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Discussion Paper

# A Maritime Sector in Transition – Learning from Other Sectoral Energy Transitions

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# Abstract

The maritime sector currently contributes approximately 2.3% of global $CO_2$ emissions, with projections suggesting that this share could rise to 10%-13% by 2050, highlighting an urgent need for decarbonization. In response to the potentially catastrophic impacts of climate change, there is increasing support for transitioning the maritime sector to cleaner fuels such as hydrogen and its derivatives to achieve net-zero emissions in the sector. This study explores how lessons from other sectoral energy transitions can accelerate and enhance the maritime sector's decarbonization process. Drawing on the adoption of renewables in the power sector and the shift from internal combustion engines to electric vehicles in the passenger road transport sector, we propose a policy framework for the maritime sector's transition. Key insights include understanding whether an applied policy measure is targeting the producers, intermediaries, or end users within a particular sector, noting that subsidies are sometimes required for more than one segment of a sector to create a pathway for a governed transition. For example, the passenger road transport sector requires a comprehensive infrastructure shift to enable its transition. Ultimately, this framework aims to identify those elements that are essential for a smooth energy transition in the maritime sector, considering its unique challenges, such as the uncertainty surrounding future fuel mixes and the necessary conditions for the large-scale adoption of alternative fuels such as hydrogen.

**Keywords:** Sectoral energy transition, governed transitions, maritime sector, decarbonization, shipping, power sector, EVs, alternative fuels, hydrogen, policy instruments

# Summary for Policymakers

This work proposes a framework for transitioning the maritime sector to net-zero emissions. Currently, the maritime sector accounts for approximately 2.3% of total global $CO_2$ emissions and is projected to contribute between 10% and 13% of total $CO_2$ emissions by 2050. The adoption of a revised greenhouse gas (GHG) strategy by the International Maritime Organization (IMO) in July 2023 and the inclusion of decarbonizing shipping on the 2023 UN Climate Change Conference (COP28) agenda indicate a global shift toward transitioning the sector. To facilitate this transition, the maritime sector can draw insights from previous transitions, such as those in the electricity sector, and ongoing transitions, such as the adoption of electric vehicles (EVs) in the passenger road transport sector, through a comparative analysis, which is presented in this work. Finally, a framework is developed to illustrate the potential pathways for transition in the maritime sector. To compare the different sectoral energy transitions (SETs); that is, an 'apples-to-apples' comparison, the sectors are divided into three segments: 'producers,' 'intermediaries,' and 'end users.' This categorization allows the reader to understand where each policy measure is proposed and how it affects a particular sector in transition. The key points for policymakers are as follows:

- The SET in the power sector has predominantly had policy measures applied in its producer segment, meaning that many of the policy instruments target the uptake of energy production from renewable sources.
- The policy measures applied in the SET of the passenger road transport sector have focused mainly on the end user segment. Variations in subsidies and tax incentives have been the main form of policy instruments that have been applied.
- The limited policy measures in the intermediary segment of the passenger road transport sector have been a factor in the slow adoption of EVs in the sector, since the charging infrastructure in the sector has not been addressed with the same prevalence of policy measures as that in the end user segment.
- For the maritime sector to attempt to expedite its governed energy transition toward its goal of zero or near-zero (ZNZ) emissions, i.e., a 50% reduction compared with the baseline of 2008, the sector must apply policies in all three segments.

# 1. Introduction

Historically, energy transitions have occurred when newer fuels have enabled greater efficiency and reliability or lower costs (Fouquet and Pearson 2012). Similarly, in the maritime sector, 'natural' energy transitions occur because of improved efficiency (technological and fuel efficiency), which allows for increased cargo handling and distance traveled, resulting in higher profits for shipping companies (Stopford 2009). The inherent characteristics of these dominant fuels, such as marine fuel oil (MFO) and marine gasoline (MGO), significantly influence the organization and functioning of this industry. For example, more efficient fuels, on an energy density basis, have made longer routes possible, which in turn has influenced the locations of ports and ancillary services (Stopford 2009). What is the implication for maritime sector organizations if such a departure from the natural flow of transition occurs? In other words, how would a governed transition (Kern and Rogge, 2016) that prioritizes low-carbon fuels trigger ripple effects across the entire maritime sector, including players, routes, costs, infrastructure, etc.? These are challenging questions to answer, as predicting the future involves inherent uncertainty due to countless influencing variables.

In this work, we propose a framework for the sectoral energy transition (SET) in the maritime sector. Our framework not only analyzes potential avenues for the transition in the maritime sector but also provides practical insights on the basis of a comparative analysis of ongoing transitions in the energy sector. By drawing on observations from transitions in the electricity sector toward renewables and electrification in passenger road transportation (electric vehicles (EVs)), we aim to shed light on different aspects of the maritime transition, thereby offering practical implications for the sector.

The maritime sector is being compelled to depart from its historical practices owing to the global shift toward decarbonizing hard-to-abate industries, thus forcing the sector to abandon its historically observed principles. Currently, the maritime sector contributes to an estimated 2.27% of total greenhouse gas (GHG) emissions (Clarksons 2024), with a forecasted contribution of 10% to 13% by 2050 if no decarbonization attempts are made (IMO 2023). Considering that seaborne trade makes up approximately 86% of global trade by volume and approximately 70% of global trade by value (Clarksons 2023), there is an urgent need for swift decarbonization, pushing the sector toward cleaner fuels.

The implementation of strict emission regulations, amid growing concerns regarding climate change, has spurred the need for the adoption of cleaner alternatives in the global shipping industry. The first resolution to address $CO_2$ emissions, known as Resolution 8, was adopted in 1997 by the International Maritime Organization (IMO) with the objective of recognizing the negative effects of those GHG emissions derived from the maritime sector.

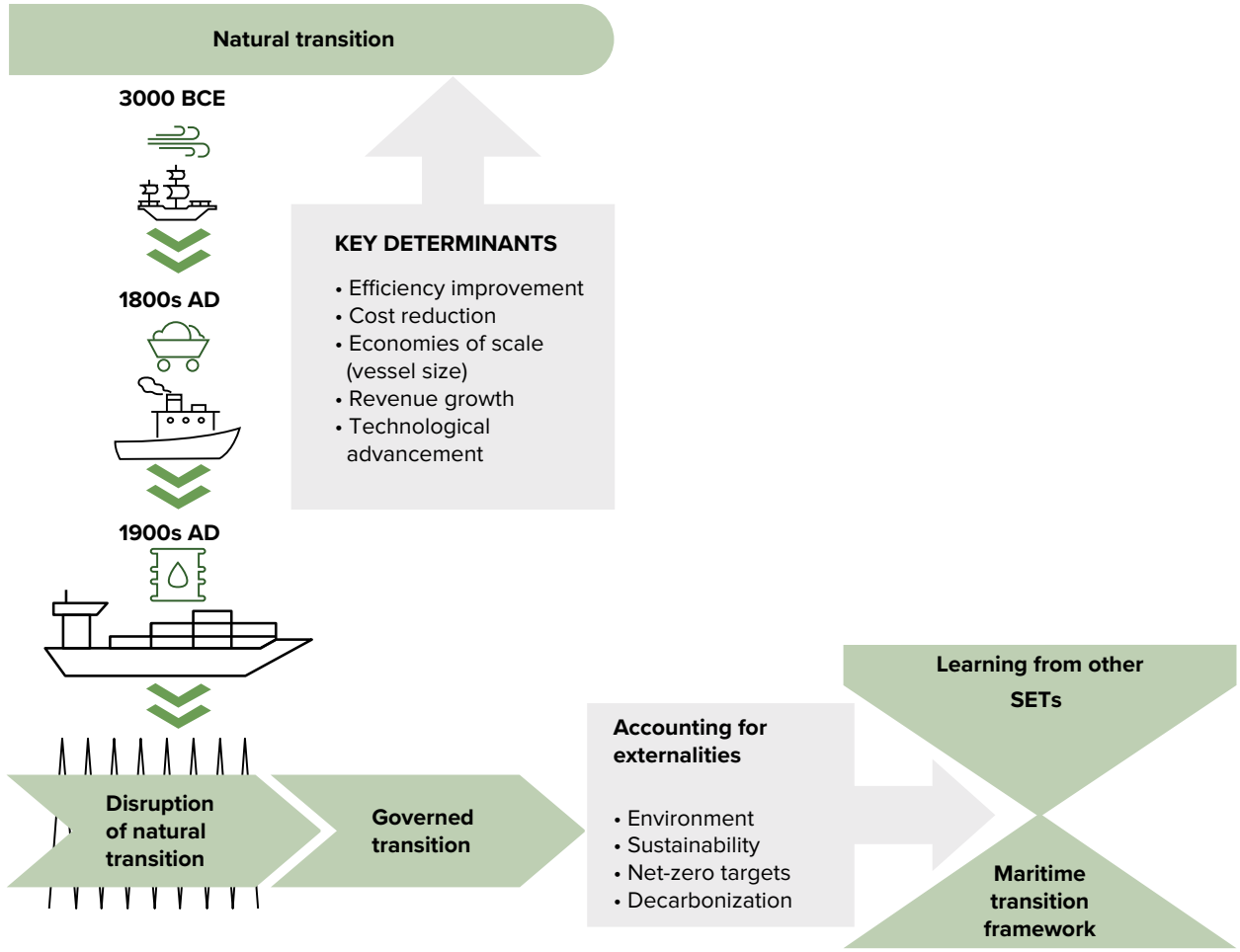
In 2023, IMO member states agreed on a revised strategy for reducing GHG emissions from ships, which aimed to achieve the following (IMO 2023):

1. Reduce the carbon intensity of ships by improving the energy efficiency of new ships.
2. Reduce $CO_2$ emissions from international shipping by 40% by 2030 compared to those in 2008.
3. Increase uptake of zero or near-zero (ZNZ) GHG emission technologies to represent at least 5% and up to 10% of the fleet mix by 2030.
4. Reach net-zero GHG emissions in international shipping by or near 2050.

These insights can be particularly useful for guiding the current governed transition — in contrast to a natural transition — in maritime shipping.

As illustrated, the natural transition observed in the maritime sector has been driven by key determinants, including revenue growth, enhanced efficiency, technological advancement, cost reduction, and economies of scale (Figure 1). Fuel transition in the maritime sector was traditionally laissez-faire based, meaning that each transition that occurred was aimed primarily at improving efficiency to increase cargo handling and maximize profits for shipping companies.

**Figure 1.** Evolution of sectoral energy transitions in the maritime sector.




*Source: KAPSARC illustration.*

Sail-based ships were historically the key vessels engaged in seaborne trade, and the dominance of such vessels lasted until the early 1800s. Since the early 1900s, vessels have transitioned from traditional sails to steamships and, ultimately, to diesel-powered engines. The current governed transition introduces new criteria that may override the principles of technological advancement thus far. These new elements encompass decarbonization, net-zero targets, and broader considerations of sustainability and environmental protection (Figure 1).

While this shift represents a new experience for the maritime industry, other sectors have undergone similar governed transitions, substituting their dominant fuel type for cleaner alternatives. Stakeholders in the maritime sector stand to benefit from the experiences of other sectors that have undergone governed transitions. On the basis of previous experience, certain guideposts can help decision-makers in policy and business 'navigate' this transition. Drawing on the transition to renewables in the electricity sector, attention is directed toward identifying effective policies that have facilitated parity and supported the deployment of renewable technologies. Similarly, in the transition toward electrification in the road transport sector, emphasis is placed on the sequential steps required to develop infrastructure, address shifts in end-user preferences, and navigate the constraints imposed by new technologies on consumers.

# 2. Literature Review

To develop our framework, we begin by delving into the literature on the history of natural energy transitions, governed energy transitions, and SETs. These concepts are all related in that they touch on the idea of energy transition, which has been defined in various ways in the literature, such as the shift from one source for energy production or use to another source (Fouquet and Pearson 2012; Hirsh and Jones 2014; Miller, Richter, and O'Leary 2015; O'Connor 2010; Smil 2010); however, when adopting different perspectives, such as exploiting the temporal element to expedite a transition and the unique element associated with a transition within a particular sector, these elements are shown to have distinct implications. Zheng, Anatolitis, and Winkler (2022) looked into lessons learned from the power sector to be applied in the hydrogen sector for the growth of green hydrogen production as an energy source. The above authors assessed several policy instruments used in the power sector to be applied in the hydrogen sector to develop green hydrogen for energy use. Below, we review the literature on governed transitions and sectoral transitions in the maritime, power and transport sectors.

Fouquet and Pearson (2012) delineated the history of energy transitions and emphasized the importance of understanding transitions from a sectoral and industry standpoint; they elucidated how improvements in the efficiency, reliability, and cost reduction of new energy technologies over incumbent technologies have traditionally driven energy transitions. Additionally, the above authors noted that, in general, for energy transitions to be successful, the cost associated with the new energy source must be lower than that associated with the incumbent source.

Stopford (2009) provided detailed insights into the natural transition in the maritime sector, offering a foundation on maritime economics, history, and sector composition, which provides a greater understanding of the organization of the maritime sector and the natural progression of the commercial fleet. Stopford (2009) noted that, historically, fuel transitions in the maritime sector operated on a laissez-faire basis, focused primarily on enhancing efficiency to bolster cargo handling and maximize profits for shipping companies.

However, contemporary challenges related to global climate change are compelling the maritime sector, similar to other sectors, to undergo a transition that is expedited using policy measures, regulations, and incentives to reach a particular level of transition within a certain timeframe. This type of transition is known as a governed transition, as noted by Kern and Rogge (2016), who argued that the pace of transition is affected by an interplay among agency, international dynamics, and the global energy system. Notably, in a governed transition, the timeframe of the transition can be controlled (Kern and Rogge 2016). This concept is an extension of the work of Sovacool (2016), who looked at the temporality of energy transitions and the necessary baseline definition required to address energy transitions.

Ampah et al. (2021) conducted a thorough review of the literature in terms of the evolution of published work on the decarbonization of the maritime sector, looking at 503 published works reviewed via bibliometric analysis. The key finding of the authors is that the decarbonization efforts, thus far, in the maritime sector have been based on improving technological efficiency and, more recently, fuel change.

Olczak and Piebalgs (2023) delved into the frameworks developed by the IMO and the European Union (EU) for decarbonizing shipping. The authors specifically looked at the policy measures applied by the EU to reduce emissions, which include the addition of maritime emissions in the EU Emissions Trading Scheme, increasing the share of renewable energy, and removing exemptions for the intra-EU maritime transport sector. These policies have come into effect only recently; therefore, their effects on the sector have yet to be clearly identified.

Urban et al. (2024) used a mixed-method approach to understand the interlinkages between the maritime sector and other sectors, specifically the transport, energy, industry, agriculture, and forestry sectors. The above authors looked for coupling opportunities between the sectors, where coupling is defined as the use of residual products from other sectors to produce low-carbon fuels for the maritime sector. In Kyprianidou et al. (2021), the authors developed a marginal abatement cost curve for the maritime sector to rank GHG mitigation efforts by testing several types of vessels; the authors reported that a 17% reduction in emissions could be achieved through the application of mitigation efforts.

Fouquet and Hippe (2022) explored decarbonization and digitalization transitions from a European perspective and noted that the key lesson learned from the sectoral transition in the electricity sector is the concept of the achievement of grid parity, which considers how alternate energy sources can produce the same amount of energy at the same levelized cost as that of the incumbent energy source. Focusing on the concept of grid parity, Olson and Jones (2012) concluded that the intersection between the decline in the cost of renewable resources and the rise in the cost of conventional resources is where 'grid parity' is achieved. The above authors also examined the role of policymaking in initially achieving grid parity for the electricity sector. Furthermore, Munoz et al. (2013) touched on how grid parity can be used as a benchmark for competitiveness. Thus, the concept of grid parity can be translated into the maritime sector in some way.

When looking at the electrification of road transport, specifically the adoption of battery EVs (BEVs) in the light-duty market, Nilsson and Nykvist (2016) explored the governance implications of transitioning to BEVs by combining scenarios with a multilevel perspective to arrive at the necessary policy interventions for successful BEV uptake. Kotilainen et al. (2019) examined the challenges and opportunities in accelerating the EV transition in Nordic countries, with a key observation being that incumbent industries, given their interdependencies with existing institutions, can shape policy choices that hinder the adoption of EVs. Lemphers et al. (2022) examined the factors that contributed to the leadership of California, Norway, and Quebec in terms of EV adoption. The literature contributes to the understanding of how regional innovations, assets, and political mechanisms shape the leadership of jurisdictions in EV adoption. Although each case study has context-specific elements, overall leadership is the result of intentional forethought with early policies promoting EV adoption and the successful implementation and execution of such policies.

By and large, the literature on SETs remains somewhat lacking, presenting an opportunity for its further development and integration with existing research.

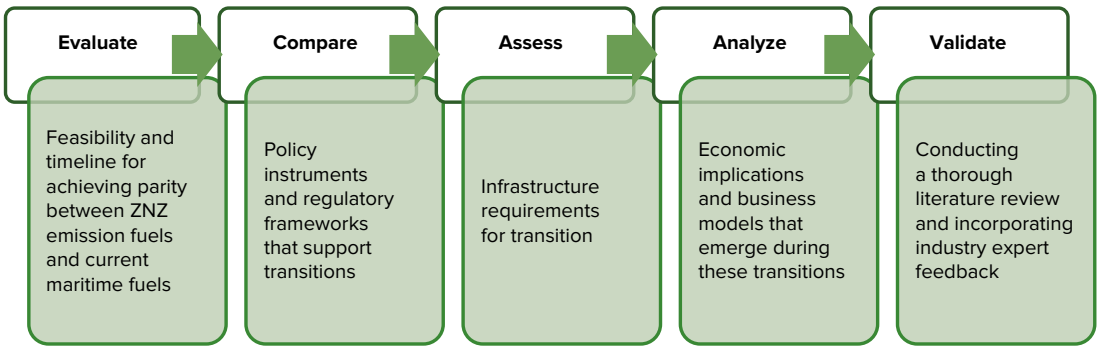
# 3. Methodology

We use a comparative analysis framework, which is a structured method used to systematically compare two or more phenomena to understand their similarities and differences (Schmitt 2012). Comparative analysis has been used to study energy transitions, providing insights into the varying factors and outcomes across different contexts (D'Amato et al. 2017). We aim to identify common challenges and opportunities in the electricity and road transportation sectors and the maritime sector to inform policymakers of more effective strategies for achieving sustainable energy transitions. We choose the electricity and road transportation sectors because they have already undergone similar substitutions, such as the use of renewable electricity and the electrification of passenger transport, and can provide valuable insights for the maritime sector (Zheng, Anatolitis, and Winkler 2022).

This study systematically compares the sectors using selected criteria to highlight commonalities and differences. The data collection process involves observing the energy transition in the mentioned sectors. A thematic arrangement is then used to identify and analyze recurring themes related to technology adoption, policy support, infrastructure requirements, and user engagement, which is achieved by conducting a thorough review of existing research on the energy transitions within these sectors. The key sources include academic journals, industry reports and policy documents. These secondary data sources establish a strong foundation on which to understand the dynamics of energy transitions and identify relevant themes and variables (Zarnikau 2011; Alagappan et al. 2011; Poudineh, Sen, and Fattouh 2018).

The comparative analysis focuses on several key variables from two perspectives. First, the analysis organizes the internal workings of each of the sectors into

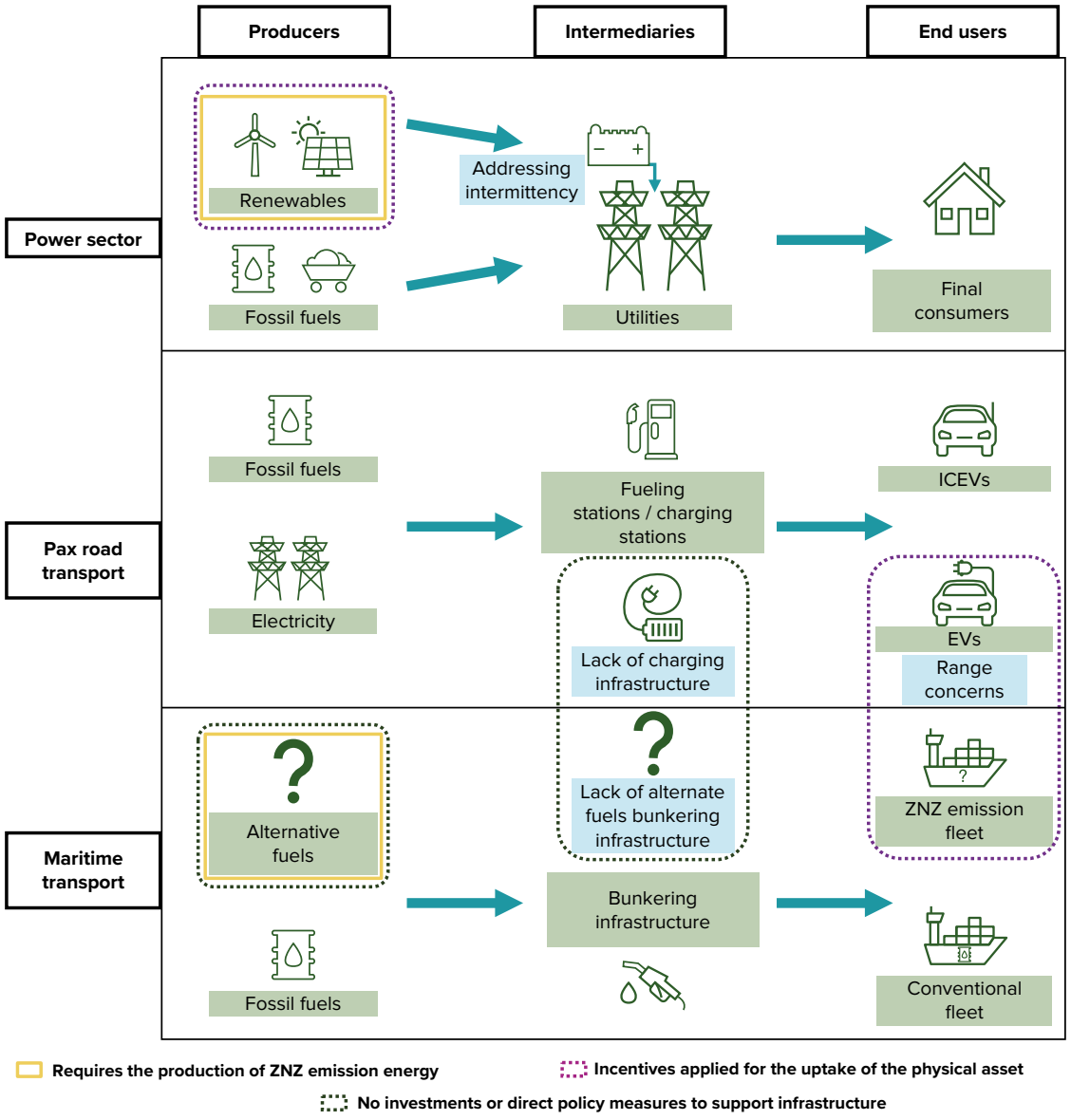
**Figure 2.** Comparative analysis criteria.




*Source: KAPSARC illustration.*

the following three segments: producers, intermediaries, and end users (Figure 3). This approach creates a baseline to allow for the comparison of the effects of policy measures on the precise segment in each sector. By doing so, a greater understanding of where policies should be applied for the maritime sector emerges. Second, the comparative analysis focuses on policy frameworks, infrastructure requirements, stakeholder engagement, and technology adoption/constraints. By investigating the success factors of technology integration in the power and transportation sectors, examining the regulatory and policy measures that facilitate these transitions, analyzing the involvement and response of different stakeholders, and assessing infrastructure needs and requirements, this study aims to draw actionable insights for the maritime sector (Figure 3).

**Figure 3.** Sector segmentation and relationship between SETs in the power, passenger (pax) road, and maritime sectors.




*Source: Authors' illustration.*

The producer segment covers all the activities related to the production of energy, whether conventional or alternative ZNZ activities. The intermediary segment details the infrastructure required or existing to transmit, fuel, and/or charge the end-use assets with ZNZ energy. Finally, the end user segment is defined as comprising the receivers/adaptors/users of these new technologies, which utilize ZNZ energy (Figure 3).

For the power sector, key policy measures and incentives are created to target the producer segment to establish an uptake of renewable technologies for use in electricity production. The reason for this is that the key transition in the electricity sector is the production of ZNZ energy to fuel the electricity sector. Similarly, the maritime sector requires the production of ZNZ energy fuels; however, in the case of the maritime sector, there have been no investments or direct policy measures to support the required development and production of these ZNZ fuels (Figure 3).

In the passenger (pax) road transport sector, directed policies such as subsidies and other incentives (financial and nonfinancial) targeting the end user segment are crucial for the uptake of sales of EVs by customers. Moreover, in the maritime sector, policies to promote the adoption of alternative fuel vessels are underway, which means that they target the end user segment as well. Both the pax road sector and maritime sector lack investments in infrastructure for the intermediary segment, meaning that both the pax road sector and maritime sector lack the necessary forms of fueling stations, whether they are EV charging stations or bunkering infrastructure for vessels (Figure 3).

The research design acknowledges certain limitations. For example, unlike other sectors, the maritime sector does not have a specific fuel in its governed transition, as is the case of renewables. Instead, various competing fuel options, such as ammonia, methanol, hydrogen, liquefied natural gas (LNG), and biofuels, many of which are in their infancy, are being explored for use in the maritime sector. Additionally, there is a risk of case study selection bias. The chosen case studies may introduce bias, as sectors with successful transitions may not fully represent the challenges faced by the maritime sector. Generalization is also a concern, as the findings from the electricity and road transportation sectors may not apply entirely to the maritime sector because of inherent differences in operations and infrastructure across sectors. We explicitly address the contextual differences in the analysis, which can guide future work in addressing these concerns in more detail.

# 4. Evidence from Other SETs

This section analyzes the lessons learned from SETs in the power and road transport sectors as proven evidence to support SETs in the maritime sector. The electricity sector's shift toward renewables and the road transportation sector's adoption of EVs offer distinct analysis perspectives. Regarding the transition to renewable energy in the electricity sector, we are looking at how grid parity has been achieved through various policy instruments, which have been successful in maintaining such parity. In terms of the transition to EVs, which is an ongoing transition, we are focused on understanding behavioral changes in transportation driven by the shift in fuel type.

## 4.1 SET – Electricity Sector

The energy transition in the electricity sector refers to the shift toward renewable sources. This shift has been achieved by making renewables competitive with fossil fuel generation (Timilsina and Shah 2020; Timilsina 2021; Luderer, et al. 2022). Grid parity in the electricity sector refers to the point at which renewable energy sources, such as solar and wind, can generate electricity at a cost that is competitive with conventional grid-supplied electricity, without subsidies. Achieving grid parity is crucial for the widespread adoption of renewable energy technologies. This transition has been facilitated by a combination of technological advancements, economic factors, and supportive policy instruments (Zarnikau 2011; Abdmouleh, et al. 2015). This section examines the impact of policy instruments on achieving this goal in each of the segments identified in the Methods section.

### Producer segment

For the power sector, the key for the decarbonization of the sector is the transition of fuel sources from hydrocarbons such as diesel, natural gas, and oil to renewable sources such as wind and solar. The key driver of the uptake of renewables in the energy mix of the electricity sector is the policy measures applied, which have led to an increase in investments in renewable technologies, specifically wind and solar technologies. Several incentives have been applied with varying degrees of success. These policies include feed-in tariffs (FiTs), renewable portfolio standards (RPSs), tax incentives and research and development (R&D), among other incentive policies.

Table 1 outlines various support mechanisms for renewable energy, including FiTs, RPSs, and tax incentives. These insights can guide policymakers in facilitating the energy transition.

No single policy instrument can be solely attributed to causing grid parity in the electricity sector (Xin-gang et al. 2020; Weigelt Shittu 2016; Lund 2011; Abdmouleh et al. 2015; Breyer and Gerlach 2012). Instead, a combination of policies tailored to local conditions, continuous financial incentives, and addressing market and regulatory barriers have been essential for achieving grid parity. A combination of FiTs and RPSs adjusted to local conditions is more effective in achieving grid parity for renewable energy sources such as wind and PV power in China. Additionally,

**Table 1.** Policy instruments applied in the producer segment for the promotion of renewables in the power sector.

| Instruments | Insights | |
|---|---|---|
| | Pros | Cons |
| Feed-in-tariffs (FiTs) | | |
| Typically, a guaranteed fixed price for renewable energy. Properly designed FiTs can provide long-term revenue certainty for investors. | – If properly designed, FiTs can provide long-term financial stability and promote renewable energy technologies more effectively than can alternative support schemes (Kim and Lee 2012).<br>– For instance, the German FiT scheme has significantly driven innovation in renewable energy technologies (Hita and Löschel 2014). | – Poorly designed schemes can lead to economic inefficiencies and increased electricity prices.<br>– In some European countries, the reduction in FiTs, after achieving parity, has led to decreased investment in new renewable capacity, suggesting that it is difficult to sustain grid parity without stable policy support (Nordensvard and Urban 2015). |
| Renewable portfolio standards (RPS) | | |
| Regulatory mandates to increase the production of energy from renewable sources. RPSs are designed to promote the adoption of renewable energy technologies and help them achieve grid parity, where the cost of renewable energy is equal to or less than that of conventional energy sources. | – The stringency and design features of RPSs, such as resource eligibility and cost recovery, significantly influence the growth of renewable energy markets. A one-point increase in RPS stringency leads to increases in renewable energy generation and capacity (Bhattacharya, Giannakas, and Schoengold 2017).<br>– In Korea, the transition from FiTs to RPSs shows a higher learning rate for photovoltaics (PVs), suggesting that grid parity is expected to be achieved under the RPS system rather than the FiT system (Hong et al. 2020). | – The introduction of RPS increases the price of regular power, and its impact on green power prices and quantities is case specific, depending on various factors such as consumer preferences and competition among suppliers (Feldman and Levinson 2023). |
| Tax incentives | | |
| Tax incentives come in various forms; however, one commonality is that they allow for users to deduct a certain percentage of expenditures from their income. They are particularly effective in the early stages of technology adoption. | – Tax incentives can lower the cost barriers for renewable energy projects (Song et al. 2020). | – Carbon pricing, although theoretically effective, has faced political resistance and has not been uniformly implemented. Inconsistent pricing levels and loopholes have limited its effectiveness (Abrell and Kosch 2021).<br>– Green certificates have been less effective due to their complexity and the administrative burden associated with them. Additionally, fluctuating certificate prices have introduced uncertainty for investors (Pavaloaia et al. 2015). |

(*Continued*)

| Instruments | Insights | |
|---|---|---|
| | Pros | Cons |
| Power purchase agreements (PPA) | | |
| Long-term contracts between energy producers and consumers, providing stable revenue streams. | – PPAs help reduce risks for investors by ensuring predictable cash flows and fostering investment in renewable projects (Backstrom et al. 2023). | – The availability of PPAs can be limited by market conditions and can require strong creditworthiness from buyers to secure favorable terms. |
| Contracts for difference (CFD) | | |
| Guarantee of a fixed price of electricity generated from renewable sources, protecting developers from price volatility. | – CFDs allow developers to secure financing by providing price stability, encouraging investment in renewable projects (Kröger, Neuhoff, and Richstein 2022). | – CFDs can impose unnecessary risks on developers, leading to higher support costs due to the conditional nature of payments based on generation, which amplifies incentives to locate in high-resource areas like windy or sunny sites (Newbery 2023). |
| Investment credits (IC) | | |
| A percentage discount (or fixed amount) on the initial investment given to reduce the costs of the technology. | – ICs help reduce the upfront cost of a particular project and are useful for renewable technologies whose cost structure usually skews more toward upfront costs (Bean, Blazquez, Nezamuddin 2017). | – If the IC is set too high, then it would make the government bear a higher share of the risk, while disincentivizing developers to minimize their costs (Bean, Blázquez, Nezamuddin 2017). |

government and private sector investments in R&D have led to significant advancements in renewable energy technologies, thus reducing costs and improving efficiency (Luderer et al. 2022).

## Intermediary segment

The role of transmission is critical to the successful penetration of renewable energy in the power sector. The variability and intermittency of renewable sources pose significant challenges to power system reliability and stability, making effective transmission planning and management essential for deployment. High levels of renewable integration necessitate comprehensive transmission expansion planning to accommodate diverse operating conditions and ensure efficient investment decisions (Zhuo et al. 2020).

As the degree of reliance on renewables increases, providing ancillary services, such as reactive power, to maintain voltage stability and overall system reliability is imperative for these generators. The increasing penetration of renewable energy has led to more frequent cycling and a greater number of load ramps in conventional power plants, emphasizing the urgent need for increased transmission capacity to effectively balance supply and demand across regions (Cuffe, Smith, and Keane 2012). Integrating remote renewable energy sources into the grid presents technical, economic, and regulatory challenges, requiring careful evaluation and strategic investments in transmission infrastructure (Kishore and Singal 2014).

Despite these challenges, the intermediary segment, which focuses on the transmission of renewable energy from production sources to end consumers, does not require public support in the same way as does the producer segment. The electricity sector has established infrastructure that requires minimal adjustments to accommodate electricity from renewable sources. An open access policy allows private utilities to compete in the market, facilitating the integration of renewable technologies that generate electricity and feed it into existing national utility grids, which are already connected to consumers. Thus, the transition to renewables in the electricity sector has been able to proceed without facing the complications associated with additional infrastructural elements, such as individual physical assets.

### End user segment

The end user segment is the least relevant for the promotion of renewables in the power sector. The reason for this is that the final consumers in this segment are removed from the nuances of the type of electricity being provided to them since there is no particular way for consumers to distinguish between the types of electrons coming into a household. Those individuals in this segment may have had to pay more for power that includes a higher share of renewables; however, this is not something that requires policy intervention.

## 4.2 SET – Passenger Road Transport Sector

The electrification of the passenger road transport sector is a global endeavor aimed at addressing the highest polluting transportation sector. In 2022, the transportation sector as a whole was responsible for approximately 24% of total global $CO_2$ emissions, with road transport contributing an estimated 74% of the overall sector's $CO_2$ emissions (IEA 2023). The main approach taken globally to decarbonize the passenger road transport sector has been the adoption of BEVs or some form of hybrid vehicles that reduces the use and reliance on traditional internal combustion engine vehicles (ICEVs). Many of the regulations adopted in the sector have focused on generally improving the efficiency (fuel economy, increased fuel blending, fuel consumption, and emission reduction) of existing passenger road transport vehicles (IEA 2024). EV promotion is pushed mainly through incentives and government spending (IEA 2024).

### Producer segment

In the passenger road transport sector, the producer segment, which is the primary source of energy fueling EVs, has not been directly supported by government policies. Policymakers assume that the existing power sector, already transitioning toward ZNZ carbon energy, will adequately supply the energy needed for EVs. This assumption is based on the expectation that increased shares of ZNZ energies via the SET in the power sector will render the electricity used for EVs relatively clean.

However, early efforts in many countries promoting EV adoption have not yielded the expected outcomes. The reason for this is that many regions, such as China and India, along with parts of the United States and Europe, still rely on fossil fuels as part of their energy mix, resulting in high carbon intensity in their electricity mixes (IEA 2021a). Consequently, the potential climate benefits of EVs are significantly affected by the power generation mix of a country; the more renewables there are in the energy mix, the lower the carbon footprint from EVs (Xia et al. 2022). Recent research highlights the critical importance of the electricity source for EV charging, revealing that without concurrent investments in renewable energy, the full mitigation potential of EVs cannot be realized (McLaren et al. 2016). This evolving understanding necessitates synergistic policies that not only promote EV adoption but also prioritize the decarbonization of the electricity sector.

### Intermediary segment

The charging infrastructure represents the intermediary segment of the passenger road transport sector. This is a necessary segment that has been largely overlooked and, at the same time, is the segment with considerable room for growth and investment since the EV charging infrastructure in this sector is underdeveloped (Deb et al. 2018). The charging infrastructure for EVs is an important yet understudied subject, with few studies that discuss, in depth, the importance of such infrastructure

for the uptake of EVs. Although the storage capacity of EV battery technologies has improved, which affects the range of EVs, the infrastructure for charging EVs needs to be developed to fit the needs of consumers and should be driven by several actors, including policymakers, original equipment manufacturers, utility companies, and workplaces, working together (Hardmen et al. 2018).

For charging infrastructure specifically, several challenges, including accessibility, charging speed, and charging strategy, have been identified (Abdul Qadir et al. 2024). In terms of accessibility, the increase in the adoption of EVs requires an increase in the availability of public charging stations in appropriately available locations to reduce uncertainty about the range capabilities of EVs. For charging speed, the following three distinct categories of charging power exist: level 1, the slowest, is the standard household charging level; level 2, the intermediate speed, can be found in homes and public charging stations; and level 3, which is a direct current (DC) fast charging station, has the quickest charging ability (Abdul Qadir et al. 2024). The charging strategy refers to several components that include interoperability and pricing. For EVs to compete with ICEVs, a common and easily accessible system is needed to charge vehicles between different networks without barriers. Additionally, regarding pricing, making the cost of charging EVs more economical and competitive with ICEVs can increase the attractiveness of EVs. To succeed, infrastructure requirements need active regulations and policy intervention. However, there have not been enough direct policy measures targeted toward infrastructure requirements for level 3 EV charging.

The intermediary segment of the passenger road transport sector has received a minimal number of dedicated policy measures for segment development. In the last decade, only 28 policies have been identified globally by the IEA's Policies and Measures Database, which focuses on that government spending specifically focused on EV charging capabilities and infrastructure development, with many of these policies being enacted between 2019 and the present day (IEA 2024).

## End user segment

The end user segment of the passenger road sector is the key segment targeted through several incentives and subsidies from policymakers, with the end goal of increasing the adoption of passenger EVs. To accelerate such adoption, significant fiscal incentives enable the initial uptake of passenger EVs. Both fiscal incentives and nonfiscal incentives, such as tax credits, preferential lanes, rebates, and strict emission enforcement, play critical roles in the successful adoption of EVs (Abdul Qadir et al. 2024). Policy measures, including purchase subsidies and tax rebates, were applied as early as the 1990s in Norway; later in 2008 in the United States, with California prominently providing grants and tax credits to those who purchase or lease EVs; and, finally, in China in 2014 (IEA 2021). Table 2 presents an overview of the types of policy instruments implemented to encourage the adoption of EVs in the passenger road transport sector.

However, policy interventions for accelerating the adoption of EVs have not been consistent globally, with only an estimated 20 countries having more than a 1% share of EVs in their vehicle mix (Abdul Qadir et al. 2024). One element noted in the literature that has been missing in the push for the adoption of EVs is a comprehensive regulatory framework, which not only tackles fiscal and nonfiscal incentives for EV ownership but also targets the infrastructural requirements that have not been addressed as clearly by regulators and policymakers to accelerate the transition in the passenger road transport sector.

Technology constraints have been one of the key variables involved in the slow adoption of EVs, with EV range anxiety being the most familiar challenge derived from the perception of customers on the range constraints of currently available EVs (Rainieri et al. 2023). Although there have been many technological improvements in EV batteries, they still maintain a lower energy density than do ICEVs, which is the key element affecting their range. Extreme temperatures significantly impact the lifespan of batteries, adding another layer of uncertainty to EV adoption. Policies targeting the sourcing of raw materials for batteries are important given that the components that go into the making of EV batteries also go into making important assets in other sectors, which means that there is more competition for the same raw materials across sectors. Policy measures targeting the supply chain of batteries are not prevalent, with few policies having been applied in recent years. One example is the funding for EV supply chain required delivery date (RDD) program applied for in the UK in 2021, which aims

**Table 2.** Policy instruments applied in the end user segment to promote the adoption of EVs in the pax road transport sector.

| Policy instrument | Insights | |
|---|---|---|
| | Pros | Cons |
| Tax incentives | | |
| Tax credits: reductions in income tax or sales tax for EV buyers, e.g., tax reduction for EV purchases (Iceland).<br>Tax exemption: creating an exception for certain types of technologies (EVs in this case) and categories to reach larger objectives, e.g., the Act on Restriction on Special Case Concerning Taxation (South Korea) or New Energy Vehicle Tax Exemption (China). | – Reduces the upfront cost of EVs, making them more accessible to consumers.<br>– Boosts EV sales, encouraging manufacturers to invest in production. | – Can strain government budgets, especially if subsidies are substantial.<br>– May lead to reliance on incentives rather than genuine market demand. |
| Subsidies | | |
| Granting a certain amount of money to help a particular industry grow and keep prices competitive compared to incumbent technologies. Additionally, incentivizing the purchase or use of particular technologies, e.g., EV purchase subsidies (South Korea), subsidy for setting up EVCEI for private residential buildings (Hong Kong), and car scrapping scheme to replace older vehicles with EVs and clean vehicles (Finland). | – Gives new technologies a competing chance versus incumbent technologies via monetary support.<br>– Reduces the cost of the production of a certain technology.<br>– Provides favorable purchase and lease agreements for increasing the uptake of EVs. | – Muted overall effects if the subsidy is removed prematurely or is conducted in a stop-and-go manner. |
| Public awareness | | |
| Initiatives aimed at educating consumers about the benefits of EVs and available incentives, e.g., Go Electric Campaign (India). | – Educates the public about the benefits and feasibility of EVs.<br>– Builds public trust and acceptance of new technologies. | – Requires funding that may divert resources from other critical areas.<br>– May not effectively reach all segments of the population. |
| Funding R&D programs | | |
| Grants and funds for research into EV technologies, battery development, and alternative fuels, e.g., funding for low-GHG vehicle technology R&D, demonstration, and deployment (US). | – Fosters innovation and supports advancements in EV technology, improving performance and reducing costs. | – Provides slow-to-materialize benefits from R&D investments, leading to short-term dissatisfaction. |

to commit to funding more than GBP 30 million (US$39.6 million) in R&D to improve battery technologies and the EV supply chain (IEA 2023). There needs to be more focus on supply chain deficiencies and the requirement of specific minerals for the production of batteries for EVs since some of these minerals are rare and their extraction process may release a high level of carbon emissions (Boateng and Klopp 2024).

# 5. Implications for the Maritime Transition

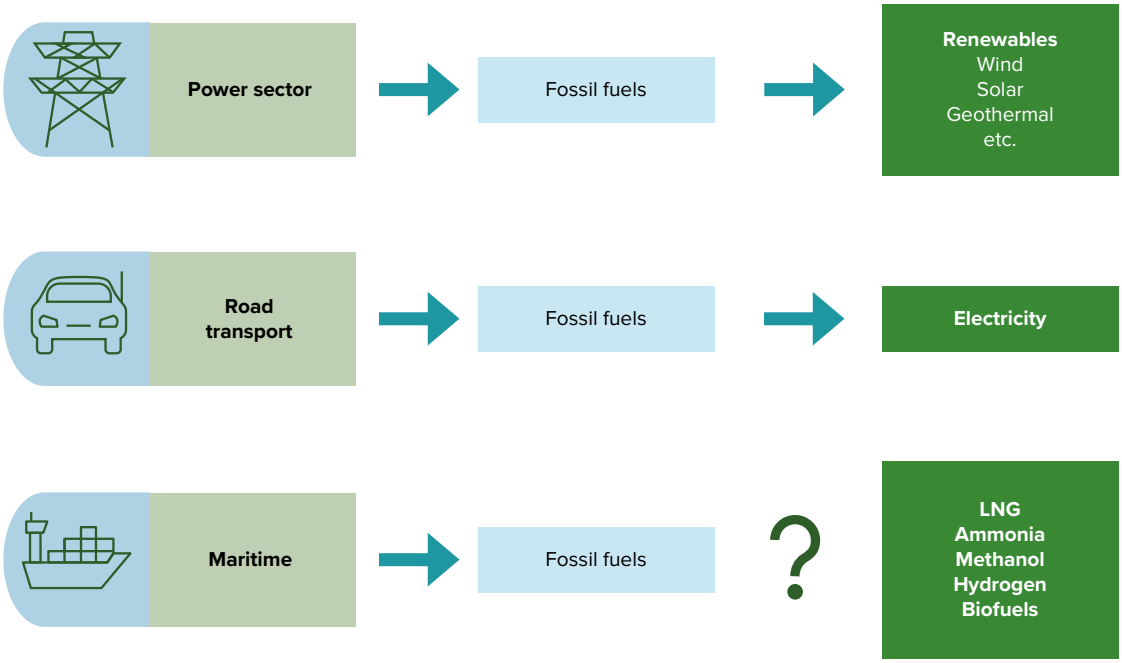
The governed SETs in the power sector and the passenger road transport sector present various lessons that can be applied to the maritime sector transition to ensure a smoother governed transition. The governed transition in the maritime sector presents challenges due to its scale, complexity, and diverse vessel types. The maritime sector is a heterogeneous industry that consists of different types of activities, including merchant shipping, naval shipping, the cruise industry, ship building, marine equipment, marine resources, marine fisheries, and marine-related activities (e.g., marine tourism, ocean surveys, and marine biotechnology) (Stopford 2009). The cost of transitioning to cleaner technologies in the maritime sector can be substantial; hence, it is imperative for policymakers to support the governed transition in the maritime sector by providing incentives and subsidies to all relevant segments of the sector.

### Producer segment

The producer segment for the maritime sector shares similarities with that of the power sector, where both sectors require a transition from energy sources with high carbon emissions to energy sources with ZNZ carbon emissions (Figure 4). In the case of the power sector, the transition aims to move away from fossil fuels toward renewable technologies such as wind, solar, and geothermal technologies (Figure 4). Similarly, the maritime sector currently does not have one particular fuel source targeted for its transition. The transition in the maritime sector faces multiple options for producing ZNZ emission energy and may lead to several options in the future (Figure 4). One element to note is that the production of alternative fuels for the maritime sector does not specifically fall under the sector's domain, unlike the production of renewables in the power sector. Ultimately, the policy measures applied in the producer segment of the power sector, which assist in increasing the production of renewables, can be useful for the uptake and adoption of ZNZ energy sources for the maritime sector.

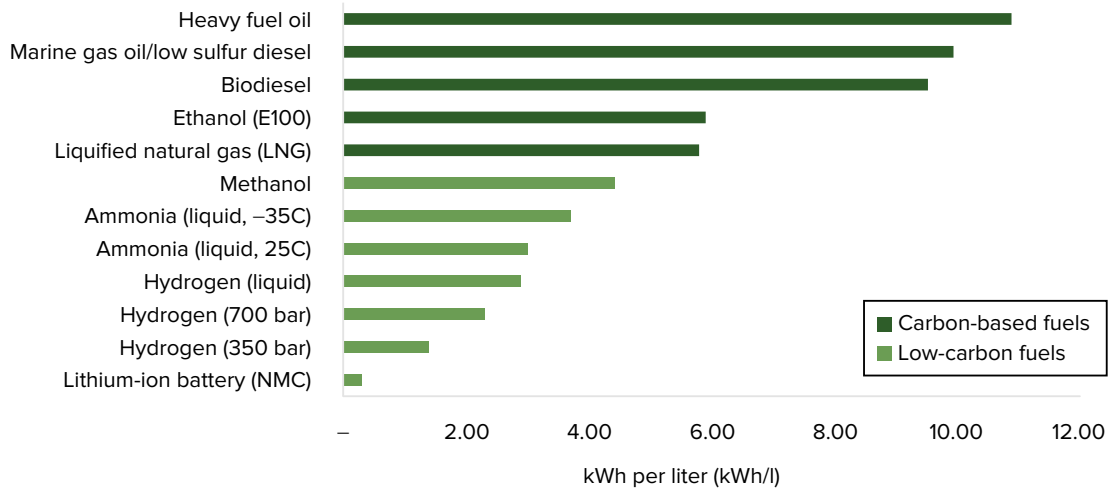
While several options are available for the maritime sector, almost all of the potential fuel sources for decarbonization have yet to be fully commercialized. Many technologies are still in their infancy and require policy-driven investments. As we evaluate different fuel options, it is important to consider key differences between them. Various metrics, including volumetric density, fuel supply chain maturity, scalability, and emission levels in terms of carbon and other particulates, can be used to compare alternative fuels for maritime use. The volumetric energy density, which indicates the amount of energy stored per unit of volume, provides insights into the range offered by a particular fuel.

**Figure 4.** Fuel type selection in each governed transition.




*Source: Authors' illustration.*

**Figure 5.** Volumetric energy density of alternative fuels.




*Sources: Nezamuddin, Shabaneh, and Anwar (2023); US DoE EERE (2024), and the Royal Society (2020).*

Figure 5 depicts the kilowatts per hour (kWh) per liter (l) of conventional marine fuels such as heavy fuel oil (HFO) and MGO compared with alternate fuels such as LNG, biodiesel, ethanol, methanol, ammonia, hydrogen, and lithium-ion batteries sourced from Nezamuddin, Shabaneh, and Anwar (2023), the US Department of Energy's (DoE 2024) Fuel Properties Comparison tables, and the Royal Society (2020). Carbon-based fuels have the highest volumetric density, with conventional marine fuels such as HFO and MGO having energy densities of 11 kWh/l and 10 kWh/l, respectively (Figure 5).

LNG, which is widely considered a short-term fuel solution in the maritime sector, has an energy density of approximately 6 kWh/l (Figure 5). Although LNG has been available for several decades, the uptake of LNG vessels has been considerably slow, with only 1,963 vessels running LNG-capable engines in 2024. LNG carriers have naturally begun to use LNG to power their ships, making the majority of LNG carriers essentially LNG-fueled vessels. Additionally, interest from shipowners has begun to peak again in recent years with the establishment of emission control areas (ECAs) in the Baltic Sea and North Sea, which has accelerated the adoption of low-emission shipping (Løvstad 2016).

Hydrogen and hydrogen-derived fuels such as ammonia and methanol are emerging technologies with the potential to play a significant role in decarbonizing the maritime sector. When produced via the low-carbon method, hydrogen does not emit $CO_2$ emissions when burned. Although hydrogen currently provides lower miles per unit of volume (2-3 kWh/l) than does MGO, which has an energy density of 10 kWh/l (Figure 5), importantly, hydrogen, as an alternative fuel option, entered the market only in 2023 through pilot projects (Nezamuddin, Koroma, and Anwar 2024), suggesting that there is ample room for improvement and scalability. Risks and safety concerns regarding hydrogen as a maritime fuel are significant and require further exploration to better understand them and implement additional safeguards to prevent or mitigate major hazards (Laursen et al. 2023).

Ammonia, a hydrogen derivative, has promising prospects with a relatively higher energy density, ranging from 3 to 4 kWh/l, although it is still not comparable to MGO on a mile-per-unit basis (Figure 5). Currently, one ammonia-run tugboat is in service, which was built in 2015 by Japanese shipbuilder Keihin Dock; no other ammonia-capable vessels have been deployed (Clarksons 2024). Although ammonia already has an existing global supply chain, there are a few concerns that need to be addressed for its further development. One such concern is the emission of nitrous oxide when ammonia is burned, as well as its high toxicity (Nezamuddin, Shabaneh, and Anwar 2023). Methanol, a hydrogen derivative, has recently attracted interest as a preferred fuel among shipowners, with a total of 23 vessels deployed since 2016 (Nezamuddin, Koroma, Anwar 2024). The energy density of methanol is slightly greater than that of ammonia, at approximately 5 kWh/l (Figure 5). Additionally, methanol is easier to handle, given that it is less toxic than is ammonia. Industry giant Maersk has signed an offtake agreement for green methanol to be used on its vessels, signaling the potential increase in the commercialization of this alternative fuel (Maersk 2023).

Finally, the speed of growth in the use of ZNZ emission technologies in the maritime sector is dependent on the policy instruments used to promote such technologies. The adoption of alternative fuels requires an existing commercial market for such fuels, which is not mature or existing currently. To bridge the price gap between ZNZ emission hydrogen (and its derivatives) and conventional fuels, support instruments for the supply of hydrogen (and its derivatives) are needed. Referring to renewable electricity (RES-E) support schemes, owing to their positive outcomes and similar policy objectives, four support instruments, namely, feed-in FiTs and feed-in premiums, and investment- and quota-based schemes, can be considered.

## Intermediary segment

The intermediary segment for the maritime sector focuses on the availability of bunkering infrastructure to support the transition in this sector. This segment is crucial for the uptake and adoption of alternative ZNZ emission fuels because it creates commercially available alternative fuels. Clear lessons can be learned from the intermediary segment in the passenger road transport sector, where government support for EV infrastructure and charging stations has been limited and overwhelmingly slow, with a few policies recently implemented across several countries. This situation has contributed to the EV range anxiety felt by consumers, which in turn has hindered the further adoption of EVs in the sector. This reality cannot be repeated in the maritime sector given the important role played by the sector, as seaborne trade is integral for a healthy, functioning global economy. Ultimately, the maritime sector necessitates the development of bunkering facilities and refueling infrastructure to support

alternative fuels and the creation of shoreside power facilities to cater to port operations.

One method of promoting the intermediary segment for the maritime sector can be supporting the development of commercial markets for alternative ZNZ emission fuels given the existing push for the adoption of vessels via ZNZ emission technologies. Lessons can be learned from the development of a commercial market for LNG trade.

Ultimately, it is important for the intermediary segment of the maritime sector to develop, using policy instruments to establish the necessary bunkering infrastructure to refuel vessels. Given the nature of the different alternative ZNZ emission technologies, the currently existing shipping and bunkering routes must be rethought.

## End user segment

The end user segment of the maritime sector operates differently than does the relatively standardized passenger vehicle market; the maritime sector encompasses various vessel sizes, functions, and operational complexities, making the transition more challenging. Currently, there are approximately 110,224 seaborne merchant vessels, with an estimated 98% running on conventional hydrocarbons such as low-sulfur HFOs (LSHFO), intermediate fuel oils, marine fuels, and diesel, among others. The remaining 2% run mainly on LNG. The industry is gradually moving toward decarbonization and sustainability, with approximately 11% of new vessel orders being able to use alternative fuels. At present, there are approximately 1,143 merchant vessels in service that operate using alternative fuels, predominantly LNG, followed by a minority mix of methanol, battery-hybrid, biofuels, hydrogen and ammonia, among others.

Policy instruments similar to those of the end user segment in the passenger road transport sector should be applied in this segment of the maritime sector because they promote the adoption of vessels using ZNZ emission alternative fuels, which in turn increases their penetration in the market and creates more demand for ZNZ emission alternative fueling stations in the intermediary segment. Specifically, applying subsidies and tax incentives for manufacturers, ship builders, and ship owners aids operators in the end user segment.

# 6. Maritime Transition Framework

To develop a framework for the governed transition in the maritime sector, the key insights for each segment must be applied. One key observation to note is that this governed transition requires a combination of demand-pull and technology-push measures that have been applied in other SETs. Technology-push policies focus on sociotechnical change by reducing the private cost of R&D, whereas demand-pull policies aim to stimulate sociotechnical change through support for the use of technologies by end users (Nuñez-Jimenez et al. 2019). Technology-push policies, such as R&D funding and support for pilot projects, are to be applied in the intermediary segment and end user segment of the maritime sector (Nuñez-Jimenez et al. 2019). Demand-pull policies, tax credits, subsidies, and standard-setting instruments should be applied in all three segments of the maritime sector (Nuñez-Jimenez et al. 2019). Table 3 details the intricacies of the governed transition framework for the maritime sector, applying the key lessons distilled from other SETs.

### Limitations

Unlike the power sector and passenger road transport sector, the transition in the maritime sector is uniquely global, as it is local. Given the interconnectedness of the sector, many of the regulations and agreements must be directed through the IMO and agreed upon by the majority of its members. The governed SET in the maritime sector is guided by agreements within international frameworks. Given its adoption in 1997, Resolution 8 became the first resolution that involved the Marine Environment Protection Committee (MEPC) recognizing and investigating the effects of GHG on the maritime sector and considering solutions for reducing $CO_2$ emissions in the sector (Anwar and Nezamuddin 2024). As an international regulator, the IMO has contributed to the overall reduction in emissions in the maritime sector by undertaking several efforts, including setting regulations, enhancing and promoting technical cooperation among its members to improve the efficiency of technologies on ships, authorizing and approving technical studies to understand the state of the sector, establishing voluntary trust funds for the promotion of SETs, and adopting measures to reduce GHG emissions (Anwar and Nezamuddin 2024). The most recent guideline adopted in July 2023 was the IMO Revised Strategy on GHG Emissions from Ships, which set several targets with the ultimate goal of reaching net-zero emissions from international shipping by (or around) 2050, considering national circumstances (Anwar and Nezamuddin 2024).

**Table 3.** Maritime transition framework – Relevant policy instruments applied in the three segments of the maritime sector to enable the governed transition of the sector.

| **Producer Segment** | | | **Intermediaries Segment** | | **End Users Segment** | | |
|---|---|---|---|---|---|---|---|
| *Conventional energy producers HFO/LSHFO, MGO, and other marine fuels. Short-term fuels such as LNG (conventional and low carbon). ZNZ alternative energy producers such as hydrogen, ammonia, methanol, biofuels, electricity, among other.* | | | *Refueling (bunkering) and charging infrastructure required in the maritime SET to move forward.* | | *Ship owners, ship builders, ship operators, ship financiers, among others.* | | |
| Demand-Pull Measures | | | Demand-Pull and Technology-Push Measures | | Demand-Pull and Technology-Push Measures | | |
| **Feed-in-Tarrifs (FiTs)** | **Power Purchase Agreements (PPA)** | **Investment credit (IC)** | **Subsidies** | **Tax Incentives** | **Subsidies** | **Tax Incentives** | **Funding R&D** |
| Given the nature hydrogen, LNG, ammonia, methanol, and biofuels, a FiT would be an effective measure to apply to guarantee a minimum fixed price for energy from these technologies | To commercialize new ZNZ alternative fuels, having a PPA would help secure availability of fuels for consumers which can increase stability for ZNZ fuel production | For renewables-based ZNZ fuel production, an IC on the upfront cost of a project can reduce the burden on the project developer and provide the necessary discount for the initiation of projects | Direct subsidies from governments to develop bunkering at ports or support companies that provide bunkering services at sea | Tax exemptions could be an effective method to promote the investment in bunkering infrastructure at ports | Subsidies applied for ship builders can assist in reducing costs for new builds and retrofitting | Tax credits would support ship owners shift their vessels towards ZNZ alternative fuels<br><br>Tax exemptions can also play a role in directing financiers towards limiting investment in conventional vessels | Continued international funding for R&D will expediate the governed transition in the sector as it can help reduce costs of technologies via commercialization |

*Source: KAPSARC illustration.*

# 7. Conclusions

The study suggests that the maritime sector adopt successful policy frameworks and stakeholder engagement strategies from the electricity and road transportation sectors while addressing its unique infrastructure and economic challenges. The study has synthesized findings to draw broader conclusions, identifying effective policies from other sectors, highlighting the role of final users versus intermediate users in these transitions, and recognizing infrastructure challenges. The aim is to provide actionable recommendations for the maritime sector's transition, ensuring a thorough and well-supported approach to this significant energy shift.

To effectively apply the lessons learned from other governed SETs, policymakers need to view the existing commonality among the sectors, which is the internal segmentation within each sector to the producer, intermediary, and end user segment. Having these segments allows for an understanding of which segment of a sector is most in need of support to achieve the uptake and adoption of technologies or alternative fuels for the overall transition of the sector.

By developing a transition framework for the maritime sector, insights from SETs, such as the adoption of renewables in the electricity sector and the penetration of EVs in the road passenger sector, offer valuable guidance. While the lessons gleaned from other sectors may not seamlessly apply to the maritime industry given its unique dynamics, our approach distills insights into their fundamental components and interplay. These insights include the use of a combination of demand-pull and technology-push measures to expedite the governed transition in the maritime sector. In the producer segment, it is clear that policy measures such as FiTs, PPAs, and ICs can be effective in increasing the production of ZNZ emission alternative fuels and promoting the commercialization of such technologies. In the intermediary segment, which considers a mixture of demand-pull and technology-push policies, subsidies and tax incentives can be effective in promoting the infrastructure required for bunkering new fuels. Finally, for the end user segment, several policies, such as subsidies, tax incentives, and R&D funding, can support the different stakeholders in the segment by reducing the costs associated with building new ZNZ emission fuel capable vessels.

Moving forward, more research needs to be conducted to understand the cost competitiveness and sustainability of the different fuel options available for the maritime sector. Specifically, a quantitative analysis of the technologies and their emission lifecycle from well to wake should be performed. Additionally, the transition in the maritime sector necessitates an overhaul in terms of how we think of modern shipping since a revamp of intermediary segment of the maritime sector is needed given the fuel density of ZNZ emission alternatives.

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# Notes

# Notes

# About the Authors



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Nora N. Nezamuddin is a Senior Fellow at KAPSARC, focusing on the pathways to decarbonizing the transportation sector. Nora's current work looks at energy transitions in the maritime sector, keeping in mind the relationship between maritime-hinterland connections. She has experience working on renewable transition policies and costs and their effects on electricity markets. Nora holds an MSc in Maritime and Air Transport Management, specializing in transport economics research, from the University of Antwerp in Belgium and a dual BA/BSc in International Relations and Business Administration from American University in Washington D.C.



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Shahid Hasan is a Principal Fellow in the Utilities and Renewables Program at KAPSARC, where he conducts research on the opportunities and challenges of establishing a hydrogen-based economy and reforming electricity markets. With over 25 years of experience in South Asia, Southeast Asia, and the Middle East, Shahid specializes in the economic, policy, regulatory, technological, and sustainability aspects of the energy transition. Prior to joining KAPSARC, he worked at the Energy and Resources Institute (TERI) in India, where he focused on electricity sector reforms and contributed to government reports that support India's energy transformation. He has collaborated closely with a diverse array of clients and stakeholders, including industry, regulators, public and private utilities, governments, academic institutions, research organizations, and both bilateral and multilateral entities across various regions.

# About the Project

This project aims to develop a framework for the maritime sector's energy transition, focusing on pathways for adopting hydrogen and its derivatives as sustainable fuels. The approach involves the following three phases: learning from other sectoral energy transitions, developing a quantifiable comparison of emerging fuel technologies vis-a-vis conventional fuels, and providing policy recommendations to guide decision-makers in implementing a sustainable transition.




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