimize emissions. Vessels benefit from enhancements in fields of aero and hydro dynamics, propulsion systems, and computerized optimization systems. Aero and hydro dynamics in principle constitutes streamlining the shape of ships in manners that are least resistant to air and water. Less air and water resistance translate as less power required which in turn reduces fuel consumption and GHGs emissions in proportionality. One of the most influential design parts pertaining to air and water resistance is hull design and air lubrication systems.

Hull Design. Hull is the main body of ships which represents the largest surface in contact with water. According to gCaptain, (2014), striking a balanced ration of hull's length ratio influences resistance significantly. Adding 10-15% extra length to a typical product tanker can reduce the power demand by more than 10%. There are other factors to account for other than movement resistance such as static stability, as well as control and handling. The hull shape is deterministic towards viscous resistance which can be further enhanced and maintained by passive and active systems.

Air Lubrication Systems. Since motion resistance is greatly influenced by the density of the medium in which an object moves, it is approximated that air is about 380 times less dense than water (Pressure and Density of Air, n.d.). Such gap elicited development of air lubrication systems whose functional principle is to reduce overall resistance by pumping compressed air to the bottom of the hull in order to minimize water contact (gCaptain, 2014). Such active technology presents an enormous source of energy saving estimated at 20% of reduced resistance and 15% reduction in fuel consumption.

Anti-fouling systems. "During a ship's lifetime microorganisms, plants, algae, or animals will gather in its hull, during a process called biofouling" (Safety4Sea, 2018, para.1). Anti-fouling systems are a form of passive technology that minimizes resistance by preventing growth of marine organisms on ships' hull. The increased frictional force caused by the growth of such organisms can hinder optimized ships operation to significant extents. Safety4Sea estimates these hindrances to cause up to 10% in speed reduction to overcome which a 40% increase in fuel consumption is required. These systems weather material-based, form-based, or a combination of both are referred to as anti-fouling systems. Historically, copper has preeminently been used as a toxic material to combat the growth of marine algae; however, such is being phased out due to associated environmental impacts (Brennan, 2005, para.2-3). One of the most effective modern approaches is inspired by shark skin where the surface flexes in and out to prevent algae growth. The shark skin-inspired technology reduced growth by as much as 85% while being environmentally safe. Aforementioned copper mixtures can have a higher prevention percentage but poses threats to the marine life and environment.

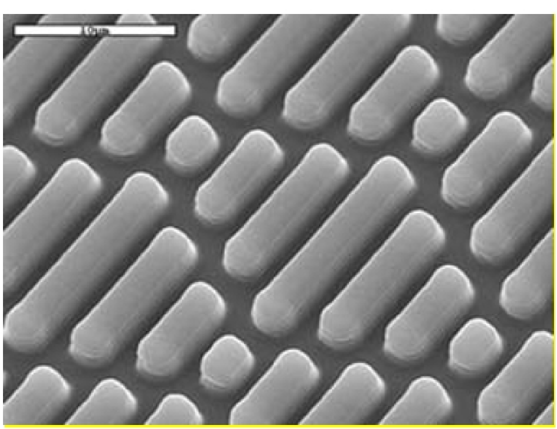


Illustration of shark skin. Source: Brennan, 2005.

2.7.3. Wind sailing systems.

Mofor et. al. (2015), states that there are no successful applications of wind sailing systems yet for the shipping sector. The major hindrance like many other green systems is the capital investment and commercial viability. Such hindrance can be penetrated through drivers as covered later in the research, but early studies predict 20–25% fuel savings on cross-equator shipping routes and 30–40% on same-hemisphere shipping routes. Unlike other types of initiatives and technologies, wind sailing deliverance is weather-dependent. The upside of this potential solutions is the practicality of retrofit in existing vessels which can further assist other types of retrofits in the mission towards lowering emissions (pp.7-9). This solution is expected to provide of up to 60% savings in fuel, as well as significant reductions in main engine and propeller wear.

2.7.4. Propulsion and energy saving devices.

Lastly for design efficiency is what is commonly referred to as Energy Saving Devices (ESDs). One of the most popular forms of this technology pertains to adjustability of propellors' blades pitch in order to maximize propulsion performance. Efficiency in symmetrical blade arrangements have near plateaued. However, discussed adjustability provides opportunities in different asymmetrical arrangements that provide a dynamic and condition-based form. The development of such technology requires computerized management systems that rely on data validated through Computerized Fluid Dynamics (CFD) modeling and other forms of testing. This enhancement showed an improvement of up to 6% power efficiency for a large crude carrier (Dang et. al. p.1).

2.7.5. Operational efficiency.

Just-in-time scheduling. A critical element supporting operational efficiency is a scheduling system referred to "Just-in-Time (JIT). JIT was first introduced by Toyota Motor Company, namely by Taiichi Ohno and the idea of the system as it relates to ships' operational efficiency is by increasing process agility. Processes usually encompass time gaps and logistical misalignments both of which needlessly overexert resources and produce emissions. According to ABS (2020), "ships spend roughly 50% of their time in berth, anchoring or maneuvering; this accounts for more than 15 percent of their annual fuel consumption" (p.84). Therefore, effective scheduling system at ports has the potential to offset waiting time at ports which in turn reduces GHG emissions and fuel consumption to considerable degrees.

Sea Traffic Management (STM). STM can be considered as the backbone of JIT where it optimizes voyages to prior to arrival to ports. The system works by interconnecting over 300 ships and shore centers. According to ABS (2020), there are currently around 50 partners spanning 13 countries at this stage of development. As the number of proponents increase, more data will be available for harnessing which aids optimized vessel-to-vessel coordination.

Weather routing. In addition to weather routing being a measure of safety to the crew and cargo, it is also responsible for efficiency and energy saving as it pertains to reducing GHG emissions. Prpić-Oršić et. al. (2015), estimates that weather routing can produce 2–4% fuel saving and a potential of 50% efficiency improvement through speed management and evading rough seas (p.857). This system does not only help optimize ship performance but can also aid in avoiding potential collisions.

Lifecycle maintenance. Lastly for operational efficiency is adequate maintenance which ensures efficiency according to design performance and international regulations. International Safety Management Code (ISM) is the entity responsible for providing guidance, monitoring, and compliance enforcement upon the shipping industry. Effective vessel maintenance is systematically achieved through a maintenance management system that is in line with manufacture recommendations and regulatory parameters. Such is not only critical for economical purposes but for an array of other strings, particularly performance efficiency and environmental impacts. Ships Business (n.d.), states "it is argued and shown that proper maintenance leads to more energy-efficient ship operation. Thus, the requirement for maintenance and energy-efficient operation fully overlaps with each other" (para. 5-6).

2.7.6. Marine fuel pathways.

The following section examines existing and future shipping fleets from the angle of fuel types as they pertain to technical viability, sustainability, and GHG reduction potential. Below table shows CO2 reduction potential for potential alternative fuels.

Measures	Possible CO_2 Emissions Reductions
Advanced biofuels	25–100%
Liquefied Natural Gas (LNG)	0–20%
Hydrogen	0–100%
Ammonia	0–100%
Fuel cells	2–20%
Electricity	0–100%
Wind	1–32%
Solar	0–12%
Nuclear	0–100%

Source: George Mallouppas and Elias Ar. Yfantis, 2021.

The fuel transition strategy is broken down into Heavy Fuel Oils pathway; Light Gases pathway; Electro-Fuels; and Nuclear. Generally, heavy fuel oil lie in the short-term window of development for bio-based fuels; Light gases fall into the mid-term development window for opportunities other than LNG; long-term includes electro-fuels (fuel-cell technology) and Nuclear.

Heavy oils pathway. Oil-based marine fuels are often differentiated by the variability of mixtures. Heavy oils can be broken down into two main categories: Heavy Fuel Oil (HFO) and Bio/Synthetic. HFO is also synonymous with technical names such as Number 6 Fuel Oil (Bunker C) and Very Low Sulfur Fuel Oil (VLSFO). Commercial names include Fuel Oil, Heavy Oil, Marine Fuel, Furnace Oil, Marine Heavy Fuel Oil, Bunker Oil, Bunker Fuel. These types of oil are minimally refined and are widely used to power existing ocean-going vessels. Degnarain (2020), mentions "Today it is used by 60% of the approximately 60,000 ocean-bound large vessels in the world, that comprise cargo ships, cruise ships, ferries, oil tankers and bulk carriers" (para.8). However, according to IMO (2020), HFO makes up of 79% of the shipping industry which shows the overreliance compared to other opportunities (p.7). HFO's attractiveness is driven by approximately 30% cost saving, power adequacy and reliability. Historically, regulations have focused on managing emissions of Nitrogen Oxide and Sulfur Dioxide while allowing Carbon Dioxide some level of freedom for the lack of competent alternatives as well as other political issues. Deganarain (2020), argues that relaxed regulations are due to pressures from the shipping industry. However, emission rates have been significantly lowered from predating rates thanks to the shift to VLSFO and the employment of scrubber systems whose function is to treat exhaust and radically reduce or eliminate NOx and SOx. Scrubber systems have been considered as an interim solution since times of their introduction. ABS (2020), mentions "current vessels retrofitted with scrubber systems are expected to phase out in 2040, considering a 20-year service lifetime, and end the use of HFO" (p.79).

The less invasive oil alternative (biofuel) is referred to as Fatty Acid Methyl Ester (FAME). This type of fuel are intrinsically lower in Sulphur content but remain a substantial hindrance towards the goal of reducing and/or eliminating carbon emissions. FAME is a semi-sustainable product derived from a variety of plant or animal oils possessing similar energy characteristics as HFO (ABS, 2020, p.91).

Light gases pathway. This category of alternative fuel is generalized as light gas due to similarities in form, technology, technical viability, compatibility, and associated challenges. Light Gas pathway stands out due to the ratio of low-carbon to hydrogen – a chemical characteristic that is consistent with low carbon emissions. The application of these family variants in Hydrogen, Ammonia and Methane includes differentiation factors that can significantly span their close chemical associations. Such factors include manufacturing techniques, transport, storage (bunkering), applied technology, and supporting infrastructure.

Liquified Natural Gas (LNG). LNG is largely sourced from fossil fuel reservoirs and though bonded to carbon, it burns cleaner than other forms of fossil fuel estimated at 25% less carbon emissions compared to HFO (Pavlenko, 2020, p.4). Though this pathway is provisionally greener than HFO, it remains overshadowed by methane slip and exhaustibility. To the renewability end, derivatives of LNG can be sourced via synthetic and renewable means. According to ABS (2020), "Synthetic Natural Gas (SNG) can be produced from coal or biomass through gasification and methanation, which yield mixtures that have at least 90 percent methane content by volume with the same physical and chemical properties as fossil natural gas. The coal-to-SNG conversion produces CO2 in amounts that can be higher than if coal was burned. Therefore, it is not a viable production pathway from the green perspective, unless the carbon capture and sequestration of CO2 is used in the production process" (p.19).

Conversely, Renewable Natural Gas (RNG) is expected to be commercially viable where biomass and/or use of renewable energy can be utilized for production. Current renewable energy infrastructure and technology are not abundant enough to scale up this mode but as the deciding factors scale up in availability and capability, RNG will have the option to follow.

Hydrogen. Can be produced from fossil fuels and biomass, or from water, or from a combination of the three. Current global production capacity of Hydrogen is approximately 275 Mtoe (million tons of oil equivalent). This makes up of around 14% of the world's energy demand. Fossil fuels represented by LNG make up about 75% of Hydrogen source of production. Hydrogen is inherently clean fuel but like other clean, synthetic fuels the concern stems from the Carbon Footprint (CFP) throughout its manufacturing cycle. CFP is largely determined by feedstock choice and source of electricity, which through current inputs emissions exceed that of fossil marine fuels. Hydrogen is currently not viable for shipping vessels as it only produces 15% of the total energy produced by the equivalent from oil fuels.

Ammonia. Contains hydrogen and nitrogen which makes their CFP exceeds rates of Hydrogen amid accounts of nitrogen production. Additionally, elements of transport, storage and delivery are to be measured as a part of the CFP lifecycle. However, as renewable energy become more mainstream, emissions across the life cycle will drop accordingly (IRENA, 2019, p.19). One of the major concerns with Ammonia is its toxicity to humans and marine life; nevertheless, robust handling procedures and equipment reliability can cap the risk to reasonable levels. Ammonia ships are sailing on Research and Development basis and their drawbacks are discussed later in challenges and limitations of light gases section.

Methanol. Is projected to be a viable fuel for marine applications because it is liquid in form at ambient conditions. Unlike other light gases that require cooled storage (crygenesis) and/or form conversion, Methanol is simpler to store and handle. Conversion and specialized storage techniques can be cost and process intensive. The technology required to develop fuel systems for Methanol is much cheaper than its commercially viable counterpart, LNG.

Methane. Is an energy dense fuel whose impracticality lies in storage requirements. Methane requires cryogenic storage which as previously mentioned is more energy, process, technology, and cost intensive. Methanol has the potential of reducing CO2 emissions by around 10 percent. However, current production feedstock and technology make it not a commercially viable solution which can be overturned amid renewable sourcing as bio-methanol or electro-methanol.

Electro-fuels (Fuel Cell Technology) pathway. As a standalone powering unit, electro fuels are not currently viable for shipping vessels due to size of batteries required, source of recharge, and required cost. Electro fuels may be effective solely for meeting power demands of auxiliaries, but the practicality of hybrid applications far outweigh that of sole-electric systems. Using renewable energy to produce electro-fuels from biomass could reduce the energy required from less efficient power-generating devices such as wind and solar which increases the chances of achieving collective viability. Hybrid applications can be made compatible across all other fuel types. In which cases there is a potential to produce bio-LNG or bio-Methanol via carbon capture and conversion technologies. There are more arrangements on which electro fuels whose viability hinges advancement of technology (ABS, 2020).

2.7.7. *Challenges and limitations of light gases and fuel c.*

All prescribed routes of alternative fuels to HFO and VLSHFO share similar domains of limitations. These limitations are manifested in the low energy density; cost of fuel, fuel accessibility, required capital investment, complexity of delivery systems. All aforementioned domains interplay into the overall viability of all these prospective pathways. Cost of retrofits and new builds is deliberately addressed in green financing and social responsibility sections. The following sections focus on energy density and cost as well as solutions around accessibility of refueling.

Energy density and fuel cost. Maritime Industries Decarbonization Council (n.d.), summons the case as

"the crucial element with regards to energy density is the energy content per volume. If said energy content is smaller than the energy content of current marine fuels, cargo capacity will be lost, as more space will be needed for fuel storage."

ABS (2020), provides the following example "Compressed hydrogen at 700 bar has only approximately 15 percent the energy density of diesel, thus storing the same amount of energy requires about seven times larger tanks on board a ship" (p.21). Below table is an illustration of energy densities, using HFO as a baseline reference for required space, fuel cost, etc.

ED/Fuel	HFO	MDO	LNG	Ammonia	Liquid Hydrogen	Methanol	Methane
Energy Density	38.3 (mj/l)	34.5 (mj/l)	25 (mj/l)	12.7 (mj/l)	8.491 (mj/l)	15.7 (mj/l)	55.5 (mj/kg)
References	Aronietis et. al. (2016)	Aronietis et. al. (2016)	Aronietis et. al. (2016)	ABS (2020, October)	Lan and Tao (2014)	ABS (2021)	Elert (2004)

Source: Authors.

These numbers are subject to slight fluctuations contingent on variations in specifications and content mixture. Apart from Methane, which is chiefly unfavored for its climate-associated impact, all light gases are less than half of the energy density baseline as established. Thus, alternative fuel viability is a formula with highly complex with interdepended factors, which necessitates the need for collective scoring that considers energy density, technological maturity, GWP, capital cost, operational cost, and bunkering accessibility. The DNV (2019), also identifies other supportive factors such as flammability and toxicity in the domain of risk; regulatory enablement; and commercial practicality as shown in below table:

Source: DNV, 2019, p.9.

Bunkering and infrastructure. Building or upgrading existing port infrastructures to accommodate alternative fuel storage and delivery is a massive undertaking that requires major capital investments. The dilemma is presented in low demand and a diverse range of propositions. By reciprocity, viability of vessels to undertake technologically proven alternative fueling requires a competent network of refueling stations. As fixed infrastructure pose significant challenges in the areas of financial access and dynamicity, the adopted workaround materialized in the ship-to-ship and truck-to-ship bunkering. Ang (2020), elaborates that globally there are only 15 ports capable of ship-to-ship LNG delivery, while the other 60 active locations deliver via trucks. The author continues to assure that as the green shift becomes more institutional, the more widespread the network of LNG is likely to be. In the interim there are 15 ports and 16 bunker vessels coming online shortly but the strategic outlook foresees a 100 bunker vessels addition to meet the projected demand of 30 million mt by 2030 (para. 7-11).

With the variety of potential fuels for maritime application, the refueling infrastructure will need to accommodate a diverse range of technologically proven fuel alternatives. ABS (2020), mentions ”information on the cost of using liquid hydrogen for international shipping is currently scarce. It is estimated that the additional cost of bunkering facilities and suggested that liquid hydrogen infrastructure could be 30 percent more expensive than LNG, but this estimate may be conservative” (p.22). However, the literature is unclear as these projections are considerate towards the ship-to-ship bunkering route.

Nuclear pathway. Nuclear technology represented by Small Modular Reactors (SMRs) is considerably more advantageous than other types of fuels particularly in the domains of power output, range, and emissions. Though technically practical, SMRs have major draw backs in areas of capital cost, potential risk, international licensing, and environmental impacts associated with end-of-life disposal. Some of these drawbacks are undergoing transitions given the development of solutions such as sustainable financing for capital cost and improved disposal techniques. Uses of SMRs are largely limited to military applications with few exceptions in Arctic Ice breakers.

In their various applications SMRs have significantly progressed in safety and power output. Though largely perceived as environmentally harmful, SMRs produce zero emissions while producing adequate power. Despite advancements in their technology, wich have rendered these reactors as melt-down safe, many regulations in regional waters still prohibit nuclear-powered vessels from entering and docking for safety-related concerns. Nuclear -Powered Ships (2021), mentions ”So far, exaggerated fears about safety have caused political restriction on port access. ”These concerns are not without strings especially pertaining to safety at sea (piracy and terrorism) as well as accidental releases. International licensing falls under the area of logistical and legal qualifications. DNV (2021), mentions ”the current licensing and regulatory regime for nuclear power may also pose a barrier. However, there is movement toward a revised international licensing procedure for small modular reactors. . . ” (p.45). Discussed SMRs constitutes far less rates of enrichment to mitigate the risk of proliferation of radioactive materials. This measure reduces the core life to a range between 5 to 7 years compared to highly enriched military applications which have an average core life of 25 years.

That said, the power output produced by various reactor sizes and uranium enrichment makes of efficiency measures beyond that of other types of fuel. The force of propulsion takes vessels to speeds of up to 30-35 knots as compared to 15-25 which exceeds the major advantage of HFOs (power output) while maintaining zero GHG emission rate. The technological maturity of SMRs remains at different levels of development sizably discouraged by capital cost and risk perceptions.

As it pertains to cost, capital investment in SMRs is different approach to the concept of continuous refueling where the cost is divided into smaller increments and stretched across time as operating cost. The cost-benefit analysis is bound to be multifactorial including factors such as vessel speeds, maintenance, cost of fuel and other factors. British Petroleum (BP) has conducted a study factoring all aforementioned and the outcome proved economic viability after 8 years for SMRs considering a refueling range between 5-7 years. Fusion-Powered nuclear technology being one of the most promising nuclear pathways, by in large, offers lower cumulated costs compared to other technologies such as Molten Sulphur Reactors (MSRs). The fusion pathway promises economic viability after 5 years of operation, eventually saving about 1billion USD after 15 years (DNV, 2021, p.48).

Nuclear challenges and risks. Although nuclear is deemed as risky predominantly from the historical meltdown incidents, advancements in technology and applications have rendered fears less credible and more on the realm of conservatism. DNV (2021), mentions “new nuclear designs are inherently safe, meaning that a meltdown cannot happen even when active cooling / control is lost” (p.44).

Exposure to personnel is briefly addressed in IMO’s chapter VIII of the International Convention for the Safety of Life at Sea 1974. Conca (2020), mentions that the Navy personnel recorded an average of only 0.005 rem/year (5 mrem/year; 0.05 mSv/year), compared to the federal allowable limit 5 rem/year. Conca (2020), continues to elaborate on the safety of nuclear-powered ships by complementing the safety track record of the U.S. Navy.

"Thousands upon thousands of people, 22,000 thousand people at any one time, have lived, worked, eaten and slept within a stone's throw of these nuclear reactors for 60 years with no adverse effects from radiation at all. In fact, nuclear sailors have lower cancer death rates than the age-matched group in the general population" (para.23)

Nuclear proliferation also presents a major risk where the unintended spread of enriched substance gets in the hand of terrorist and piracy groups. While efforts exerted in making the technology proliferation-resistant are yet to yield practical results, an intrigue is growing in the potentiality of using unenriched uranium for novel applications. The path forward from a wide perspective looks to minimize uses of enriched fuels in commercial vessels and enact more stringent procedures to reduce risks of weaponization as result of proliferation.

2.8. Drivers and incentives.

2.8.1. Advancement of Sustainability goals

The United Nations' Sustainable Development Goals (SDGs) aim to approach sustainability from a root-cause and all-encompassing perspective. Such approach is consistent with nested solutions that enable resolution of complex and interdependent issues as explained throughout the paper. As defined in Our Common Future (n.d.), sustainable development is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (p.41). From these SDGs a multitude of initiatives have and continue to demonstrate positive impacts driven by the goodwill for the future of our planet and our descending generations. Decarbonizing the maritime industry pertains to several goals such as

- SDG 9 Industry, Innovation and Infrastructure - Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
- SDG 13 Climate Action - Take urgent action to combat climate change and its impacts
- SDG 17 Partnership for the Goals - Strengthen the means of implementation and revitalize the global partnership for sustainable development

2.8.2. Social Responsibility

The United Nations Convention on the Law of the Sea (UNCLOS) has published a chapter titled "Arctic Governance and Gender: Climate Change or Social Change?" This unique outlook aims at exploiting administrative approaches to various practices and initiatives. Issues of climate change are inadvertently social issues in the realms of livelihood, health, and safety. Therefore, what is done to mitigate the effects of climate change is inherently connected to social change and responsibility. On a practical tone, the drive of compliance has overshadowed a more fundamental part of responsibility and the prescribed mindset calls for an authentic restoration of environmental consciousness beyond the parameters and political objectives of compliance.

Herewith, a reasonable definition to social responsibility as it relates to businesses can be "a concept whereby companies integrate social and environmental concerns in their business operations and in their interaction with their stakeholder on a voluntary basis" (Froholdt, 2018, p.6). Another deliberate definition is "Corporate Social Responsibility is the continuing commitment by business to contribute to economic development while improving the quality of life of the workforce and their families as well as of the community and society at large." (Froholdt, 2018, p.7). Having the perceptual part established, social responsibility can be summoned into three main pillars in environmental, social, and economical. These three pillars are consequently quantified under what is known as the Triple Bottom Line (TBL) framework. The TBL is a universal measure that measures collective social responsibility performance as detailed in underlying performance indicators.

Motivated by voluntary set of drivers, issues of environmental correspondence constitute effective and efficient apparatus whose objective is to reduce impacts of climate change and promote environmental sustainability. Socially, the apparatus can be geared towards mitigating personnel and community exposures to immediate risks. These conditions can be dissected into three main categories: short, medium, and long-term onset. Short onset risks are encountered frequently in the unfortunate occurrences of incidents which can be traced to quality concerns at the expense of maximizing profitability. The medium-term risks are the prolonged exposures to physically straining and/or mentally stressful conditions. The long-term onset is the impacts of climate change whose complete traces have not been fully explored and understood. This lends safety and quality controls as deterministic elements towards voluntary social responsibility rather than enforcible measures of compliance. Economically, the apparatus shall deliberately be geared towards avoiding safety and quality undercuts in the name of maximizing profitability. The paradox of profitability also lingers in the balance between expedience representing maximization on available opportunities vs. prudence as it pertains to generational exponential impacts. Lastly, social responsibility should start with transparency and public data disclosures which are indirect drivers towards maintaining reasonable standings.

2.8.3. Market Based Measures (MBM)

Market-based measures form the futuristic approach of handling the persistent dilemma of business feasibility against regulatory and environmental constraints. Enabling the green shift requires a set of incentives that fulfill the extra commitment made by initiators.

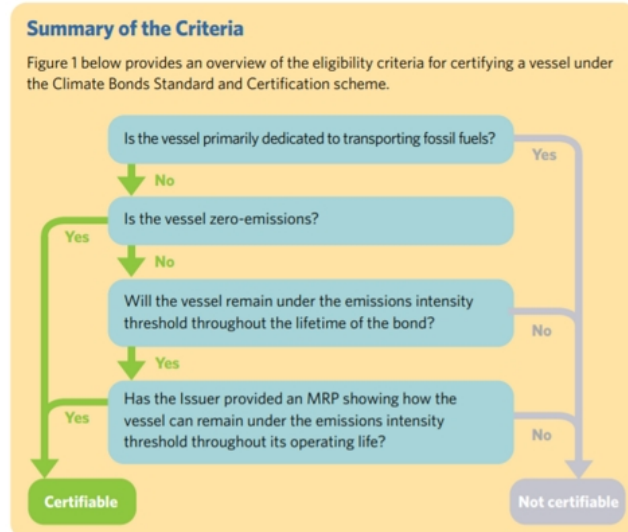
Sustainable financing and green taxonomy . An instrumental enabler to this shift is financial investment which in its isolated domain constitute profitability as the leading principle. Recognizing financial investment as an enabler is a key understanding, one that should be amalgamated towards practical facilitation of solutions i.e. customizing business transactions to befit climate-related objectives. The Task Force on Climate-Related Financial Disclosures (TFCD) is one entity that has initiated recommendations for more effective climate-related disclosures in order to promote more informed investments, credit, and insurance underwriting decisions. The task force consists of 32 members who were strategically selected to support an all-encompassing approach were sourced from a variety of disciplines including large banks, insurance companies, asset managers, pension funds, large non-financial companies, accounting and consulting firms, and credit rating agencies (TFCD, 2017, p.iii). Information generated in reports, in turn, enable stakeholders to better understand the concentrations of carbon-related assets in the financial sector and the financial system's exposures to climate-related risks (TFCD, 2020, para.4). The report establishes recommendations for disclosing clear, comparable, and consistent information about the risks and opportunities presented by climate change. A widespread adoption will ensure that the effects of climate change become routinely considered in business and investment decisions in aims to smoothen the transition to a more sustainable, low-carbon economy (TFCD, 2017, p.i).

Pertinent to the Maritime Industries, the TFCD has assessed business and economic impact and determined three influential factors to the risk of the green transition. A mainstream term to such dilemma is referred to as the transitional risk, contextually encompassing policy and legal; technology; market; and reputation. As such, maritime transportation is highlighted as a sector being at a great risk but by the same token provides ample of investment opportunities (TFCD, 2017, p.16). Climate change is projected to cause business impacts through altering the dynamic of industries. For example, the agriculture and fossil fuel sector make

Another initiator to discussed approach is the Climate Bonds Initiative (CBI) which aims to achieve low-carbon economy through a criteria-based financing. CBI aims to act as an enabler for purchasing, maintenance and retrofits as they relate to the green shift. EU green taxonomy was brought forth by CBI which provided scientific and market basis for the green and sustainable outlook. CBI applies to several key amenities/industries as follows:

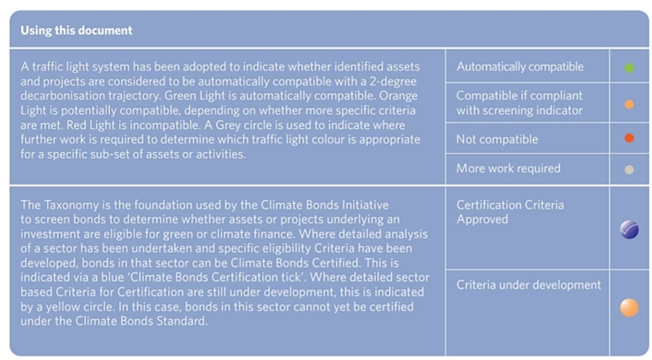
Energy	Water
Transport	Buildings
Land and Marine	Industry
Waste	Information and Communication Technology (ICT)

As maritime shipping falls under the category of transport, it is a certifiable sector as per below criteria:



Source: Climate Bonds Initiative, 2020, p.1.

A more detailed criteria warrants further analysis of pathway and maturity and as such qualification scheme is assigned based on situational standings. For developed criterion, a scheme of census allocation is mapped according to the following:



Using this document		
A traffic light system has been adopted to indicate whether identified assets and projects are considered to be automatically compatible with a 2-degree decarbonisation trajectory. Green Light is automatically compatible. Orange Light is potentially compatible, depending on whether more specific criteria are met. Red Light is incompatible. A Grey circle is used to indicate where further work is required to determine which traffic light colour is appropriate for a specific sub-set of assets or activities.	Automatically compatible	
	Compatible if compliant with screening indicator	
	Not compatible	
	More work required	
The Taxonomy is the foundation used by the Climate Bonds Initiative to screen bonds to determine whether assets or projects underlying an investment are eligible for green or climate finance. Where detailed analysis of a sector has been undertaken and specific eligibility Criteria have been developed, bonds in that sector can be Climate Bonds Certified. This is indicated via a blue 'Climate Bonds Certification tick'. Where detailed sector based Criteria for Certification are still under development, this is indicated by a yellow circle. In this case, bonds in this sector cannot yet be certified under the Climate Bonds Standard.	Certification Criteria Approved	
	Criteria under development	

Source: Climate Bonds Initiative, 2021, p.1.

These classifications play into the decision of whether or not financing is warranted and the degree to which interest rates are relaxed in proportion to practicality of the solution. This European-led initiative is further complimented by a social responsibility adoption where public disclosure of performance is also deterministic towards the nature of financing solutions. Hapag-Lloyd (2021), integrates these dimensions through the following statement

"In order to provide investors of the Sustainable Linked Bond (SLB) and related other stakeholders with adequate information on the progress of our emission reduction in light of the SLB Sustainable Performance Targets (SPT), a Sustainability-Linked Finance Progress Report ("SLFPR") will be made publicly available on HLAG's website" (p.12).

The Poseidon Principles is another coalition spearheaded by global shipping banks such as Citi, Societe Generale, and DNB who facilitated a collaboration with leading industry players such as A.P. Møller Mærsk, Cargill, Euronav, Gram Car Carriers, Lloyd's Register, and Watson Farley & Williams. This coalition is further supported by industry experts such as the Global Maritime Forum, Rocky Mountain Institute, and University College London Energy Institute.

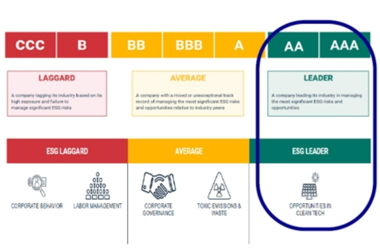
A series of three workshops held in June 2018 across Singapore, London and New York City brought together a total of 45 senior ship financiers along with a select group of ship owners and experts in order to explore practical approaches for integrating climate risk into financial decision-making in the maritime industry. Throughout these workshops, there was a shared vision of success: a group of aligned and committed institutions taking ownership of a set of principles with the aim of integrating climate considerations into lending decisions in alignment with the climate-related goals of the IMO (Poseidon Principles, 2020).

A specialized committee was subsequently formed to develop the Poseidon Principles. The specialized group was ensured to be diverse in backgrounds, contexts, and geographies. These principles are categorized under three main domains in

1. Assessment of climate alignment – a provision for selecting the right metric for measuring climate alignment equilibrated by aggregating alignment for products and portfolios.
2. Accountability and enforcement – a provision for standard development, enforcement, and accountability.
3. Transparency – a provision for effective information acquisition and flow (Poseidon Principles, 2019).

The European Investment Bank's Green Shipping Guarantee (GSG) provides a scheme of green financing where new builds and retrofits are facilitated at incentivized rates. A futuristic look warrants leasing new builds to defray the initial capital cost. The green lease model correlates well with other aspects such as prolonging the lifetime of vessels though condition-based maintenance upkeep, as well as, end-of-life recycling (Singapore Maritime Foundation, 2021, p.26).

One of the most popular nested-solutions model is Social Bond Framework by Morgan Stanley. This framework relies on three main pillars: Environmental, Social, and Governance (ESG). Environmental constitute a measure of environmental performance monitoring and data collection. The social pillar constitutes a measure of transparent reporting as well as other social responsibility activities as linked to SDGs (Morgan Stanley, 2020). Governance constitutes a third-party auditing to verify accuracy of monitoring and reporting. These pillars combined result in a collective Morgan Stanley Capital International (MSCI) score that determines standings according to which financeability and rates are decided as per below (MSCI, n.d).



Fund ESG Quality Score	Fund ESG Rating
8.6* - 10.0	AAA
7.1 - 8.6	AA
5.7 - 7.1	A
4.3 - 5.7	BBB
2.9 - 4.3	BB
1.4 - 2.9	B
0.0 - 1.4	CCC

Source: MSCI.

Tax and levies. Frameworks for tax and levies are being developed to facilitate regional and global crediting systems, influenced by operational (SEEMP) and design (EEDI) efficiency standings. Examples for these agreements and structures are:

1. **"Leveraged Incentive Scheme (LIS) (Japan (MEPC 60/4/37))**: GHG Fund contributions are collected on marine bunker. Part thereof is refunded to ships meeting or exceeding agreed efficiency benchmarks and labelled as "good performance ships".
2. **Port State Levy (Jamaica (MEPC 60/4/40)):** Levies a uniform emissions charge on all vessels calling at their respective ports based on the amount of fuel consumed by the respective vessel on its voyage to that port (not bunker suppliers).
3. **Ship Efficiency and Credit Trading (SECT) (United Sates) (MEPC 60/4/12))**: Subjects all ships to mandatory energy efficiency standards. As one means of complying with the standard, an efficiency-credit trading programme would be established. These standards would become more stringent over time,
4. **Vessel Efficiency System (VES) (World Shipping Council) (MEPC 60/4/39))**: Establishes mandatory efficiency standards for new and existing ships. Each vessel would be judged against a requirement to improve its efficiency by X% below the average efficiency (baseline) for the specific vessel class and size. Standards would be tiered over time with increasing stringency. Existing ships failing to meet the required standard through technical modifications would be subject to a fee applied to each tonne of fuel consumed" (Market-based Measures, n.d.).

2.8.4. *Regulatory and compliance*

International. The international Maritime Organization (IMO) is the main governing body regulating matters related to international shipping and trade, but this does not undermine the important roles played by other governing bodies. Historically, the organization was known as Inter-Governmental Maritime Consultative Organization (IMCO) whose prime purpose was the safety and security of international waters. To the context of this paper, IMO nowadays embodies a much larger role in technicalities driving initiatives of reducing emissions from international shipping.

IMO materialized their initial strategy to reduce emission of greenhouse gases in 2018 where 100 participants attended at the IMO headquarters in London. The initial strategy served as an international acknowledgement and commitment of the goal to achieve net-zero-carbon emissions by year 2050 with a supporting benchmark of 40% reduction by year 2030 in comparison to data from 2008 (IMO, n.d.). The strategy also called for empowering measures towards capacity building, technical cooperation, research and development. Conversely, constraints were also identified and listed as challenges to be resolved collectively.

Though IMO is indirectly invested in green technology design, their frontline drivers are code and regulatory compliance. Such is accomplished through two main streams in the

Energy Efficiency Design Index (EEDI), and the Ship Energy Efficiency Management Plan (SEEMP). EEDI aids the mission of reducing emissions through design efficiency, while SEEMP assist by enhancing operational efficiency.

The Carbon intensity indicator (CII) is a metric that is enforceable by IMO which relies on amount of consumed fuel for covered distance. The CII can be calculated from the more inclusive Energy Efficiency Operational Indicator (EEOI) which factors in time, distance, and fuel consumption during voyages, birthing, and anchoring. Average Efficiency Ratio (AER) is a slight variant of EEOI relying on the overall deadweight instead of cargo weight. EEOI and AER metrics are not enforceable but can be disclosed on voluntary basis for research and development. (Odfjell, 2020, pp.7-8).

That said, Ships Manufacturers can struggle to obtain such information post ship delivery in support of design efficiency, except where collaboration agreements are in place with the owner(s). Kim et. al. (2020), states:

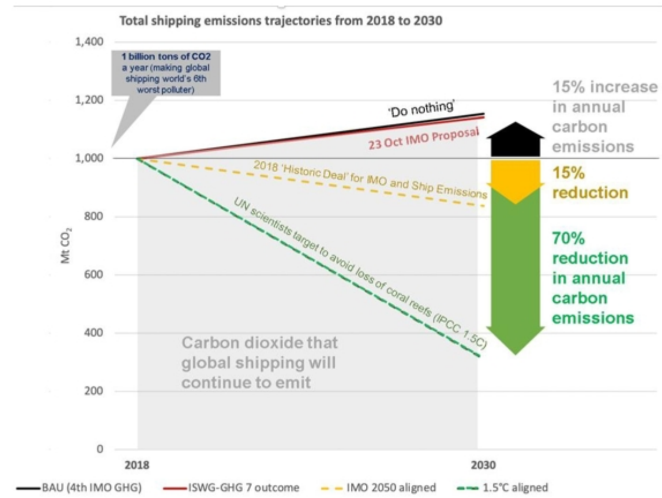
"The public data available to shipyards include ship dynamic data, ship static data, and ocean environmental data. The ship dynamic data include time, position, speed, draft, and other variables which are time- and condition-dependent. These data can be obtained from the Automatic Identification System (AIS). The ship static data include principal dimensions, engine specifications, and other constants that are unchanging over time and condition. The ocean environmental data refers to weather data such as wind, waves, and current" (para.3).

It is increasingly becoming a popular model for owners to own stakes in shipyards to reduce costs of new-builds and maintenance; benefit from shares in net profit; and collaborate towards research and development projects.

Though IMO has exerted meaningful efforts to achieve its strategy objectives, it has fell short of pre-set benchmarks. The consequences of current trends are projected to exceed the 1.5 °C benchmark which jeopardizes the survivability of various ecosystems. Degnarain (2020), explains after the 2020 convention "IMO will not be imposing any meaningful penalties for ships that fail these weaker greenhouse gas standards" (para.3). The outcome of 2020 convention deviated from the central point into important but less prominent issues surrounding spills and ship sinking. Below graph shows projections for current trajectories as compared to IMO's goals and the 1.5 °C global benchmark.

A major reason for this shortcoming is the mismatch of commitments where some countries opted to capitalize on gaps such as by registering ships under different nation flags. These practices provide an relief from the collective responsibility and accountability. One country was found to host registration for 70% of global shipping vessels as a measure of increasing profitability by creating an ambiance of relaxed enviromental standards. As portrayed in above graph, the failure of 15% reduction remains far beyond the 1.5C goal which is set at 70% by year 2030.

Regional. As international regulatory enforcement is being politically challenged, more customized and regional approaches are being encouraged. One of these approaches is exemplified



Source: Degnarain, 2020.

in the Euro Emissions Trading System (EU-ETS). The system integrates important realms of flexibility, cost effectiveness, and business-practicality. The EU-ETS works by enacting an overarching carbon cap on all industries and amenities with GHG emissions. The program works by assigning specific carbon allocations while allowing for carbon trading as a measure of flexibility and enablement. The model provides effective symbiosis where entities that cannot afford the capital cost associated with green transition can be mandated to incur smaller but affordable payments through purchasing carbon allocations. This measure works to ensure continuity for industries who otherwise would be unable to coop with the burden of capital cost but also benefits those who incur the capital investment by enabling them to sell unused carbon allocations. To the later, these payments contribute to the overall Return On Investment (ROI) which is a measure of further incentivizing heightened green performance. The EU-ETS practice is increasingly popularized with interests from countries like Canada, China, Japan, New Zealand, South Korea, Switzerland, and the United States (European Commission, n.d.).

3. Decarbonization and neutrality pathways.

Post lowering emissions, the next step towards carbon neutrality is to enact decarbonization projects in order to offset mid to long-term emission inevitabilities as well as reversing the historical build up. Carbon accounting and inventory can be accomplished through pollutant emissions across the value chain reflected against 100-year and 20-year GWP (Comer and Osipova, 2021, p.2). The accumulation of such data serves as a critical interlink with carbon disclosure as covered previously in the Social Responsibility section.

Decarbonization can be attained through two main streams: industrial via Carbon Capture and Storage (CCS) and natural via Carbon Sequestration means. Additionally, the Climate Neutral Now provides opportunities to offset carbon records via sustainable development.

The natural route through the support of carbon-capturing ecosystems chiefly through the nourishment of forests and oceanic ecosystems. According to Waring et. al. (2020), “forests absorb approximately two gigatonnes of carbon (GtC) annually, making an important contribution to the terrestrial carbon sink” and by measures of human interference “A recent analysis suggested that planting trees on an additional 0.9 billion hectares could capture 205 GtC” (para.3). Both potentials are estimates over a 100-year timeframe with linear returns on the time axiom. That said, there are other subliminal rewards to the green cover, namely subduing the extreme hot temperature on the local and regional levels as scaled with proportional levels of logistical and biophysical challenges.

Oceans sequestrate between 1400 and 20,000 GtC of CO2, the highest amongst other sedimentary basins forming one third of carbon capture (Rabiu et. al., 2017). Earth oceans also account for 90% of atmospheric heat absorption. Though the carbon capture process is natural, the overwhelming amount of carbon uptake paralleled by various compromises to oceanic ecosystems highlight the need for man-made intervention to nourish these systems. In a particular context, ocean acidification, a consequence of increased emission of CO2, reflects negatively on the sustenance of seaweed and coral reefs largely responsible for ocean sequestration. This further reinforces the need for acting in parallel to reduce emissions and nourish ecosystem in order to achieve a sustainable balance.

The industrial route, on the other hand, has the potential to expand towards exciting prospections. Roberts (2019), explains the Carbon Capture and Sequestration (CCS) as the means to directly pull CO2 out of the air and bury it underground in saline aquifers (para.4). The utility and necessity of such pathway has a direct correlation to current rates of emissions where upon its reduction, the economic feasibility of such pathway can be significantly reduced. Lebling and Northrop (2020), mentions “How much carbon to remove from the atmosphere will depend on emissions in the coming years, but estimates point to around 10-20 billion tons of CO2” (para.2).

Climate Neutral Now – a secretariat of the United Nations Framework Convention on Climate Change provides opportunities to compensate for emission inevitabilities through Clean Development Mechanism (CDM). This window of opportunity targets developing countries for sustainable development projects while offering credits to offset GHG emissions to contributors. The crediting system is referred to as Certified Emission Reduction (CER) credits which indirectly pours into several other SDGs in addition to previously addressed climate-focused SDGs.

4. Discussion

Mid-term consequences (Iatrogenics) are bound to happen in the transition towards green and sustainable technology. Their prevalence can be considered a disguised as in the noise vs. signal paradox. Methane slip for example as an Iatrogenic to LNG has the potential to overthrow the feasibility of the entire pathway. While the noise can be to encourage more advancements and technical improvements to mitigate unintended releases; the signal could be to abandon development given the amount of commitments required for contemplative returns.

It is encouraging to explore multiple alternative fuel pathways but the magnitude of investments and exertion of resources must continually be weighed against the principle objective. So far, all pathways are presenting significant hindrances, the resolution of which leads to even more investments and exertion of resources. A balanced weighing approach is ought to be employed to avoid exceeding the point of diminishing returns after which investments become more burdening than empowering. Projects may be driven to continue only to attain the ROI which can be considered as a sub-iatrogenic. Future developments ought to be mindful of the blind cascading approaches whereby following a chain of interlinked logic, the focus shifts towards succeeding in the pre-established mission at the expense of the principal objective. This abstraction is exemplified in the LNG vessel-to-vessel refueling solution where the solution to overcome the cost of upgrading of infrastructure elicited the vessel-to-vessel concept development. While such can seem like an effective solution providing dynamicity, the carbon footprint across the entire value chain of building and operating refueling vessels can offset the marginal reduction in emissions to that of the LNG pathway. These investments ought to be directed to more fundamental resolutions that inherit objectives rather than misled optimism. This is not to say that LNG has no viable future but if the wight of investments is contemplated across the domains of challenges, better net results could be achieved in other pathways. The principal goal should be anchored on minimizing emission and perpetuating sustainability. Our diligence, therefore, should be to balance resource allocation across all potential possibilities and with a long-term lens rather than overcommitmentting to preconceived paths whose aids to the original mission have been realized to be insignificant.

5. Research Limitations

Literature review availed that more research is needed in areas of nuclear-powered vessels for shipping applications. Nuclear is already a potent green technology whose drawbacks are fundamentally regulatory and legal, paralleled by over conservatism towards its exposure safety. Because nuclear technology for powering vessels is largely military-based, there are not enough sources to be analyzed as unenriched SMRs remain promising but contemplative.

Another limitation relates to the sustainability of supply chains and recycling approaches where the concept is yet to be considered mainstream for credible data analysis. Examples provided serve as a precursor to future explorations in sustainable sourcing and power-saving opportunities. This limitation is already deliberately and inadvertently in the works towards resolution largely made by advancements in green energy in power grids.

More data collection towards unintended impacts associated with (iatrogenics) is needed along the various pathways of development with lifecycle assessment approach. Lifecycle research aids full technological and logistical maturity for any given pathway. As addressed previously in this paper, these data are critical to formulate standings which then can serve as qualifications for various entities within the supply chain. In modular approach such score would then interface to that of the products for a collective green score.

6. Future research

Nuclear technology spearheads the purpose of this research given it transformative potential. SMRs surpasses all other limitations posed by other alternative fuels which makes them a great prospect towards the goal of net-zero emissions. SMRs are inherently long-lasting fuel ranging from 5-7 to 20-30 years largely hinging on amount and enrichment levels of uranium. This self-sufficiency factor bypasses the struggle of port infrastructure and complex fuel delivery systems which might translate into a much lower carbon footprint across the entire value chain measured by a lifecycle assessment. The risk of nuclear proliferation needs to be mitigated by exploring various methods of control and governance. However, political tensions surrounding access and know-how can be a struggle, especially towards developing countries. All these complexities may be demotivating to investigate but in the lack of dependable alternatives, our climate may be worth having these guards lowered.

All sections of this paper warrant a future research even in cases where technologies are well-established from other industries. Technological transcendence requires extensive compatibility analyses and testing prior to adoption. On the other hand, technologies that are early on in their development such as fuel cell and other alternative fuels will continue requiring additional research for intended outcomes.

Big data and digitalization have great potentials to aid sea traffic management, condition-based monitoring, and maintenance, as well as design efficiency. As systems become more advanced more data will be available for harnessing which maximizes on the chances of exploiting little hidden efficiencies that are hard to be discovered and acted upon via manual means.

Conclusions.

As our world realizes the diverse implications associated with increasing GHG emissions, it is imperative to have green and sustainable solutions enabled, incentivized and/or mandated. Maritime shipping though marginal in GHG emissions according to current standings, poses severe trajectories as global trading continues to expand. As these solutions are explored, short-to-medium term iatrogenics are bound to happen. These hidden indirect consequences often lie outside isolated frames of assessment which renders lifecycle thinking as the ultimate measure of solutions' viability. The shift towards green and sustainable maritime shipping is largely challenged by an interface of economics and technology both of which require a robust enabling structure to ensure practicality and competitiveness. Although significant advancements are made in technical, economical, and regulatory enablement, overall GHG goals remain in serious jeopardy. Technical advancement has relaxed parameters of expectations justified by the financial resources required to achieve unactualized potentialities. That said, meaningful technological advancements are still being undertaken at a contemplative pace. On the economic front, sustainable financing is championing efforts of financial enablement as it works sway financing solutions towards industries with enhanced environmental performance. The regulatory part seems critical but not prominent towards the green shift; however, the network of social responsibility, sustainable financing, and various pathways of neutrality are increasingly taking lead roles. Social responsibility is a measure of heightened community engagement through public disclosure of factors that influence the common fate. By the same token, sustainable financing accounts for disclosed environmental performance in its financing criteria. Moreover, neutrality pathways serve as the second line of defense as it works to offset short-to-midterm inevitabilities as an enabler of environmentally conscious livelihood.

Question 1.

What is the maturity ranking of alternative fuel pathways and how can current platforms be adjusted to accommodate their limitations?

Answer. HFO and VLSHFO coupled with double scrubbers and other mitigating solutions remain the most competent fuel for maritime shipping. Carbon reduction measures coupled with abundant energy density qualify HFOs and VLSHFO for 1^{st} place given corresponding limitations of alternative fuel pathways to varying degrees. Despite HFOs being predominantly considered as the most impactful pathway with regards to emissions, incremental developments throughout its service have rendered its GWP less than its most competitive rival: LNG.

LNG is the second technically mature fuel as it has the highest energy density to that of other gases and 25% less carbon emissions than HFO. However, because of the associated methane slip, its viability as a green solution is greatly compromised. LNG throughout its well-to-wake assessment produced higher GWP (at varying rates corresponding to various engine applications) than HFO and VLSHFO. While advancements in technology is likely to curb such inadvertent impact, LNG remains as potent semi-practical with drawbacks in the areas of reduced cargo space, competent access, and renewability. The only exception which overturns these constraints into advantages is for LNG carriers where the fuel is consumed from the cargo. HFO-powered LNG carriers are reversely disadventageous for the extra room needed for fuel storage.

Ammonia ranks third due to its renewability potential and 0 carbon emissions. Though ammonia has significantly less energy density than HFOs, it is increasingly being popularized with solutions such as vessel-to-vessel bunkering. The vessel-to-vessel bunkering reduces fuel space requirements by enabling shorter refueling intervals. However, compromises to cargo space and cost associated with complex fuel delivery systems remain as significant challenges. Other light gases and pathways have greater struggle in the areas of energy density, sustainability, and reliability.

The nuclear pathway is discussed in separation because the maturity of technology is contextual to desired application. While military applications have matured to great extents, commercial outlooks require further development in various SMR applications. Nuclear is advantageous in areas of cost, emission, refueling, space required, power & capability. Drawbacks of nuclear applications to power commercial vessels is largely regulatory and political which is likely to subdue as novel nuclear technology become more common. Further, Low to unenriched SMRs bypass the environmental challenge associated with disposal of radioactive materials. Though HFO and VLSHFO were ranked 1^{st} in the category of accessible technology and fuels as they pertain to commercial applications, Nuclear offers the most promising results in technical requirements.

Question 2.

What hindrances are posed by the network of support domains indirectly responsible for overall pathway feasibility?

Answer. Fueling is a central factor that can act as an enabler or a hindrance where accesibility is deterministic towards overall viability in considerations of well-to-wake scoring as well as operatoinal practicality. Solutions to ensure competent accessibility of fuels have been materialized through the vessel-to-vessel bunkering which is projected to expand in proportion to increased fuel demand. This remains a good option providing flexibility of location and diversity of contemplated fuel pathways as opposed to upgrading ports infrastructures which are fixed and require major capital investments.

As economics are major driver of success to the green shift, sustainable financing acts as an enabler towards greener and more sustainable economy. Advancement of technology hinges heavily on availability of funds for research and development as well as marketability of end-products. Therefore, it is essential to not only empower development of green technology but to disincentivize its commercially competitive counterpart. Hence, sustainable financing models such as TFCD and ESG integrate environmental performance, social responsibility, and regulatory compliance in holistic approach that ensures a calculated balance between empowerment and accountability.

Question 3.

What is the achievable level of greenhouse influx from contemplated alternatives and what are the inadvertent mid-term consequences resulting from this shift?

Answer. The entire value chain needs to be at a relative range of equilibrium to support sustainable lifecycle approach. Conventional steel sourcing and manufacturing (being upstream) could render downstream solutions as ineffective to a level of null offset. Disproportionate positively geared investments could lead to nullifying desired impact by virtue of misalignment or hidden consequences. Hidden consequences are referred to as iatrogenics and those are demonstrated in conventional power generation to produce green products such as batteries and fuels such as hydrogen. As the power network becomes greener and more sustainable on mainstream scales, these inadvertent impacts are likely to subside but in a global context, these are examples of mid-form iatrogenics.

Having established that HFOs currently outperform LNG and with a less environmental impact according to 2020 report by The International Council on Clean Transportation; the, the most practical green pathway to be explored and/or contextualized is the nuclear pathway. Overall technical viability of green solutions can be scored objectively; however, other attached domains of relevance can render interpretations as subjective. Herewith, nuclear power as represented by the SMR technology is deemed as the most practical and potent pathway due to uncompromised power delivery, GHGs reduction potential, self-sufficiency in refueling, and no notable loss to cargo space.

Question 4.

What are the performance indicators that quantify decarbonization initiatives towards climate change and what is the optimum solution to achieving a state of carbon neutrality?

Answer. There are various environmental performance schemes that interface with enablers through a mutually constructed scoring system such as the ESG model. The reliability of such model is validated through an interposition of a third-party auditor that is indifferent to the outcome of the assessment. Also, the TFCD is an equally potent solution that started out of Europe but is expanding to other regions like Singapore and the United States. All decarbonization and neutrality pathways pour into the SDGs, but the most direct and sensible form is through socioeconomic development such as in the UN's Clean Development Mechanism. Solving issues of poverty and health and safety provide tangible and expedient evidence of reflection. Offsetting carbon emissions through natural and industrial systems are two instrumental pathways whose importance must not be undermined.

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