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The Effects of Regulation Enforcement and Fuel Availability on the Deployment of Methanol by Container Liners in Europe

An agent-based approach to explore future scenarios

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Abstract: Increasing ship emissions are of big concern because they contribute to the effects of climate change and have an impact on the local and regional environment. Due to these concerns, stricter regulations are enforced upon the shipping sector by the International Maritime Organisation and the European Union. However, since new regulations are enforced, stakeholders have been slow to react. A key reason why investment decisions are not taking place is that of uncertainty in regulations and policy. Besides, the availability of bunker infrastructure in ports is key to the development of alternative fuels. The objective of this study is to obtain insight into what possible future scenarios of the deployment of methanol for the short sea shipping might arise and to provide insight into the effects of collaborative port strategies on the emergence of methanol as a maritime fuel taking into account regulatory and technological uncertainties. By means of an agent-based modelling approach and exploratory modelling and analysis approach, the influence of these uncertainties and policies is addressed. This enables to obtain a better understanding of where the system might go. The findings of this study show the effect of regulation enforcement and the need for well-developed methanol bunker infrastructure across Europe to enable the deployment of methanol as a maritime fuel.

Keywords: Emission abatement technologies, Maritime shipping, Container liners, Maritime methanol, Agent-Based Modelling, Exploratory Modelling and Analysis

1. Introduction

Sea transport is an important contributor to the world's economy, as it is the biggest carrier of freight around the globe, 90% of trade is transported by ship (Lister, 2015; Mansouri, Lee, & Aluko, 2015). Although shipping is stated to be the least environmental harming mode of transport, it is not completely free of negative effects on the environment. It is responsible for 2,5% of global emissions, such as CO2, SOx and NOx emissions (Maritime Knowledge Centre, TNO & TU Delft, 2018). In 2015, about 298 million tons of fuel was consumed by global shipping, consisting of 72% heavy fuel oils, 26% distillate fuels and 2% LNG (Lister, 2015; Olmer et al., 2017). The amount of fuel consumed is likely to get even worse due to increasing global trade. The pollution and waste caused by sea shipping lead to environmental degradation and resources depletion. Solutions must be found if we wish to reduce the negative effects of sea shipping on the environment (Lai, Lun, Wong, & Cheng, 2011). Sustainable sea shipping is, therefore, a key challenge for the international community. Concerns are raised among stakeholders, ranging from shippers to governmental bodies and international communities (Lai et al., 2011).

Due to these concerns, stricter regulations are enforced upon the shipping sector by the

International Maritime Organisation (IMO), the European Union and other regulatory or bodies. These regulations aim to reduce the emissions of vessels by limiting the allowable amount of SOx and NOx emissions. Special areas in the North- and Baltic Sea are assigned as Emission Control Areas (ECAs). In these areas, the accepted emissions are even stricter regulated. Here, the local and regional environmental impacts are of more concern. These regulations have a major impact on vessels sailing in ECAs. Especially for short sea vessels spending most of their time in ECAs. Short sea vessels generally operate in limited geographical areas on relatively short routes with port calls taking place frequently. Therefore, short sea vessels could use fuels which are only regionally available.

To comply with regulations, vessels could either install after-treatment systems, which wash away the emission from the exhaust gases or switch to alternative fuels. Examples of alternative fuels that could be used by the shipping sector are liquefied natural gas (LNG), liquefied biogas (LBG), biodiesel, hydrogenated vegetable oil (HVO), (bio) methanol, or (bio) ethanol (Brynolf, Fridell, & Andersson, 2014). However, these alternative fuels, except LNG, are still in an experimental stage, and thus niche markets for the shipping sector (Maritime Knowledge Centre et al., 2018). Biodiesels have a high NOx emission rate and do not comply with the stricter NOx regulations. Furthermore, biofuels like HVO and bioethanol are mostly produced from first-generation biomass and therefore not favourable to use as fuel. Currently, LNG and methanol are the most promising alternative fuels for shipping (Maritime Knowledge Centre et al., 2018). LNG and methanol do comply with the regulations and have advantageous costs compared to other alternatives fuels (Andersson et al., 2015). From these emission abatement options, bio methanol is the only one that has the potential to mitigate climate change and therefore is the most favourable fuel from a sustainable point of view (Brynolf et al, 2014).

However, since new regulations are enforced stakeholders have been slow to react. The uncertainty of fuel and shipping markets burden the take-off of investment decisions by the ship operators, fuel suppliers, and port authorities. A key reason why investments are not taking place is that of uncertainty in regulations and government policy (Alphatanker, 2018). For example, for a long period of time, it was unclear if the implementation of the IMO sulphur cap would be delayed until 2025. In addition, technological replacement is slow, since the lifetime of a vessel is about 20-30 years, and it is uncertain if regulations change in the meantime. For instance, will the installation of scrubbers comply with future regulations. Moreover, it is unknown how these regulations will be enforced and what the consequences are of not being compliant.

Nevertheless, due to regulations, it is unavoidable that a shift in both fuel and shipping markets will take place. The emergence of an alternative fuel depends on regulatory authorities with respect to emission regulations and availability of bunker infrastructure in ports. This emergence requires investments from both port authorities and ship operators. However, becoming more sustainable might become at the cost of being economic in-efficient. Shipping companies compete for profit and implementing abatement options is costly. Moreover, ship operators never adopt a fuel until it is cost-effective, easily available, and compatible with the existing and future technology. Furthermore, it requires the fuel to be compliant with current and future regulations. Ship operators need reliable and accurate information about the technologies, so the financial risks can be kept to a minimum. They need to have some certainty about the availability of fuels and the availability of bunker infrastructure in ports before committing to investments in alternative fuels (Maritime Knowledge Centre et al., 2018).

Ports in Europe compete for shipping traffic. Therefore, local authorities and the ports authorities themselves are concerned about the loss of competitiveness and the additional costs of regulations (Zhang, Loh, Louie, Liu, & Lau, 2018). The regulations can influence the number of port calls and the operational rotation schedule of vessels. Since there are many stakeholders with different objectives, it is difficult to foresee how changes in a particular part of the system will influence the entire system. For this reason, ports need to be adaptive because not responding in time to changes, could result in negative consequences for the ports itself. However, preparing for a wide range of possible futures is challenging. All components of the fuel supply chain are subjected to strong interdependencies. Therefore, it is possible that minor changes result in a substantial change in the overall system (Halim, Kwakkel, & Tavasszy, 2016).

This paper is structured as follows: Section 2 entails a high-level overview of the current state of literature and identifies the knowledge gap. In section 3, the research objective and scope are discussed. The research methods are described in section 4. Section 5 presents the findings of this research. Section 6 entails the discussion and section 7 is considered with the conclusions. Finally, section 8 provides recommendations for further research.

2. Knowledge gap

The European short sea maritime fuel system is a socio-technical system consisting of technical subsystems, such as operating vessels, fuel production plants and bunker infrastructure. These technical systems are influenced by a complex network of many social systems, such as regulations of authorities and fuel markets. Many actors, like shipping operators, regulatory authorities, and fuel producers are involved in different segments of the value chain of maritime fuels, with each its own goals, means, and assets. The behaviour of these actors is adaptive in the sense that they learn and adapt their behaviour over time on the bases of their own status and their environment, such as fuel prices and regulations.

In this system, the transition to alternative fuels will emerge over time in which the interactions between external factors and actor behaviour are dynamic and complex. It involves both the changes in physical infrastructure, such as bunker infrastructure and vessels, and institutions that govern the behaviour of stakeholders. The interactions between technical and social systems can lead to emergent and co-evolutionary behaviour. For this reason, it is hard to understand and predict the outcomes of these interactions (Chappin & Dijkema,.2008). In addition, the maritime fuel system is subjected to path-dependency, meaning that options in the future are influenced and limited by decisions taken today and in the past, such as the investments in vessels by ship operators, the investments in bunker infrastructure by ports and fuel suppliers, and the investments in refineries by fuel producers. For this reason, there is a need for a clear understanding of the effects of policy measures. Besides, there is a need to test the different policies with the uncertainty involved in the system to evaluate the impact of these policies.

Literature has assessed the technological, economic and environmental performance of emission abatement technologies. Svanberg et al. (2018) examined the performance of methanol as a maritime fuel. The analyses showed that methanol is a technically viable option to reduce hip emissions. In addition, a comprehensive study on the use of ethanol and methanol as fuels for the maritime industry is performed by Ellis and Tanneberger (2015). The technical, economic and environmental performance of the two fuels were assessed. A similar study is performed by DNVGL (2016). This study showed that methanol is only a potential fuel under certain circumstances, stated that the MGO price is an important variable, as well as the time spent is ECAs.

Besides, literature is available concerning port strategies towards sustainability. Gritsenko and Yliskylä-Peuralahti (2013), performed a qualitative analysis to explain how the change in ship emission reductions affect maritime governance. They identified the changing position and strategies of ports. In addition, they identified two strategies which are likely to be adopted by Baltic ports: 1) investment in compliant fuelling infrastructure, and 2) supporting the attractiveness of shipping as sustainable transport. Adams et al. (2009) examined drivers for ports to improve their environmental performance. By means of a survey, 5 drives were identified: 1) Regulatory compliance, 2) social pressure, 3) corporate conscience 4) improving operational performance, and 5) competitive advantages. Aciaro et al. (2014) identified the role of port authorities as an energy manager. Port authorities can support energy management by energy production, consumption and the uptake of renewable energy. The uptake of innovative technologies, such as alternative fuels calls for more attention to energy matters within port management. They argue that energy management can contribute to the competitiveness of the position of ports. For example, the future use of biofuels might be beneficial for the of development of bunker services, which is already noticed for the development of LNG services. Chang & Wang (2017) performed a study on the effects of green port policy. They argued that implementing emission control areas to regulate the use ow low sulphur fuel is difficult to achieve in the short term because it will increase the ship owner's costs by 36,2%. According to Gibbs et al. (2014), ports should focus on reducing ship emissions, rather than trying to reduce the emissions from other port activities. Suggestions for future research include the assessment of the change in propulsion technology, stating that some of the abatement options may depend upon the availability of infrastructure in ports.

Less attention has been paid to the effects of interactions between stakeholders on the transition to alternative fuels. Therefore, it is not yet known what the impact is of policies implemented by international, European and national authorities to enable the transition towards the use of sustainable fuels (Maritime Knowledge Centre et al., 2018). Bas, De Boo, Vaes-Van de Hulsbeek, & Nikolic (2017) performed a study that presents a comprehensive systems perspective of the maritime fuel system. An agent-based model was developed that can be used to study the effects of policy measures on the use of alternative fuels. This study was focused on the adoption of LNG for deep-sea shipping on a global scale. However, such a study has not yet been performed for the short sea shipping sector and the deployment of methanol.

3. Research objective and scope

The objective of this study is to obtain insight into what possible future scenarios of the deployment of methanol for the short sea shipping might arise. A second objective is to give insight into the effects of collaborative port strategies on the emergence of methanol as a maritime fuel. In this way, long- and short-term robust strategies that support the deployment of alternative fuels for liner vessels in Europe could be developed.

This study considers the uncertainties to which the system is subjected and takes into account the interests of the stakeholders involved. The scope of this research is bounded to short sea shipping in Europe. This means that only vessels and ports operating in Europe are considered, as well as the institutions that are relevant to this region. Besides, the results presented in this paper are concerned with the container liner vessels which are operating in ECAs. This paper presents the results associated with the development of methanol as a maritime fuel. Nevertheless, the study was performed by including more propulsion technologies in the analysis, namely: HFO in combination with a scrubber and SCR installation, MGO with SCR installation, and LNG. In this way, the trade-off between different compliant technologies could be identified. Furthermore, the study explored the transition of the European short sea fuel system for a time horizon up to 2028.

4. Research methods

Because the European short sea maritime fuel system is adaptive and assumes a bottom-up approach, an agent-based modelling approach was applied. The model is used as an exploratory tool to identify future scenarios towards the deployment of alternative fuels. In this way, insight is obtained into the effects of interaction of the social and technical systems.

Bas et al. (2017) created an agent-based model which represents the maritime fuel system: Maritime Fuel Policy Exploration Model (MarPEM). This model can be used to study the effects of policies on the development of alternative fuels. In this research, MarPEM is used to create a model that represents the European short sea sector.

The rotation schedules of liners operating in the ECAs were included in this study. However, simplifications were needed. Therefore, the model only included the 30 ports having the most liner calls. These ports represent over 70% of all port calls.

The agent-based model captures the operational behaviour of vessels, e.g. sailing, mooring, and bunkering. Besides, the model includes the supply of fuels in ports. In addition, the investment decision of ship operators towards compliant propulsion technologies are included in the model. These decisions are either made when considering retrofitting a vessel and for newly built vessels.

Besides, three different port strategies are included in the simulation model. Collaboration between ports might be effective and could be advantageous in many ways: 1) By sharing market and promotion costs, 2) shared costs for development of infrastructure, 3) shared risk among ports, 4) smaller ports could achieve a stronger position by collaborating, and 5) collaboration could strengthen ports against outsiders (Mclaughlin & Fearon, 2013). Therefore, policy options evaluated in this research comprise several ways of collaboration between European ports. The following three options of collaboration are implemented in the model:

1) Ports providing methanol bunker infrastructure.
2) Applying discount on port dues for vessels operating with LNG or methanol propulsion technology. This policy option is already implemented in some the European ports for the use of LNG. However, such a policy could be extended for vessels using methanol.
3) Applying discount on ports dues for vessels when bunkering bio methanol in the associated port. This policy does not only stimulate the investments in methanol propulsion technology but does also stimulate the use of bio methanol.

The collaboration between ports is represented by means of 5 scenarios. In each scenario, a different number of ports has methanol infrastructure available in the port or is applying a discount on port dues.

Besides, the European maritime fuel system is subjected to various uncertainties, such as fuel prices, investment costs, and regulations. To deal with these uncertainties and assess the impact of the policies, an exploratory modelling and analysis (EMA) approach is used. This approach uses a large number of computational experiments to explore the implications of the assumptions that are made in the modelling process, as well as the uncertainties to which the system is subjected. In this way, the uncertainty space and decision space of the model can be identified and related to the output space.

Uncertainties: Fuel prices, investment costs, space requirements of technology, costs of lost cargo capacity, amount of fine, control percentage, willingness to pay for bio methanol, and CO2 prices

For the experimentation and analysis of the model outcomes, the EMA workbench is used, an open source library implemented in Python.

The uncertain parameters were varied to obtain 500 unique scenarios. Besides, 35 policies were created by combining policy levers. Combining the uncertainties with the policies resulted in 17.500 unique experiments. Due to the stochasticity of the model, each experiment was repeated 10 times.

Feature scoring, scenario discovery are methods used to explore the uncertainty and the decision space. Feature scoring is used to identify the most relevant features. By means of Scenario discovery, the uncertainty space and decision space of the model is identified and related to the output space. In this way, regions of interests could be identified.

5. Results

The results are obtained by executing computation experiments with the EMA workbench. Figure 1 and 2 show the deployment of methanol technology in combination with a small and large fuel tank over time. The boxes on the right sight of the line plots illustrate the distribution of the outcomes at the last time step of each model run. It is observed that the deployment of large methanol fuel tanks remains in most scenarios rather low. The deployment methanol technology in combination with a small fuel tank is more likely to emerge. However, a percentage above 40% is not common.

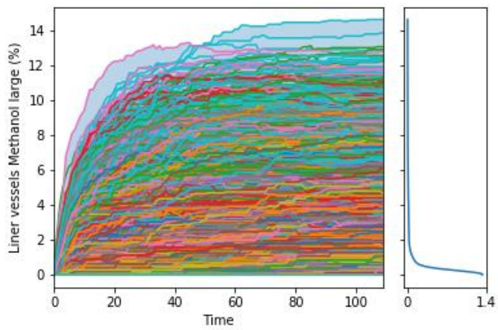

Figure 1: Deployment of methanol vessels with large fuel tank over time

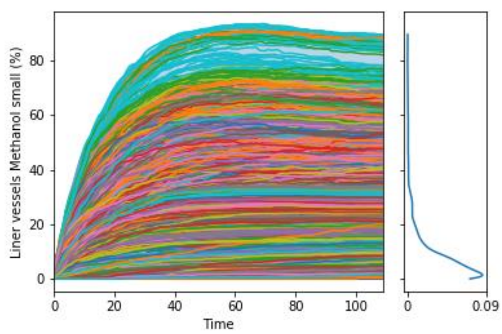

Figure 2: Deployment of methanol vessels with small fuel tank over time

The results show that the most important uncertainties regarding the deployment of methanol as a fuel for short sea container liners were HFO fuel price and methanol fuel price. The bio methanol price and CO2 price are do not have an effect on the investment decisions of ship operators. Therefore, bio methanol is not competitive enough yet. Even the ship operators who are concerned with the effects on climate change and are willing to pay a little more for bio methanol are not likely to have enough incentives to choose for bio methanol as a fuel. In addition, the investment costs of the propulsion technology are not perceived as a key contributor to this development. Nevertheless, space requirements are of concern, and therefore vessels are not expected to invest in methanol technology in combination with a larger fuel tank. It is more likely that ship operators will use methanol propulsion technology in combination with a smaller fuel tank. However, this implies that vessels have to bunker more often. Consequently, a well-developed bunker infrastructure across Europe is needed.

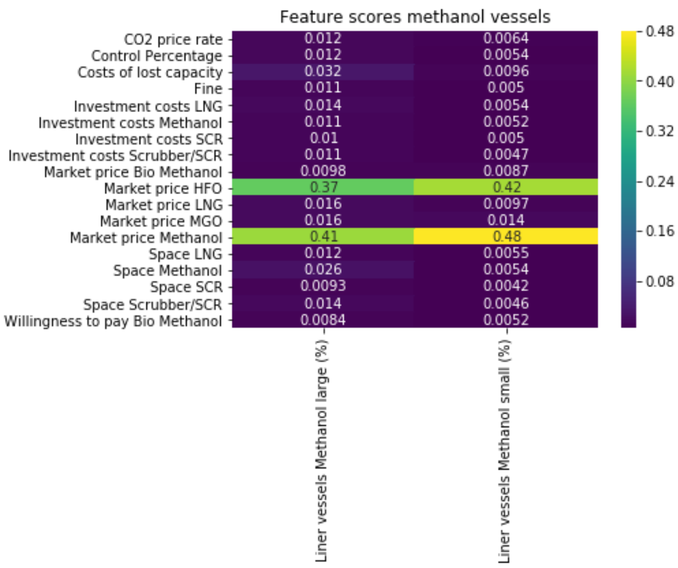

Figure 3: Feature score of uncertain variables

Assessing the impact of the availability of methanol bunker infrastructure in ports on the deployment of methanol propulsion technology showed that ship operators are hesitated to invest in methanol technology when methanol bunker infrastructure is not well developed in ports. When comparing the number of methanol vessels with a large fuel tank and with a small fuel tank with respect to the availability of methanol infrastructure in ports, it is noticeable that vessels do not make investments in methanol technology in combination with a small fuel tank when the methanol infrastructure in ports is not well developed yet. Contrary, when bunker infrastructure is widely available, vessels are investing in methanol technology with a small fuel tank instead of a large fuel tank. An increase in the availability of methanol allows more vessels to bridge the distances between bunker ports with a small fuel tank.

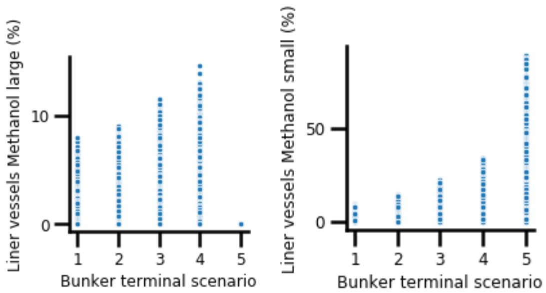

Figure 4: Bunker terminal scenario versus methanol vessels

In addition, the outcomes showed a strong correlation between regulation enforcement and the development of compliant abatement technologies. The outcomes showed that without any regulatory incentives, it is unlikely that investments in abatement technology will take place. Enforcement of regulation is therefore needed. The scatter plots depicted in figure 5 indicate that the stricter the regulation enforcement is, the less HFO vessels remain to operate. Besides, a clear relation could be indicated between regulation enforcement and the number of vessels with a scrubber. Namely, the higher the regulation enforcement is, the more vessels install a scrubber. However, it is noteworthy that the higher the enforcement of regulation is, the less investments take place in methanol propulsion technology. This indicates that when ship operators experience the pressure emission the emission regulation enforcement to early, ship operators are likely to make investment decisions in the technologies with the least radical implications. Scrubber and SCR systems are then often considered since vessels can continue to operate with cheap HFO and the fuel is available in all ports. For this reason, it might be more beneficial to give vessels more time to make well-considered decisions towards the application of emission abetment technologies.

Furthermore, the policies related to the application of discount on port dues was not observed to have an effect on the deployment of methanol. The cost savings of the discount do no add up to the total investment costs of LNG or methanol and the higher fuel prices.

6. Discussion

In the course of this study, assumptions and simplifications were made, since it is difficult or even impossible to capture the full complexity of a system in a model. These assumptions can affect the representativeness of the model and influence the findings of this study. The model was simplified by not taking into account the adaptiveness of line rations over time. By making this assumption, the model does not account for the fact that vessels might change their line schedules according to the availability of methanol infrastructure or fuel prices in ports.

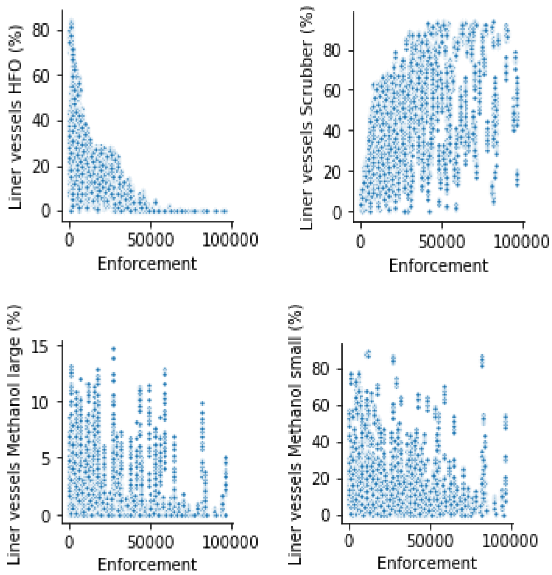

Figure 5: Correlation between the deployment of technology and enforcement of regulation

Another reservation of the findings is the fact that it is not taken into account that the level of deployment of a propulsion technology might influence the investment costs over time. Generally, when a technology is more applied, innovation and scaling benefits might lead to a decrease in investment costs. This again might lead to more investments in the propulsion technology. Contrary, it is not sure if the market is able to supply the demand for certain technologies, this might induce an increase in investment costs or shortage, which force vessels to invest in other technologies.

Further, the model does not take into account the adaptiveness of ports to the deployment of fuels and the effect other's port strategies have on a port's policy. However, it might be that with an increase in vessels using a certain fuel, more ports start considering to offer the fuel as well.

This research was concerned with the exploration of scenarios and the analysis of policy strategies. Because of the exploratory nature of this study, no optimal outcomes are identified. The availability of methanol infrastructure has shown to be effective towards the development of methanol as a fuel for the shipping industry. However, these findings make it hard to translate them in direct policy requirements. The study showed the effects of collaboration associated with the availability of methanol in the ports. However, it did not make any suggestion about how collaboration should take place and this might be a complex process as well. Whereas large ports might have more resources available to enable the facilitation of the infrastructure in ports, smaller ports are more likely to be unable to fund the infrastructure. Besides, the risk for smaller ports is also more obvious. Moreover, the availability of methanol in larger ports might threaten the position and competitiveness of smaller ports (Gritsenko et al. 2013). In addition, it has been indicated how well the methanol infrastructure has to be developed but does not make any suggestions for specific locations to provide methanol bunkering facilities.

7. Conclusion

This study provides complementary knowledge to the existing literature. Whereas current literature is mostly concerned with providing static analysis about the environmental, technical and economic performance of emission abatement technologies, this approach is fundamentally different and therefore provides new insights. ABM and EMA proved to be useful to actually analyse the problem because it captures the mutual influences of the technical and social systems.

Insight into possible future scenarios for the development of methanol as a maritime fuel for the short sea liner sector is obtained. Uncertain factors and the impact of policies are explored.

The transition to a maritime fuel system that highly dependents on methanol is not likely emerge. Although, a transition to methanol might emerge under favourable circumstances, e.g. with a low fuel prices for methanol and a high HFO fuel price. Besides, the methanol fuel transition is not expected to happen when methanol bunker infrastructure is not yet well developed in ports. In addition, regulation enforcement is recognised as an important factor that can steer the transition towards alternative fuels. When a transition to alternative fuels is more favourable than a transition to the compliance of vessels with the regulation, it is expected that governing the fuel prices is more effective than the enforcement of regulations.

8. Recommendations

Though the deployment of methanol as a maritime fuel across Europe is not likely to emerge in the upcoming years, it might be possible to establish such a transition on a smaller geographical scale. For this reason, it is advised to conduct further research and look for collaborations with ports serving similar line rotations and operating in a small geographical area. This might accelerate the uptake of methanol propulsion technology and reduce the risk of ports and ship operators. Nevertheless, ports should asses the number of bunker calls they need in order to benefit from suppling the fuel infrastructure. It might be that on a small scale, the supply of methanol is not profitable.

The central issue concerning the results is the sustainability of certain pathways. Bio methanol has the potential to mitigate the effects of maritime shipping on climate change. However, it is not yet widely available and therefore in order to start this transition, the use of conventional methanol is required. Nonetheless, the use of conventional methanol is less sustainable than the use of LNG. Hence, the transition to methanol might be less desirable. Especially, if other alternatives such as hydrogen or batteries will be better developed. Nevertheless, with the development of more renewable electricity, it might be possible to produce methanol in a sustainable manner by converting the electricity to methanol. For this reason, it is important to look beyond 2028 and see what futures might arise and are desired. Not taking into account long-term developments and goals might lead to a less sustainable transition. Thereby coming that decisions made at present will influence the options available in the future, since the long lifetime of assets present in the system.

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