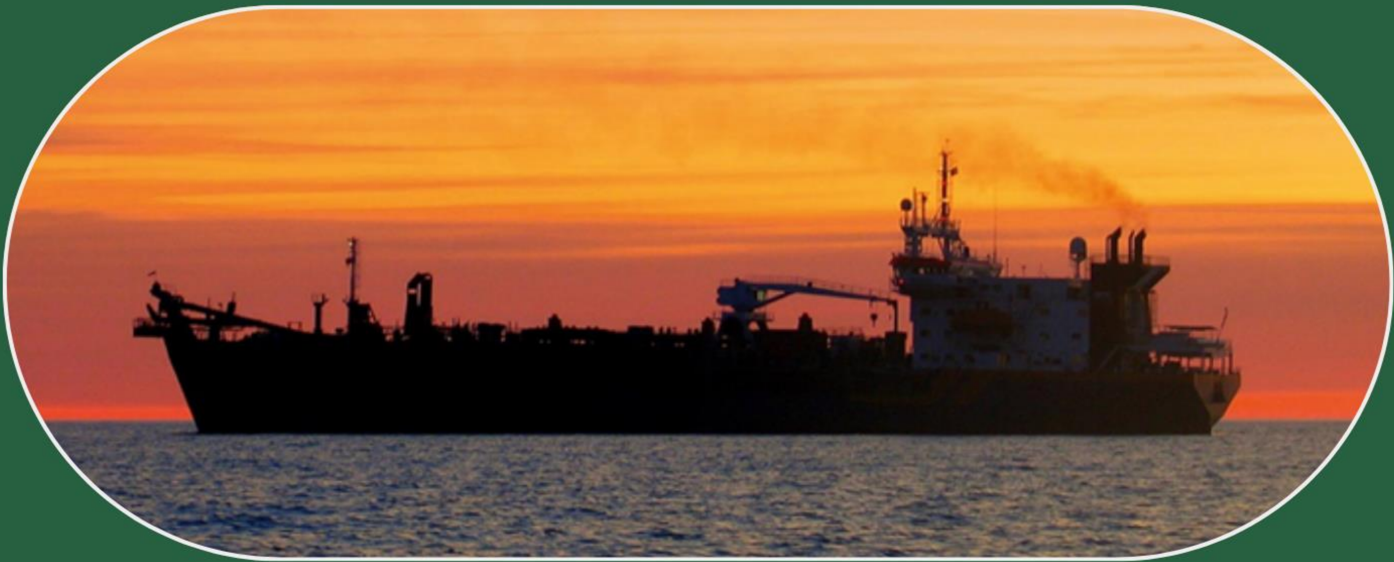
going green

the Dutch dredging's sector journey to net zero



Decreasing CO2 emissions within the Dutch dredging sector: tangible or a pipe dream?

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Abstract

Ambitions to tackle climate change are developing more rapidly in the EU over the last couple of years. This led to the inclusion of more industries within policy proposals such as Fit For 55. The maritime industry, previously unaffected by climate policies, is now also included. Given long life spans of vessels and often challenging working conditions, this puts pressure on the maritime industry, especially for sectors that rely on work vessels such as the dredging sector. Fit For 55 does not directly impact the dredging sector yet, but it already casts uncertainty over the future of the dredging sector. This thesis aims to explore how the Dutch dredging sector makes decisions surrounding carbon reduction measures in relation to climate policy. It identifies the challenges and opportunities that the transition to alternative fuels presents for the dredging sector, as well as how alternative fuels, as a decarbonization measure, fits within stakeholders' CO_2 reduction strategy. My findings show that stakeholders embarked on several initiatives to limit their environmental impact. While the sector is motivated to transition to sustainable alternatives, there are several roadblocks that are slowing down decarbonization in the sector. Experts from the dredging sector deem the transition to alternative fuels technologically feasible, yet the ambiguity of the market, lack of infrastructure and lack of stimulation by governments, specifically internationally, fosters a hesitance to invest in sustainable alternatives on a large scale. From this, I conclude the need for extrinsic drivers such as stricter requirements set by governments to stimulate the energy transition within the dredging sector. Intrinsic drivers, such as the exchange of knowledge, cooperation, and transparency could also boost decarbonization.

Chapter 1: Introduction

In December 2019, the European Commission presented the European Green Deal (Siddi, 2020). The European Green Deal sets out policies to achieve carbon neutrality by 2050. In July 2021, the EU adopted the 'Fit for 55' package which sets the goal of a net 55% reduction of emissions, as compared to 1990, by 2030 (Mallouppas et al., 2022). This goal was set to achieve the target set by the European Green Deal for 2050. Until 2021 decarbonization policy did not impact the maritime industry. However, the 'Fit For 55' package also targets the maritime industry, specifically vessels in the maritime transport sector of over 5000 gross tonnage. Fit for 55 regulations that affect the maritime industry include the EU Emission Trading System (EU ETS), the Energy Taxation Directive (ETD), the FuelEU Maritime Regulation, the Alternative Fuels Infrastructure Directive (AFID) and the Renewable Energy Directive (RED). [1] The goals outlined in the Fit For 55 plan are undeniably ambitious. They require active involvement of all the Member States of the EU and immediate action (Piebalgs & Jones, 2021). This raises several challenges for the maritime industry relating to cost, competitiveness and change. Currently only the maritime transport sector is included in the regulations in Fit For 55 as the EU CO_2 reporting system makes use of Monitoring Reporting and Verification (MRV) which includes ton-kilometer report of emissions (Deane et al., 2019). This structure is not easy for work vessels as they have varying activities and it is hard to define a Key Performance Indicator (KPI) that works. At the same time, future revisions will likely include more types of vessels such as work vessels. Meeting the requirements set by Fit For 55 regulations could be tricky for work vessels, as they need to operate under heavy conditions (Castro et al., 2019). This makes it complicated for sectors, such as the dredging sector, to reach decarbonization goals. The energy consumption of dredging vessels namely largely occurs during the excavation process which is complex (Castro et al., 2014). The sector is important as dredging projects provide port and waterways maintenance and dredging techniques are often used for coastal protection projects (Bray & Cohen, 2004). With rising sea level, this is becoming more relevant worldwide. The sector would not only have to make sure they deploy cleaner vessels but also find ways to make sure the operational work can be performed at the same efficiency. Thus, possible future revisions as well as the indirect effects of Fit For 55, put pressure on the dredging sector to decarbonize their dredging vessels. The dredging industry also recognizes the need for sustainable alternatives. For example, Boskalis, Van Oord and DAMEN are involved in a program called "methanol as

[1] Appendix II for details about the Fit For 55 regulations

an energy step towards zero-emission Dutch shipping", as part of the Maritime Masterplan[2] (Boskalis Sustainability Report, 2021; Van Oord Annual Report, 2021; DAMEN Corporate Social Responsibility Report, 2021). The project's aim is to develop sustainable energy technology for maritime application. Past research has already shown the potential of alternative fuels and efficient designs for future dredging vessels that want to use clean innovations (Castro et al., 2019). However, the uncertainty of for instance market trends and policies influence whether this potential is viable (Castro et al., 2019). This represents the need to carefully consider how technological development is shaped by different factors such as political, economic and social factors. This thesis aims to answer the following question:

> *How does the Dutch dredging sector determine its carbon reduction measures in relation to climate policy?*

To answer the main research question, the following sub-questions will be answered:

1. What alternative fuel(s) can be implemented for dredging vessels?
2. How do stakeholders within the Dutch dredging sector currently approach the decarbonization of their dredging vessels?
3. What shapes stakeholder choices regarding alternative fuel options for dredging vessels? What are the effects of national, EU and IMO policy respectively on the implementation of alternative fuels for dredging vessels?
4. Would the decarbonization of dredging vessels impact the Dutch dredging sector's position within the global dredging sector? If so, how?
5. How does alternative fuel as a decarbonization measure fit within overall carbon reduction measures within the Dutch dredging sector?
6. How can decarbonization be boosted within the Dutch dredging sector?

This thesis answers these questions by zooming in on the Dutch dredging sector as it has a strong international position and is crucial for global dredging projects (ECORYS, 2009). In the thesis, I identify challenges and opportunities of the transition to alternative fuels for dredging vessels. I also determine how choices in relation to the implementation of alternative fuels are shaped by stakeholders, and how alternative fuels as a decarbonization measure fits within stakeholders' CO_2 reduction strategy.

[2] The Maritime Masterplan is a roadmap created by the Netherlands to make 30 different types of vessels zero emission by 2030.

Chapter 2: Methodology

This thesis aims to answer the research question "*How does the Dutch dredging sector determine its carbon reduction measures in relation to climate policy?*" by performing both a literature review and meta-analysis, as well as interviews with stakeholders. A set of sub questions help answer the main research question by highlighting different aspects. Findings from the literature review, meta-analysis and stakeholder interviews establish current opportunities and issues surrounding alternative fuel options for dredging vessels. The interviews with experts determine how the Dutch dredging sector approaches decarbonization of dredging vessels. I conducted a thematic content analysis to create a clear picture of different key variables affecting the implementation of alternative fuels and the different decarbonization measures the Dutch dredging sector is researching. Additionally, I determined how decarbonization can be boosted within the Dutch dredging sector.

Literature Reviews

In this thesis a literature review and meta-analysis explore the alternative fuel options for dredging vessels. I performed a meta-analysis on top of a normal literature review, because it is more precise. This makes it an excellent tool for finding patterns across different papers (Fagard et al., 1996). I linked the patterns within the meta-analysis to patterns within the interviews to determine how the Dutch dredging sector applies knowledge about technological development to dredging vessels.

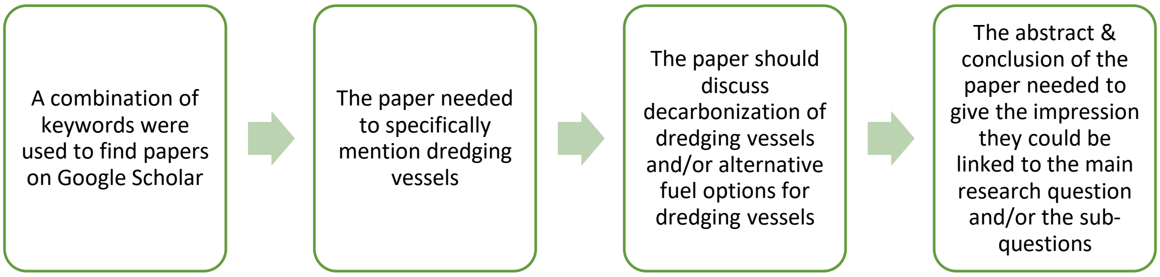


Figure 1: Methodology Meta-Analysis

Interview with Stakeholders

I conducted semi-structured interviews, because they provide in-depth understanding and make it possible to recognize patterns between different stakeholders (Zhang & Wildemuth, 2009). I interviewed representatives from dredging companies, shipbuilding companies, intermediary bodies, governmental bodies and other maritime sectors (Figure 2). The intermediary bodies KVNR (Koninklijke Vereniging van Nederlandse Reders), NMT (Netherlands Maritime technology) and Vereniging van Waterbouwers provide a platform between governments (national, EU and international level) and shipowners. Vereniging van Waterbouwers provides a platform for the Dutch dredging sector, for both seagoing as well as inland vessels. KVNR provides a platform for all seagoing vessels within the Dutch maritime industry and helps drive the cooperation between parties on Dutch ground. NMT represents the Dutch shipyards and maritime manufacturing industry. Zero Emissions Dredging-hub (ZEDhub) is an initiative involving four of the big companies in the Dutch dredging sector, namely Boskalis, van Oord, Damen and Royal IHC. Together they developed a roadmap to figure out the path towards zero emission dredging. Moreover, I interviewed two researchers from other maritime sectors (NIOZ & the Netherlands Defense Academy). Those interviews provide more information on the way alternative fuels affect maritime engines with one of those experts having a background and experience in working in the dredging sector. I chose to anonymize the interviewees and thus they were given numbers; e.g. 'Interviewee 1'.

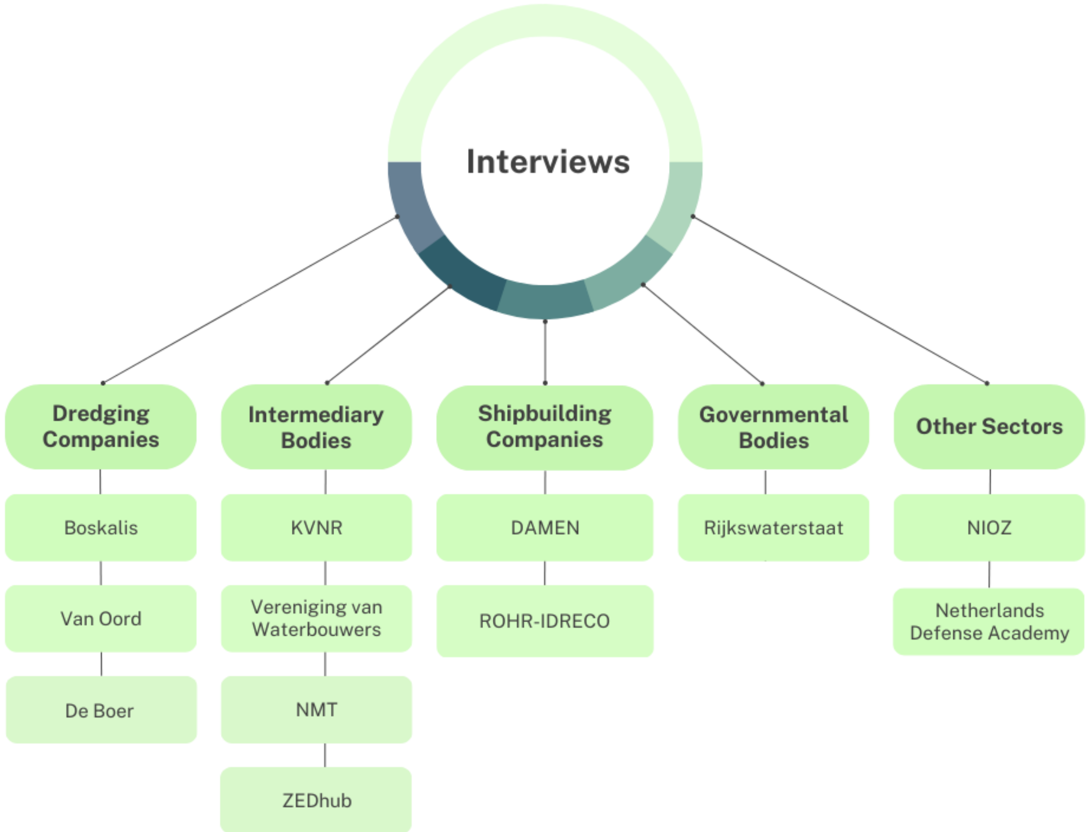


Figure 2: Interviewed Companies / Organizations

Thematic Content Analysis

I performed a thematic content analysis to assess the findings from the interviews (Perera, 2017). Many key variables affect the implementation of decarbonization ambitions within the Dutch dredging sector. The thematic content analysis is thereby useful to use as an orientation tool to understand which factors will affect choices relating to decarbonization in the Dutch dredging sector. I used the results from the literature reviews and thematic content analysis of the stakeholder interviews to establish recommendations that would facilitate the effective implementation of decarbonization in the Dutch dredging sector.

Chapter 3: Alternative Fuels for Dredging Vessels

The following chapter discusses the alternative fuel options most viable for dredging vessels with the help of both a literature review and meta-analysis. For the meta-analysis, I used key-words to select sources (Figure 3). Main alternative fuel options that sources discuss in relation to dredging vessels are LNG, methanol (grey methanol, biomethanol and e-methanol), biodiesel, hydrogen, ammonia and batteries. Based on the meta-analysis, patterns show a couple of themes that recur frequently, being environmental impact, economic feasibility, infrastructure, maturity and safety. Qualitative information from the papers explore the challenges and opportunities in relation to the themes mentioned above. Finally, I used the interviews with experts from the Dutch dredging sector to complement the findings from the literature reviews.

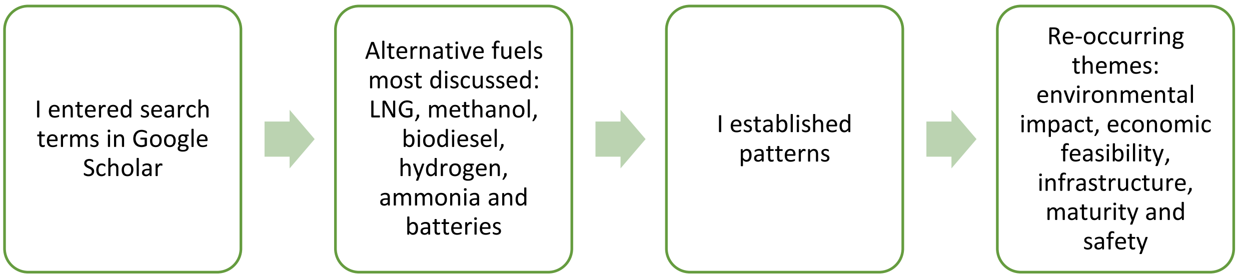


Figure 3: Themes Meta-Analysis

Emission Scopes

Companies use emissions scopes to quantify their GHG's (Hertwich & Wood, 2018). The GHG protocol is the most widely used international accounting tool. This consists of three scopes, namely scope 1, 2 and 3. The direct emissions of fuel consumption associated with an activity, such as dredging, are scope 1. Scope 2 and 3 are indirect emissions. Scope 2 addresses emissions that are generated from the purchase of energy (Ehlers et al., 2020). Scope 3 addresses emissions that occur within a company's value chain. This thesis takes into account that dredging companies are aiming to address emissions from all scopes. Dredging companies are tackling their scope 2 emissions by, for instance, electrifying their cars, and placing solar panels on their buildings and warehouses. The interviewees deemed this as an easy measure as it is in their direct sphere of influence. The transition to alternative fuels, on the other hand, includes an entire chain of suppliers such as producers of engines and alternative fuels and is thus complex (Interviewee 1).

Emissions Dredging Vessels

Two types of dredging vessels that the dredging sector often employs are Trailing Suction Hopper Dredgers (TSHDs) and Cutter Suction Dredgers (CSDs) (Bray & Cohen, 2004). They are mechanical/hydraulic dredgers and thus use a combination of mechanical means for excavation and centrifugal pumps that apply an excavating force. The main source of CO_2 emissions from vessels comes from the combustion engines (El-Houjeiri et al., 2019). While conventional fuels, crude oil distillates such as Heavy Fuel Oil (HFO), Marine Diesel Oil (MDO) or Marine Gas Oil (MGO), are currently the most economically viable option, they produce a lot of carbon emissions from a well-to-wake perspective. Emissions can be divided into well-to-tank, tank-to-wake and well-to-wake emissions (Lindstad et al., 2021). Well-to-tank emissions are the emissions generated by the production of the fuel. Tank-to-wake emissions are those that result from the burning or using of a fuel. Fit For 55 adopts a well-to-wake approach, which encompasses emissions from every stage in the life cycle of a fuel; so from its production to when it is used. This means that a fuel can be defined as carbon-neutral even if it releases emissions as long as the entire life cycle has net-zero emissions. There are several options for alternative fuels ranging from fossil fuels with lower CO_2 emissions, carbon neutral fuels and zero carbon fuels (Xing et al., 2021).

Engines

Most conventional dredging vessel designs hold a combustion engine to power the vessel (Mestemaker et al., 2019). However new technologies are emerging due to the need for decarbonization. This led to the development of dual-fuel engines, fuel cells and batteries[3]. There are several technological challenges that the sector is facing with the emergence of these new technologies. The main issues are related to the energy density of the fuel, the availability of the fuel as well as the safety of the fuel storage and handling on board. A challenge specific to the dredging sector is engine fluctuations, and its power demand which varies a lot during dredging operations (Interviewee 4, Interviewee 7). It is often still unknown to what extent an alternative system can handle these fluctuations and thus the usage profile of a vessel is important. While there are still current technological constraints, interviewees deem transitioning to alternative fuels technologically feasible. They think the technology itself will not be the biggest problem to face during the energy transition. Several interviewees noted that the lack of infrastructure and finding craftsmen and experts to build,

[3] Detailed information about conventional engines, dual-fuel engines, fuel cells and batteries in Appendix III

maintain and operate the equipment will be most challenging for the deployment of sustainable technology (Interviewee 3; Interviewee 5; Interviewee 12; Interviewee 14).

<u>Alternative Fuels</u>

There are different types of alternative fuels including fossil fuels with lower CO_2 emissions, carbon neutral fuels and zero carbon fuels. Carbon neutral fuels have no net CO_2 emissions and thus they offset CO_2 combustion emissions during their production (Carvalho et al., 2021). There are two kinds, namely synthetic fuels which capture CO_2 from the atmosphere or an industrial process and biofuels, which take up CO_2 by photosynthesis. Biofuels are produced from biomass, such as renewable organic material (Xiao et al., 2022). Measures within Fit For 55 push for the use of advanced biofuels, which stem from sources such as lignocellulosic biomass, non-food crop feedstocks, agricultural and forest residues and industrial wastes (Panoutsou et al., 2021). Moreover, there are zero carbon fuels, which have no net release of CO_2 emissions, such as hydrogen and ammonia (Madsen et al., 2020; Xing et al., 2021). These can be used in combustion engines or fuel cells, but their entire life cycle needs to be green for them to classify as zero carbon (Madsen et al., 2022). For instance, the fuel should be produced by renewable energy and transportation by truck, or bunker barge should be green. Lastly, batteries are zero carbon alternatives, if the electricity generated comes from renewable energy (Xing et al., 2021). A study conducted by Mestemaker et al., showed fuel options that can be considered as alternatives for work vessels (2020). The study provides a table with a short overview on the tank to propellor emissions, technological readiness (TRL) and total cost of ownership (TCO) (Appendix IV: Alternative Fuel Options Work Vessels, Table 2). The alternative fuel options for dredging vessels that findings from sources and interviews discuss are LNG, methanol (grey methanol, biomethanol and e-methanol), biodiesel, hydrogen and ammonia (Figure 4). The sector is already applying biofuels to some vessels and has electrified and/or hybrid equipment (Interviewee 5, Interviewee 2). Moreover, an initiative within the Dutch dredging sector showed that alternative fuel options most interesting for the coming 10-15 years are methanol and hydrogen, and for a smaller niche batteries, mainly in combination with one of the other alternative fuel options (Interviewee 4). To explore how the Dutch dredging sector approaches alternative fuel options, this thesis thus zoomed in on the alternative fuels listed in Figure 4.

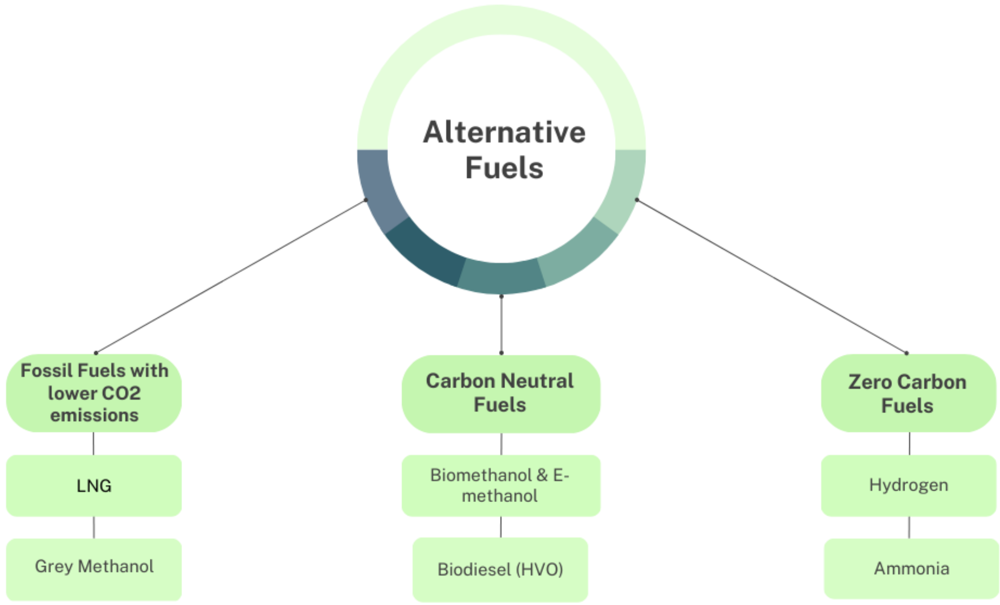


Figure 4: Alternative Fuels for Dredging Vessels

LNG

Environmental Impact

A case study in Argentina, that researched the atmospheric and economic impact of using LNG fueled trailing suction hopper dredgers, showed that LNG fuel reduces dredging vessel emissions that are harmful to health such as NOx and SOx emissions, as well as particulate matter (PM) (Podetti, 2021). LNG was one of the first alternative fuel options explored by the dredging sector, mainly because of its benefit of reducing NOx and SOx emissions (Interviewee 12). Additionally LNG lowers CO_2 emissions and, according to the study by Podetti, can be mixed with biogas which can bring down CO_2 emissions up to total decarbonization (2021). Other studies also highlight the ability of LNG fuel to reduce CO_2 emissions, owing to a higher hydrogen-carbon ratio (Mestemaker, B., van den Heuvel, H., & Gonçalves, 2020; Taneja et al., 2021; Perčić, 2022). However, due to the high operating intensity of dredgers, the fuel consumption levels of dredging vessels can be very high. An interviewee noted that on board the CO_2 reduction of LNG is only estimated to be roughly 10%, making the benefit very low (Interviewee 12). This is because often LNG engines need to be paired with a diesel engine to continue working properly (Interviewee 13). Additionally, there are concerns about methane slip (Santos et al., 2022; Al-Enazi et al., 2021; Sheikh, 2019; Mallouppas & Yfantis, 2021). A study points out that even with a 2% methane slippage LNG fuel would not be more favorable than conventional fuels due to a similar global warming potential (GWP) (Al-Enazi et al., 2021). Methane slip is unburned fuel in a vessel's engine which is caused mainly by poor fuel combustion, owing to technology used for LNG admission in the engine (Wang & Wright, 2021). Engines with one gas admission valve in the inlet result in large methane slip, whereas engines with port injection have lower methane slip (Georgescu et al., 2016). Port injection is often used in LNG dual-fuel engine designs. A study, that describes CSD designs using the life cycle performance assessment tool, shows that when LNG is used within a hybrid dual-fuel engine, it were to result in a lower GWP. However, when used in a dual-fuel design with more engines to guarantee operational conditions in gas mode, the GWP is slightly higher (Mestemaker, B., van den Heuvel, H., & Gonçalves, 2020). This is mainly due to more methane slippage occurring in this design as well as a reduction of the engine efficiency at low load which results in more fuel consumption. However, this depends on the vessel type (CSD or TSHD), and low load and low efficiencies are relevant for diesel-driven vessels as well. Emissions thus highly depend on the design of the vessel and slip emissions. This means that LNG fuel and engines must meet the highest standards to reduce CO_2 emissions.

Economic Feasibility & Maturity

Studies state that LNG fuel is available at a competitive fuel price (Perčić, 2022) and projected cost is even lower than that of refined Diesel Oil (Podetti, 2021), with one study noting that the price for LNG is presumed to be 70% of the price of MDO (Van Leeuwen, 2017). A case study on cutter suction dredgers shows that the combination of dual-fuel engines, running on LNG and MDO, and a battery energy storage system, allows the cutter suction dredger vessel to run on LNG continuously (Van Leeuwen, 2017). This creates a cost reduction of 17-33% during dredging operation compared to MDO. However, these findings might not accurately reflect the present reality. Gas prices are namely higher due to the political state of Europe, which makes LNG less attractive (Interviewee 13). One study points out that while technology for LNG driven dredging vessels is available, in many cases, a new dredger has to be built (Podetti, 2021). The retrofitting of existing dredgers to LNG dredgers is 30% higher in cost than building a new one. This is difficult to justify in the case of vessels at the end of their life span. Representatives from the Dutch dredging sector state that their studies show that it requires huge investments and most of the retrofitting scenarios do not have a significant impact on CO_2 reduction (Interviewee 5).

Infrastructure

Other challenges are the infrastructure required to supply dredging vessels with LNG fuel and the storage of LNG fuel (Ewert & Kerolus, 2022; Perčić, 2022; Wasim & Nine, 2017). Past research points out that dredging vessels' geographic working areas need to be as flexible and large as possible due to the wide variation in projects that require dredging equipment and thus the choice of fuel cannot become a limiting factor (Sansoglou, 2014). There are several options for supplying dredging vessels with fuel, namely truck to ship, ship to ship and shore to ship (Ewert & Kerolus, 2022). The first variant is most often implemented. Ship to ship requires LNG vessels that are often too large for port locations, are expensive and not widely available. This is largely due to the equipment and control systems needed to keep the temperature and pressure stable in order for LNG to remain in a fluid state. LNG fuel namely requires insulated tanks for storage, because of its cryogenic nature, and over time evaporation is unavoidable while stored (Perčić, 2022; Al-Enazi et al., 2021). Shore to ship is the most expensive alternative but also more suitable and stable on the long term. Thus, there are plenty alternatives to supply vessels with LNG but each comes with its own challenges.

Methanol

Methanol is the alternative fuel option that market companies are aiming for right now as a viable alternative for dredging vessels to reduce emissions to nearly zero (Interviewee 10). Methanol has multiple production routes that influence emission reduction including fossil fuels (grey methanol), biomass (biomethanol) and electrolysis (green methanol/ e-methanol) (Harmsen et al., 2020).

Environmental impact

CO_2 emissions of methanol fuel largely depend on the production route chosen for methanol fuel, as it does have tailpipe emissions and any significant reductions depend on the well-to-tank emissions (Perčić, 2022). Methanol fuel would reduce NOx emissions with about 70% as well as SOx emissions to about a 100% compared to conventional fuels (Harmsen et al., 2020). Fossil fuel based methanol does not significantly impact GHG reduction. Despite its lower carbon content, methanol based on fossil fuels can in some cases even add to an increase of GHG compared to conventional fuels (Zomer et al., 2020; Perčić, 2022). To make the use of methanol fuel low-carbon, production routes need to become greener (Wang & Wright, 2021; McCarney, 2020). Biomethanol is carbon neutral because it is produced by biomass (Harmsen et al., 2020). The major issue surrounding biofuels is the debate on food vs. fuel (Wang & Wright, 2021; Santos et al., 2022; Sheikh, 2019). Often the production of biofuels requires large-scale deforestation and/or competition with food resources, which creates other environmental issues. Fit For 55 thus promotes the use of advanced biofuels to avoid this issue. If produced from biogenic waste biomethanol is considered to be an advanced biofuel[4] (Zomer et al., 2020). E-methanol is carbon neutral if the capture itself is powered by carbon-neutral power sources (Zomer et al., 2020). A study states that it can significantly lower GHG emissions of up to 86% compared to conventional fuels (Perčić, 2022).

Economic Feasibility

A study researching several alternative options for dredging vessels states that, besides the conventional diesel system, methanol fuel is the most cost effective solution compared to other alternative fuels for dredging vessels (Perčić et al., 2021). The price of methanol in the future will mainly depend on its production route and the maturity of the production routes (Harmsen et al., 2020; Zomer et al., 2020). Fossil fuel based methanol is relatively competitive in comparison to other alternative fuels and available at an affordable price, specifically compared to hydrogen (Harmsen et al., 2020; Perčić, 2022). Research shows that it is expected that the projected fossil fuel based methanol demand can be met by the global methanol production capacity and that this will not be limited in the short or medium term (Zomer et al., 2020). As the availability of biomethanol and e-methanol is still low, the expectation is that fossil fuel based methanol will still play an important role for global supply in the future (Zomer et al., 2020). Currently biomethanol is still more expensive than grey methanol due to its production route and lower availability. For biomethanol to be considered an economically feasible option, it is likely that a premium of up to 45% is needed to be cost-competitive with fossil fuel-based methanol (Zomer et al., 2020). Increasing experience and research could reduce the costs of biomethanol in the future. Subsidies or legislative measures such as taxes on conventional fuels could make stakeholders within the maritime industry willing to pay higher prices for biomethanol. E-methanol is seen as one of the less costly e-fuels due to its energy efficiency (Mestemaker et al., 2020; Zomer et al., 2020). Additionally it is relatively easy to distribute and store, making it more practical than hydrogen and ammonia (Zomer et al., 2020). Despite it being one of the less costly e-fuels it does still have high production costs, making it the most expensive form of methanol (Perčić, 2022; Zomer

[4] Renewable Fuels of Non-Biological Origin (RFONBO)

et al., 2020). Production potential of green methanol namely strongly relies on the availability of electricity from renewable sources and CO_2 (Zomer et al., 2020). Research thus deems it unlikely that it will be largely applied before 2030 (Zomer et al., 2020). In order for green methanol to become competitive with grey methanol, regulations, such as CO_2-fees on natural gas production, are needed. Including the dredging sector within national and international policies that implement a tax system, could thus be beneficial to stimulate companies to invest in other alternatives.

Infrastructure & Maturity

Some dredging companies are considering retrofitting vessels to methanol, which is more feasible than retrofitting to LNG, as the properties of methanol are closer to the distillate of marine diesel oil (Interviewee 2). Some engines already operate on methanol with the main challenges remaining related to maintenance, blending and lifespan of an engine operating on methanol (Interviewee 12). Methanol namely attracts water and can be bad for metal which leads to corrosion in the engine. Additionally, the average percentage of diesel required to ignite methanol is 25% with the desired percentage being 5%[5]. The expectation, however, is that a wide range of engines, that will be able to operate on methanol, will emerge within this decade. Methanol fuel can be integrated into existing infrastructure with minor modifications and is more accessible on the short-to-medium term than other alternative fuels such as for instance hydrogen (Perčić, 2022; Harmsen et al., 2020). Those modifications are related to the reduced energy content of methanol. Methanol consumption namely is twice as high as for MDO (Zomer et al., 2020; Interviewee 2; Interviewee 8). A lower energy content of a fuel requires adjustments in the operations or technical layout of the dredging vessel (Harmsen et al., 2020). Either more volume is required or there needs to be a higher bunker frequency (Zomer et al., 2020). These modifications can make even fossil fuel based methanol pricy (Zomer et al., 2020). Thus bunkering methanol could present itself as an issue during the early stages of transitioning from conventional fuels to methanol. Ship-to-ship bunkering is favorable for methanol but this would only be an option if that market reaches high level of maturity (Zomer et al., 2020). Additionally, the use of methanol fuel for dredging vessels would require a worldwide availability of it at ports (Harmsen et al., 2020; Zomer et al., 2020). It does seem that the use of biomethanol will become more viable in the future but this

[5] High diesel percentage for lower engine loads and lower diesel percentages up to 5% for higher engine loads.

largely depends on the availability of biomass as well as production facilities which is influenced by sustainability policies, prices and sector supply (Zomer et al., 2020).

Safety

Methanol fuel has specific safety requirements. This means vessel adaptations are necessary for both the bunkering process and the storage on board of dredging vessels (Harmsen et al., 2020; Zomer et al., 2020). Methanol has a low flash point, thus there could be risks of leaked fuel mixing with air and catching fire (Harmsen et al., 2020; Zomer et al., 2020; Perčić, 2022; Interviewee 2). Moreover, the fuel is toxic to humans which could be a danger to crew on board of dredging vessels that needs to handle the fuel. However, past research states that it is possible to do design fuel systems which provide similar safety levels as conventional diesel fueled vessels (Harmsen et al., 2020). A double wall design and hazardous zones with specific work instructions, for example, reduce the risks associated with a low flash point (Perčić, 2022).

Biodiesel

Environmental Impact

The use of biodiesel creates a smaller footprint but blend combustion does result in GHGs (Taneja et al., 2021; Perčić, 2022). The sustainability highly depends on the feedstock use of the fuel and it thus needs to be an advanced biofuel to comply with Fit For 55 regulations (Santos et al., 2022). Advanced HVO is a fuel originating from waste and the estimate is that only about 6% of the energy need can be met with the current volumes of waste available to create HVO (Interviewee 12).

Economic Feasibility, Maturity & Safety

Dredging companies are using advanced biodiesel on some vessels as it can easily be integrated into current engines of dredging vessels (Perčić, 2022; Interviewee 2; Interviewee 5). When biodiesel is blended with other fuels, with a share of up to 20%, no engine modifications are needed (Perčić, 2022). The fuel is non-toxic and bio-degradable (Perčić, 2022). It is however not produced on a global scale, as it is considered to be a transition fuel, and therefore more expensive (Taneja et al., 2021). It has prices of up to 40% higher compared to normal diesel and thus dredging companies mainly apply it in cases where the client is stimulating it in projects (Interviewee 3; Interviewee 1).

Hydrogen

Environmental Impact

Research points out the high potential of zero-emission dredging vessels by implementing hydrogen fuel cell technologies within the designs of dredging vessels (Mestemaker, van den Heuvel, & Gonçalves Castro, 2020; Ewert & Kerolus, 2022). When renewable hydrogen, generated by electrolysis, is used, the emissions over the entire life cycle are very low.

Economic Feasibility

Green hydrogen is currently the most expensive alternative fuel option. It is even 2 to 3 times more expensive than blue hydrogen, which mainly has to do with the high investment costs (Ewert & Kerolus, 2022; Perčić, 2022; Mestemaker, van den Heuvel, & Gonçalves Castro, 2020). However, in a sustainable development scenario, hydrogen fuel could be the most economically viable alternative (Mestemaker, B., van den Heuvel, H., & Gonçalves, 2020). The price of green hydrogen is namely expected to decrease through 2050 because alternative electrical energy sources will become more available, and fuel cell technology will become mature and thus cost effective (Ewert & Kerolus, 2022; Perčić, 2022). A sustainable development scenario, in which there is implementation of emission taxes, may however not be enough to give a hydrogen fuel cell design an advantage over other alternative fuel concepts (Mestemaker, B., van den Heuvel, H., & Gonçalves, 2020). Mestemaker et al., described four different self-propelled CSD designs using the life cycle performance assessment tool (2020). The study showed that a LNG fueled hybrid design concept overall has the same expenses as the hydrogen fuel cell design if emission taxes are introduced. An LNG fueled hybrid design concept, however, is considered more polluting and does not reduce emissions significantly. Thus, the research concludes that stricter policies are needed to make the application of low-carbon alternatives within the maritime industry more viable. This demonstrates that the viability of the application of hydrogen fuel within the maritime industry primarily depends on the price of renewable energy sources, which is influenced by subsidies and policy developments.

Maturity & Safety

Hydrogen can be produced with current technology (Mestemaker, B., van den Heuvel, H., & Gonçalves, 2020). There are, however, still some limitations to the use of hydrogen as an alternative fuel. Production of hydrogen from electrolysis requires a large amount of energy (Mestemaker, B., van den Heuvel, H., & Gonçalves, 2020). Moreover, the lower energy density of hydrogen makes it an ineffective option for marine applications, specifically for work vessels as they have a higher power density (Ewert & Kerolus, 2022; Mestemaker, B., van den Heuvel, H., & Gonçalves, 2020; Interviewee 12). The estimate is that about seven times as much of the fuel is needed on board in comparison to conventional fuels (Interviewee 13). A lower energy density also means that there is more space required to store liquefied hydrogen but dredging vessels already have limited fuel storage (Ewert & Kerolus, 2022; Mestemaker, B., van den Heuvel, H., & Gonçalves, 2020; Van Ingen et al., 2021; Van der Blom et al.,; Perčić, 2022). The storage requires strict safety measures due to the flammability risk associated with hydrogen (Perčić, 2022). Shipowners and ports will therefore have to make tactical choices to approach hydrogen storage (Van Hoecke et al., 2021; Wang & Wright, 2021).

Ammonia

Environmental Impact

Ammonia, NH3, is a very clean alternative fuel as no carbon is chemically bound to it. This means it does not have tank-to-propellor CO_2 emissions. Moreover, it can be produced from renewable resources (Wang & Wright, 2021; McCarney, 2020).

Economic Feasibility

Ammonia fuel is not cost-competitive but the expectation is that the costs will become competitive by 2050 (Mallouppas et al., 2022; Mallouppas & Yfantis, 2021). The current high costs are due to SOFCs having a high life cycle cost, as well as renewable ammonia fuel having high production costs (Cheliotis et al., 2021; Cames et al., 2021; Mallouppas et al., 2022). However, the expectation is that production cost of ammonia will decrease because more electrolysis technology will become available due to the increasing interest in hydrogen, (Cames et al., 2021).

Maturity

Ammonia fuel can be applied in both ICEs and fuel cells but requires huge volumes within their tanks (Perčić, 2022; Interviewee 2; Interviewee 5; Interviewee 12). SOFCs and ICEs use ammonia directly whereas PEMFCs do not, which renders SOFCs more suitable for ammonia fuel (Ewert & Kerolus, 2022). SOFCs are more promising because they make the application of ammonia directly possible whereas PEMFCS require separating of hydrogen first (Tsang & Van Vrijaldenhoven, 2021). An SOFC does have a low power density and start up time, and requires the support of a battery system (Machaj et al., 2022; Cheliotis et al., 2021). Just as with hydrogen, green ammonia fuel cannot currently support the supply required by the maritime industry. It is not yet mature and therefore not produced at commercial level (Wang & Wright, 2021; McCarney, 2020; Al-Enazi et al., 2021; Tsang & Van Vrijaldenhoven, 2021; Machaj et al., 2022; Cames et al., 2021; Interviewee 12). Scaling up the production of renewable ammonia will depend on whether electrolysis technology will become widely available.

Safety

Ammonia is highly toxic and thus requires specific safety measures (Mestemaker, B., van den Heuvel, H., & Gonçalves, 2020; Perčić, 2022; Interviewee 2; Interviewee 5; Interviewee 12). A study points out that the strong odor of ammonia could help in recognizing leaks (Cheliotis et al., 2021).

Batteries / Electrification

Environmental Impact

A study on alternative fuels states that the application of battery systems in a dredging vessel is most environmentally advantageous due to it being a very clean alternative (Perčić, 2022).

Economic Feasibility

The costs for battery systems are currently too high (Gerritsen, 2016; Wasim & Nine, 2017; Castro et al., 2019). A study on a hybrid cutter suction dredger shows that even though the combination of an engine operating on a conventional fuel and battery system lowers fuel consumption and thus lowers CO_2 emissions, the battery system is currently not very cost effective due to low fuel prices (Gerritsen, 2016). Battery systems are also more expensive, partially due to stricter requirements and safety measures owing to the insulation and cooling needed for battery systems (Wang & Wright, 2021).

Maturity

Batteries by itself are not the best option for large dredging vessels (Perčić, 2022). This mainly has to do with the large battery systems required for dredging vessels (Wasim & Nine, 2017). Dredging vessels, however, have a limited storage capacity (Castro et al., 2019). Combining diesel and batteries might be a viable alternative for dredging vessels because the power usage of them varies a lot during dredging operations (Zomer et al., 2020). Additionally, battery energy storage systems are needed to support fuel cells, and they can support dual-fuel engines by accommodating for heavy dynamic loads which would remove the need for the engine to switch back to diesel mode (Mestemaker, B., van den Heuvel, H., & Gonçalves, 2020). For cutter suction dredgers, which are often in locations near the coast and thus have a pipeline to the coast, an option could be electrification (Interviewee 13). Some industries, such as the mining industry, use electrified zero-emission CSDs as they usually have access to the grid on land (Interviewee 6). In places where there is no grid, either diesel-generators or hydrogen-generators are opted for to keep the vessel electrified. The latter could decrease emissions over the entire life cycle if the hydrogen is generated by renewable energy. For the dredging sector, however, there is not always the opportunity to stay connected to shore, thus rendering this option more complicated.

<u>Conclusion</u>

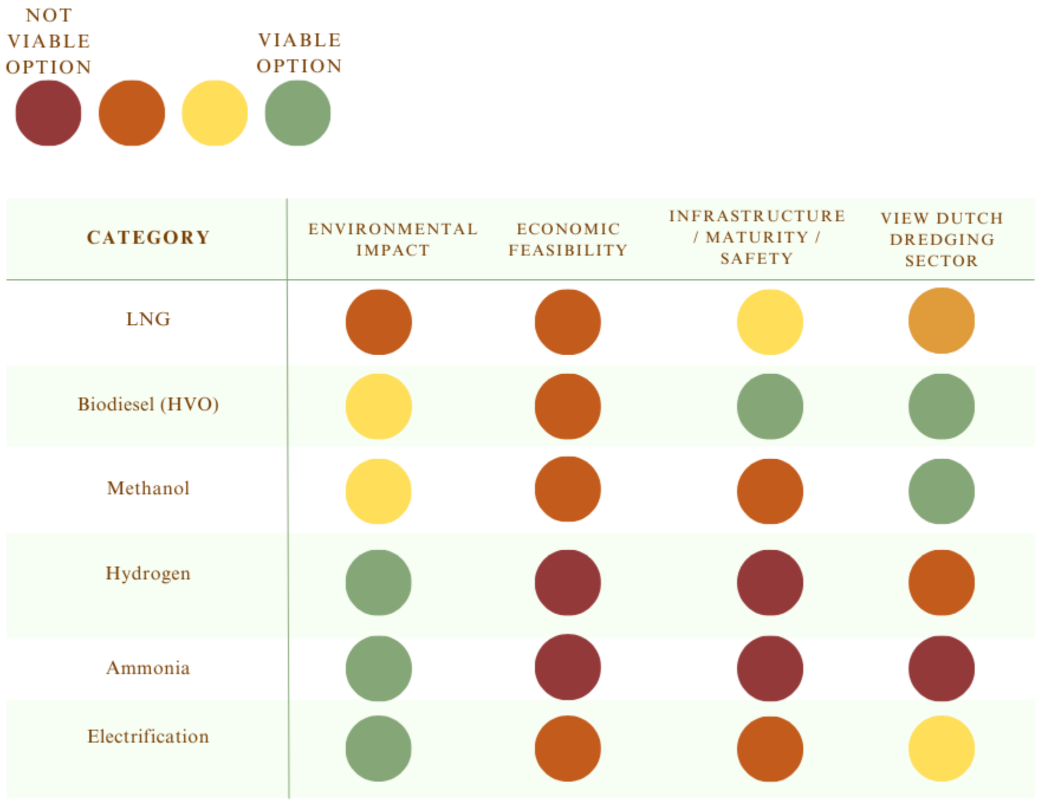


Table 1: Alternative Fuel Options deemed viable for Dredging Vessels (Reflecting Current Situation)

Findings show that biodiesel, methanol and batteries/electrification (mainly for hybrid solutions and/or smaller near-coast vessels) are currently seen as the most favorable alternative fuel options by the sector (Table 1). Hydrogen might become more viable in the future and is thus also an option the sector is carefully considering. CO_2 reduction targets cannot solely be achieved by transitioning to fossil fuels with lower CO_2 emissions, such as

LNG, and thus the sector is researching cleaner alternatives. The use of methanol and biofuels in the short-to-medium term is more viable for dredging vessels given the technological readiness, high investment costs of other alternative fuel options and the modifications required to implement them. It is, however, important that the production routes of the fuels are bio-based (advanced) or green to significantly reduce GHG emissions. Although the use of hydrogen fuel cells or battery systems, if generated by renewable energy, would be most environmentally advantageous, the technology is not mature yet and/or too costly. Additionally, the battery capacity required within a large dredging vessel is hard to meet, rendering it mainly suitable for smaller vessels. The most cost-effective option, besides a diesel-driven dredger, would therefore be one operating on biodiesel or methanol. If the dredging sector were to fall under regulations where tax drives up the prices of fuel, alternative solutions might become more viable and cost effective to implement. This thus raises the question how climate policy, such as Fit For 55, influences stakeholder choices in relation to these alternative solutions.

Chapter 4: The Dutch Dredging Sector's Choices in Relation to Alternative Fuels

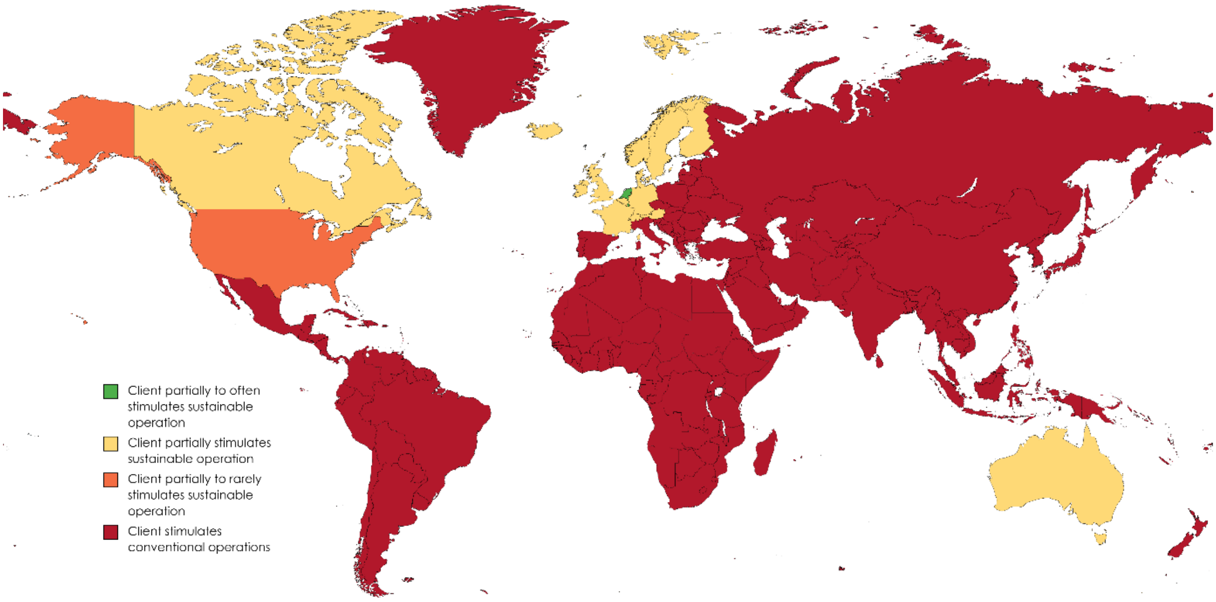
To determine how climate policy, specifically Fit For 55, influences the Dutch dredging sector's choices in relation to the implementation of alternative fuels, I conducted interviews. Themes that often recurred within the interviews were policy, the international market, the role of the client and companies' drivers to decarbonize.

Policy & the Role of the Client

The interviews showed that there is a strong dependency of the dredging sector on the client. To make it more logical and profitable for the dredging sector to invest into decarbonization of their vessels, governments need to set standards (Interviewee 4; Interviewee 3; Interviewee 14). Successful instances of governments stimulating companies to operate with cleaner vessels can be seen throughout the sector, specifically on a national level. In the Netherlands, Rijkswaterstaat collaborates with dredging companies on an ambition program that rewards the sustainability of a project (Interviewee 2). Moreover, vessels with Selective Catalytic Reduction (SCR) installations, to reduce NOx emissions, is commercially giving dredging companies an advantage in tenders (Interviewee 5). The government stimulates companies by adding a fictional price to the tender price to include the company's emissions. The tender bid and fictional emissions costs equal the total bid and can thus provide a fictive discount[6]. At the moment, however, there are no binding CO_2 rules that apply to dredging vessels and in many cases, especially internationally, lowest bid is still decisive within tenders (Interviewee 5; Interviewee 10). Even though there are a number of companies that want to take the lead, it is too risky. If a dredging company makes an investment into making a vessel more sustainable, this automatically makes the vessel more expensive than the competition (Interviewee 10). It is therefore the responsibility of governments to set stricter policies, as well as concrete steps to realize these policies. Once a clear trajectory is realized by governments, can the dredging sector make viable investments in alternative fuels.

[6] Details in Appendix V

Fit For 55



Effects of EU climate policy are evident throughout the maritime industry. Dredging companies, as well as shipbuilding companies, notice that continents such as Africa, South-America and Asia usually do still ask for very conventional designs driven by diesel engines. European clients, however, are more often asking for alternatives (Interviewee 13; Interviewee 5; Interviewee 4). Specifically within the Netherlands the client is stimulating the use of cleaner vessels within projects while this is partially happening within the rest of northwest Europe, Scandinavia, Canada and Australia, with North-America[7] behind that (Interviewee 5; Interviewee 3). While Fit For 55 regulations still exclude work vessels, the interviews show that they indirectly impact decisions surrounding alternative fuel options for dredging vessels. The EU ETS system is a big driver, because this binds companies to pay for their emissions (Interviewee 1). Dredging companies are thus preparing for revisions within their decarbonization roadmap. One interviewee noted it is likely dredging companies will adhere to Fit For 55 regulations by making a difference between vessels operating within the EU and outside of the EU (Interviewee 7). Opinions, from representatives of dredging companies, varied in relation to this. A leading argument to not make a difference between vessels was that their vessels need to be able to operate worldwide (Interviewee 5). Technologically they have relatively little equipment that is designed to just operate within Europe. They would therefore ensure they can abide to regulations, while safeguarding the ability of their vessels to operate worldwide by, for instance, applying advanced biofuels to

[7] Due to the Jones Act Dutch dredging companies may not engage in dredging projects in North-America with 'foreign-built vessels' (Bruun & Esposito, 1993).

diesel engines. Representatives that deem it likely their company will make a difference between vessels operating outside and inside of the EU if Fit For 55 regulations were to apply to the dredging sector, stated this mainly has to do with a large amount of their profit coming from projects within Europe (Interviewee 2). This would make it more attractive for their business model. There was a general consensus under interviewees that Fit For 55 regulations would create an even playing field and not jeopardize the competitiveness of dredging companies. One interviewee did note it could cause challenges on the international scale[8] (Interviewee 1). These findings highlight the weight and influence of the international field the market operates in.

International market

Representatives from the sector find it likely the Dutch dredging sector will focus on following the trend set by the international market. Several interviewees pointed out the importance of scalability in relation to this (Interviewee 4; Interviewee 8; Interviewee 9). For one, different sectors within the maritime industry cannot all decide to operate on different fuels, because this would not make the energy transition economically feasible (Interviewee 9). Secondly, there are developments at EU-wide and international level focused on including a wider range of different sectors as well as vessel types and vessel sizes (Interviewee 8; Interviewee 9). The expectation is that within the next five to ten years the demand for cleaner vessels, within the EU, will be larger than the demand for conventional vessels (Interviewee 9). Given the speed of the current climate ambitions within the EU, developments like this could already be seen within two to three years. This notion implies that investments in sustainable vessels will potentially become more economically feasible throughout the EU within the next couple of years, with climate policies like Fit For 55 positively stimulating this trend. Similar policy changes, such as ones like Fit For 55, are starting to emerge on a more global scale (Interviewee 2; Interviewee 1; Interviewee 8; Interviewee 9). There are ongoing discussions at IMO level about the decarbonization of the maritime industry (Interviewee 8, Interviewee 9). These discussions include topics such as CO_2 prizing as almost a copy paste of Fit For 55, without the ETS. It focuses on how taxation of emissions can be applied to vessels. This would make the playing field more even as the entire maritime

[8] For instance, vessels traveling to the EU have to pay for 50% of their emissions which could lead to weird constructions of international competition. An example would be that international competition could try to reduce this price by harboring at Morocco, on their way from Asia to Europe.

industry would be included. Policy, both on EU and international scale, is thus an important external driver for the sector.

Drivers

Whereas policy is a strong external driver, other external mechanisms, such as criticism from media outlets or activist groups, are not huge pressures to decarbonize. While stakeholders do read media pertaining to them, they have different drivers to decarbonize (Interviewee 5). These drivers are internal, examples being social responsibility and existence of the company. Part of the dredging sector’s work is protecting countries against rising sea level. On this account, companies feel they cannot pick or choose what environmental challenges they want to be a part of (Interviewee 5). This is one of the reasons dredging companies entered the offshore wind market or set their own sustainability goals. Moreover, companies feel pressure to decarbonize from their own staff and the job market (Interviewee 2; Interviewee 5). To safeguard their reputation in the job market they need to be aware that young people do not want to work for polluting companies (Interviewee 5; Interviewee 6). Some representatives stated that a lack of knowledge and awareness, both within and outside of the maritime industry, is slowing down decarbonization in the sector (Interviewee 2, Interviewee 11, Interviewee 1; Interviewee 14). This notion indicates that the pressure to decarbonize exerted by staff is indeed prevalent in the sector. It also shows that representatives find it important that there should be more of a nuanced discussion from the outside looking in. This demonstrates the need for a less binary, and more refined, dialogue surrounding the topic of decarbonization in the sector.

Conclusion

My findings show that the sector is investing in sustainable alternatives, specifically within the Netherlands, but that those are not deemed viable yet outside of the EU. Decisions within the dredging sector primarily depend on international developments. The international operating field of the sector is a challenge in terms of the decisions to make surrounding decarbonization of dredging vessels. While Fit For 55 would act as a financial stimulator to decarbonize, decisions surrounding decarbonization of dredging vessels largely depends on the locations of the dredging projects of a company. As representatives highlighted the importance of scalability, it could be worthwhile to use the rapid developing climate ambitions in the EU as an opportunity to test out new sustainable technology. Similar carbon reduction trends, as the one set by Fit For 55, are notably starting to spread over the globe. This illustrates that dredging companies will likely have to adhere to stricter standards in more places over the coming years. As such it could become viable to invest in alternative fuel options. While external drivers, such as policy developments, are most significant, there are also several internal drivers that could further investment in sustainable alternatives. Pressure from staff and the job market is increasing awareness throughout the sector and could facilitate the intrinsic motivation needed for cleaner investment. These findings prompt the need for next steps to stimulate the implementation of alternative fuels in the Dutch dredging sector.

Chapter 5: Alternative Fuels & Next Steps

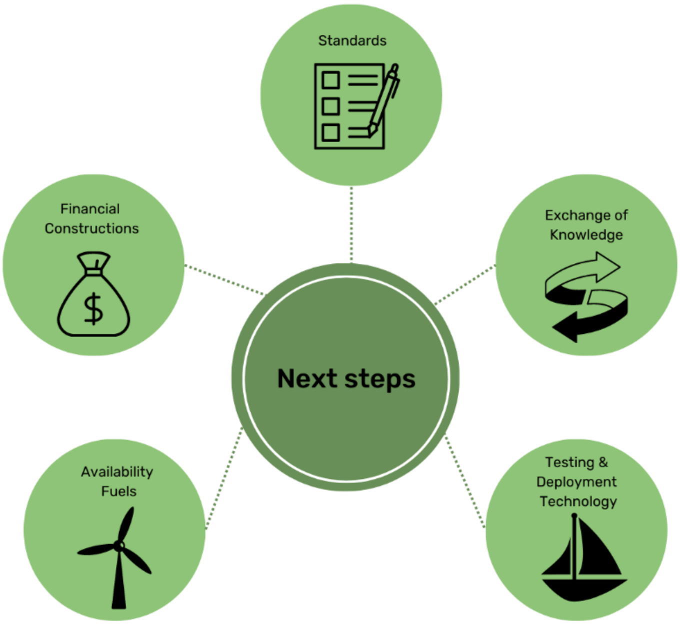


Figure 5: Next Steps to Boost the Implementation of Alternative Fuels

To make the transition to alternative fuels feasible for dredging companies, representatives from the sector deem the steps outlined in figure 5 as vital.

<u>Standards & Financial Constructions</u>

As findings previously indicated, the extrinsic influence of governments and clients is leading for investments in sustainable technology. Unless governments stimulate the sector, by making conventional fuels the less attractive business model, the sector is hesitant to invest in cleaner alternatives for infrastructure projects. Interviewees mentioned several ways in which governments can set stricter requirements. Governments can establish regulations mandating that infrastructure projects be performed with carbon neutral vessels. Conjointly, they should specify what alternative methods must be employed to make it more logical for dredging companies to invest into certain types of alternatives (Interviewee 12; Interviewee 14; Interviewee 3). Or governments can let the market do its own thing but put price tags on carbon emissions. Several interviewees deem the combination of policy and financing as vital. As such, the government should come with a long term investment plan[9], an example of that being the innovation financing that was given for the maritime masterplan (Interviewee 9, Interviewee 10; Interviewee 3). Another interviewee brought forward an opposing view. He

[9] An interviewee deemed the government has enough budget to finance this as an analysis with TNO showed that the effect of the investment for the dredging sector would be quite a profitable process if compared to other decarbonization initiatives (Interviewee 4).

noted that financial constructions are important, but that the responsibility of financing is at times too quickly placed on the government (Interviewee 7). He deemed there are also other ways to finance decarbonization of vessels. For instance, with a long term contract[10]. Some dredging companies, however, do not work with the financing of banks and thus those are more dependent on the client and/or government (Interviewee 3). These different considerations show that representatives view policy as the key component, with ranging ideas about governments' and/or clients' roles in financing the energy transition. This implies that it is vital to understand why the sector considers investments in cleaner alternatives either financially possible or not possible. Conjointly, it highlights the importance of a financing strategy that recognizes the difference in dredging companies' business models. Thus, government in conjunction to sector investment is needed to deliver the financial flows essential to obtain a low-carbon dredging economy. Inclusive policies can thereby create strong incentives for the sector to invest in cleaner alternatives to further decarbonization.

Testing of Technology & Deployment and Availability Fuels

Moreover, ensuring that vessels get deployed with new technology is critical to establish whether alternative solutions are reliable (Interviewee 7; Interviewee 9). To further deployment of new technology, a first step could be the implementation of dual-fuel methanol vessels (Interviewee 13). As such, there is a methanol system on board and the amount of time operating on methanol can gradually be increased. Being prepared with dual-fuel gives both the user and producer a pathway for scalability. A fast development of the availability of e-fuels, such as green methanol, is thereby important (Interviewee 5; Interviewee 8). To develop e-fuels, accessibility to hydrogen is crucial. This showcases a current issue in facilitating the energy transition, namely the "chicken and egg problem" (Interviewee 12; Interviewee 14; Interviewee 3). In order for vessels to operate on alternative fuels, there needs to be an infrastructure, which cannot be created without policy and reliable technology. An option could be for companies to take the lead, after which legislation will follow. Representatives, however, view such a step as too risky and therefore dredging companies are hesitant to take it (Interviewee 3). Moreover, the ambiguity of the market is making it hard to predict which alternative fuel(s) are most likely to be implemented throughout the maritime industry (Interviewee 13; Interviewee 7; Interviewee 14). These notions exhibit that

[10] This were to mean that if a dredging project within a certain location needs to be performed each year, a client could for instance set up a 20-year contract for a dredging company. The dredging company could then go to the bank and ask financing for a green vessel for that 20-year project.

uncertainty fosters hesitance to invest in alternative fuels which steers back to the importance of clarity by governments. Conjointly, it underlines that it is essential governments invest in infrastructure to make it more feasible for the dredging sector to invest in clean technology.

Exchange of Knowledge

Lastly, exchange of knowledge is crucial to ensure cooperation and for the sector to keep pace with the speed of decarbonization that other sectors are moving at (Interviewee 9). An interviewee noted that there are people that deem that, because the maritime industry is only 3% of the footprint, there are other industries in which the carbon footprint can be decreased more significantly (Interviewee 12). However, most vessels that are bought now will be employed till 2050. Hence, if investments in cleaner technology and infrastructure are not made now, the sector will fall behind on the energy transition. While it is not economically feasible for one company to make the difference, by for instance switching their entire fleet to operate on biofuels, representatives find it important that companies do not all adopt the mindset that "they are too small to make the change" (interviewee 2). One interviewee noted collaboration is thereby crucial but that at times stakeholders have the tendency to keep their cards close to their chest (Interviewee 3). This hesitant approach towards exchange of knowledge could potentially slow down the cooperation needed to facilitate the energy transition in the dredging sector. An increase in transparency, especially within cooperative context, is therefore important to determine ways in which the sector can collaboratively bring about change.

Conclusion

The interviews showed that hesitance, fostered by a lack of clarity from governments, is slowing down decarbonization within the sector. My findings indicate stricter requirements in combination with investments in infrastructure, deployment of technology and exchange of knowledge could further the energy transition in the sector. Representatives namely find it important for the sector to take action now so it does not fall behind on other industries. Equivalently, it is important to carefully consider that technology, infrastructure and policy, as well as legislation, is not that far yet that an immediate switch to alternative fuels can be made. This calls for the need for more nuanced discussions in relation to decarbonization and other carbon reduction measures to facilitate companies' transitional period to alternative fuels.

Chapter 6: The Role of Alternative Fuels within CO2 Reduction Strategy

In addition to researching alternative fuels, the sector embarked on several other initiatives to address decarbonization. This chapter explores the role of alternative fuels within CO_2 reduction measures.

<u>Carbon Reduction Measures</u>

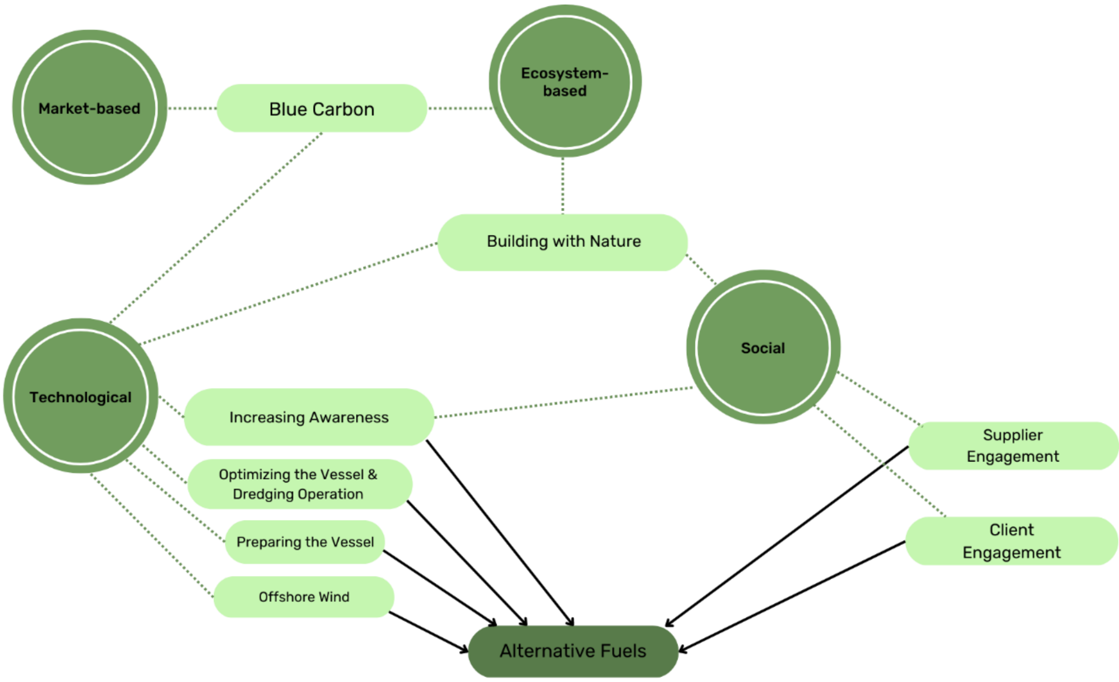


Figure 6: Examples Carbon Reduction Measures

Interviewees mentioned several ways in which carbon reduction can be addressed in the sector and/or measures that can be taken to reduce the carbon footprint of the company. These findings demonstrate the weight of the interdisciplinary field of decarbonization measures (Figure 6: Examples Carbon Reduction Measures).

Vessels

Representatives deem that optimizing the vessel and efficiency, as well as the continuity, of dredging operations is the first step. Examples mentioned by interviewees include the optimization of the hull shape of the vessel so it has the least possible resistance, hybrid propulsion systems using battery power for peak shaving, sailing more efficiently, fine-tuning engines, maintaining the vessel, dredging more efficiently and improving the dredging pump (Interviewee 13, Interviewee 4, Interviewee 7; Interviewee 11; Interviewee 5). Reducing the peaks in power and making the energy system more efficient does not only reduce emissions but also makes it easier to implement alternative fuels (Interviewee 4). Until the sector can implement alternative fuels, it is preparing their vessels in such a way that they can convert them once alternative fuels become ready for use (Interviewee 5; Interviewee 2). In addition, several dredging companies entered the offshore wind market years ago to help facilitate the transition to cleaner energy (Interviewee 2).

Environmental Impact

Dredging companies' sustainability measures do not only address emissions from equipment. They target the entire environmental impact of dredging operations. The Building with Nature program is an example of this. It focuses on incorporating nature within project designs to create more sustainable hydraulic engineering operations which saves emissions and costs (Interviewee 2). An example is 'de zandmotor' which is a natural solution for coastal protection in which the stream alongside the coast transports and distributes the sand (Interviewee 2). The Building with Nature program does not only offer technological solutions within projects but also increases awareness around environmental care and provides the opportunity to work as a social incentive to address decarbonization. Moreover, stakeholders are carefully considering the impact of potential ecosystem-based emissions. Ecosystem-based carbon emissions do not always occur during dredging projects but can under certain circumstances be significant (Wetlands International, 2022). By incorporating nature in designs those effects can be mitigated and/or reduced, additionally providing opportunities to increase sequestration, for instance in blue carbon ecosystems.

Market-based Measures

Another initiative the sector is researching is the feasibility of blue carbon projects (Boskalis Sustainability Report, 2021). Blue carbon ecosystems are coastal ecosystems that store carbon such as mangrove forests, salt marshes and seagrass. They can function as nature-based solutions to help companies achieve their goal of becoming carbon neutral. While the EU ETS system excludes carbon credits from forestry and/or wetland projects, the voluntary carbon market (VCM) provides a platform for organizations and companies to trade emission allowances to reduce residual emissions to achieve their reduction targets (Claes et al., 2022).

Engagement & Awareness

Moreover, dredging companies are increasingly engaging with scope 3, for instance with supplier engagement (i.e. asking for carbon neutral products) or annual meet the buyers sessions (Interviewee 2; Interviewee 1). Interviewees mentioned many companies struggle with tackling scope 3. It takes into account the whole supply chain and is complicated. Therefore, at this present stage, companies' focus is on mapping out supply chains (Interviewee 1). Besides supplier engagement, representatives consider engagement with clients equally important. While clients should set standards to stimulate companies to invest in sustainable alternatives, dredging companies can increase environmental awareness by engaging with clients and discussing standards for infrastructure projects (Interviewee 1; Interviewee 2). This notion implies that companies have a certain agency in projects that they can use to stimulate sustainable operation. Moreover, stakeholders addressed several initiatives to increase both internal as well as external awareness. Creating awareness under crew can be done with help of technological changes such as installing dashboards (Interviewee 1; Interviewee 3). They show in real time what the fuel consumption of the vessel is. With this, they try to find measures that they can apply to reduce fuel consumption (Interviewee 1). To further internal awareness, some companies started an internal report which looks at the global fleet and all projects worldwide (Interviewee 2). With this internal report they are aiming to spot improvements in relation to project-based sustainability. As a next course of action they are considering to take this external. For instance, by comparing their footprint to the rest of the Dutch economy based on public data. They deem this can increase the awareness of the public.

Conclusion

The implementation of alternative fuels is important in tackling large parts of the carbon footprint of the dredging sector. Stakeholders struggle with this decarbonization measure as it is not in their direct sphere of influence. This highlights the weight of social aspects within technological challenges. There are several measures that can facilitate that part of the transition to alternative fuels. Increasing engagement and awareness encourages addressment of sustainability and carbon reduction opportunities within operations. In addition to alternative fuels, dredging companies are researching other carbon reduction measures that do not only pertain to equipment. As accounting for indirect emissions is more complex than accounting for direct emissions, initiatives currently focus on understanding the dynamics as well as significance of these emissions. This displays that measures to reduce the environmental impact of dredging operations should encompass all ecological, technological and social components. My findings thus amplify the importance of holistic approaches within carbon emission reduction strategies.

Chapter 7: Discussion

Alternative fuel(s) most likely to be implemented throughout the Dutch dredging sector

Stakeholders deem biofuels, methanol, hydrogen and batteries / electrification (mainly for hybrid solutions and/or smaller near-coast vessels) as the most favorable alternative solutions. It is likely that on the short-to-medium term the sector will continue increasing the use of advanced biofuels and implement hybrid solutions where possible. In conjunction, initiatives will likely focus on researching and/or implementing alternatives such as methanol on the short-to-medium term. It is thereby important that biofuels are advanced to avoid issues such as increased deforestation as well as to ensure green production routes for methanol to ensure a lower carbon footprint. E-fuels and/or hydrogen might become viable for the sector on the medium-to-long term, if the price of green hydrogen decreases, due to the expected increase of alternative electrical energy sources. However, this partially relies on spatially-based political decisions as my findings showed that EU ambitions are developing more rapidly. For instance, hydrogen would instantly become relevant if Rijkswaterstaat enables long term projects for the Dutch coastline together with CO_2 taxes. This amplifies the spatial variability and corresponding uncertainty the sector has to deal with.

Bottlenecks

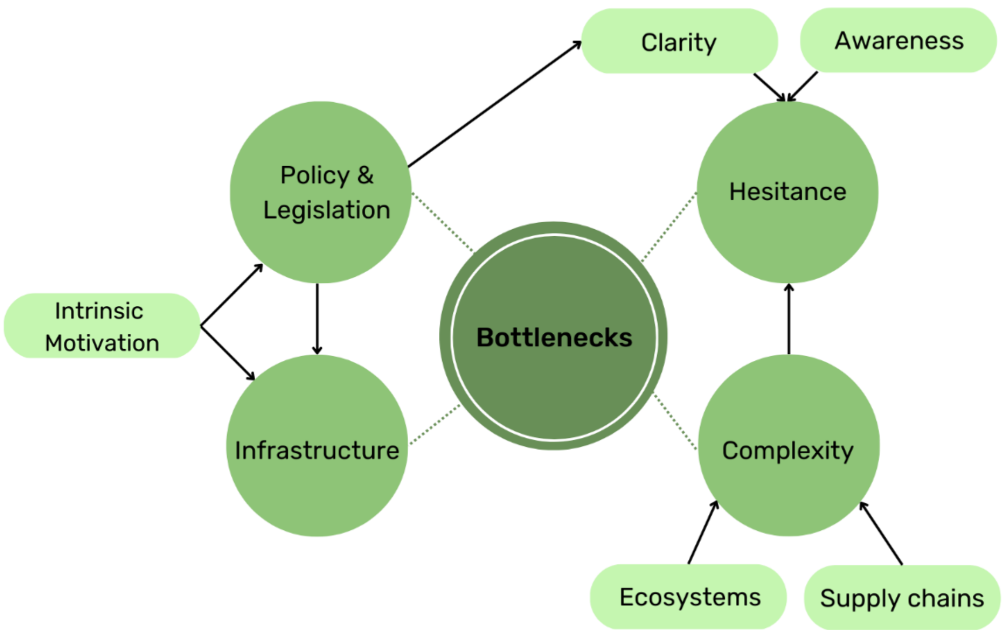


Figure 7: Roadblocks slowing down Decarbonization in the Dutch Dredging Sector

Representatives from the Dutch dredging sector deem the transition to alternative fuels technologically feasible. The biggest challenges the sector is facing are the worldwide availability of fuels and infrastructure, the legislation and policy needed to facilitate the latter, the ambiguity of the market and emissions that are not in direct spheres of influence. These are, among other things, being facilitated by a lack of intrinsic motivation by governments to prioritize the environment over cost benefits (mainly internationally), complexity of the emission scopes and a lack of long-term clarity on alternative fuels. While the sector is motivated to transition to sustainable alternatives, these factors foster a hesitance to invest in them on a large scale. This highlights the weight of social roadblocks in the transition to cleaner alternatives.

Scenarios

Based on my findings, two roughly-sketched scenarios[11], of how policy developments of Fit For 55 regulations could impact the Dutch dredging sector, seem likely. It could be worthwhile to think about the consequences of these.

Scenario 1

The dredging sector will not be included in revisions of regulations set by Fit For 55, but IMO will come with stricter standards and thus the clients will also be stricter. This would create an even playing field internationally, and is likely to be the most desired outcome by the sector. However, IMO developments are slower than current EU development due to globally oriented stakeholders. This creates the risk of the Dutch dredging sector falling behind on the energy transition.

Scenario 2

The dredging sector will be included in revisions of Fit For 55 regulations. This will grant dredging companies the choice to make a difference between their fleet operating inside and outside of the EU. The amount of projects within the EU is likely a leading factor. It is probable that companies that have little equipment designed to just operate within the EU, will not make a difference between their fleet operating inside and outside of the EU. Their equipment namely needs to be able to be deployed worldwide. This could mean that, unless biofuels are implemented, taking into account there is not an unlimited supply of advanced biofuel, companies continuously start paying more for conventional products. This would

[11] A wide variability of scenarios is possible, these two scenarios present two opposite contexts to demonstrate the range of possibility.

likely drive them to invest into sustainable alternatives. Or that the client requires specific types of cleaner vessels within projects and companies have no choice but to invest in the sustainable alternative.

Recommendations

Based on my findings, I identified several areas of improvement to facilitate the energy transition throughout the sector. Recommendations are given for policy makers, governments, clients and dredging companies. I chose this order as the extrinsic role of the government and/or the client is significant in stimulating cleaner operation within the dredging sector.

Policy Makers / Governments

- Policy makers should include the dredging sector in climate policy that implements CO2 prizing in a well thought out manner.
- Governments should give long-term clarity on alternative fuels and invest in infrastructure to make the investment in cleaner technology more logical for the dredging sector.

Interviewees noted that while climate targets are being set by governments, there is not enough substantive action to realize them. For instance, the cheapest bid is often still decisive within tenders. Thus, it is important for governments, not to just set climate targets, but to ensure concrete steps are being taken to reach the desired targets. A first recommendation to facilitate the latter, would be an inclusion of the dredging sector in climate policy. It is thereby important to note that an MRV with a ton-kilometer approach such as in place for transport shipping is not viable for the dredging sector. Strong government policies are, however, of critical importance to ensure finance flows to decarbonization measures on the scale required to limit carbon emissions throughout the sector. Dredging companies consider CO_2 prizing to be a big driver. Several representatives thus deem the inclusion of the sector in policy that implements CO_2 prizing crucial as price is leading in investment decisions, both on governmental as well as on company level. Governments should, in conjunction, give long-term clarity on alternative fuels, then can investments in cleaner vessels be viable for ship owners. Additionally, the lack of infrastructure is fostering a hesitant approach towards investment in cleaner technology. On that account, I also recommend that governments invest in infrastructure to make the investment in cleaner technology more logical for the dredging sector.

Recommendations for Clients

- Clients should stimulate companies to address decarbonization by the means of comprehensive approaches.

The role of the client is crucial for dredging companies. The client can play a facilitating role, specifically on a project basis. Dredging operations involve many components that impact the environment, as they often operate in complex ecosystems. As such, we need more comprehensive approaches to consider a multitude of components of the environment, a good example being the Building with Nature approach. Moreover, dredging operations vary widely. Not only in terms of what ecosystem dredging operations occur in, but also what type of equipment is needed per project. Representatives from dredging companies deemed clarity within tenders as vital. Clients should hereby provide a facilitating role. For instance, by rewarding renewable fuels in tenders such that ship owners can invest in cleaner vessels.

Recommendations for the Dredging Sector

- The Dutch dredging sector should ensure holistic approaches within mitigation hierarchies to account for the entire environmental impact of dredging operations.
- The Dutch dredging sector should implement small-scale change, where possible, and prioritize active engagement with suppliers, clients and governments.
- The Dutch dredging sector should increase internal as well as external transparency to boost cooperation and create more nuanced discussions in relation to decarbonization.

A first recommendation is to continue exploring holistic approaches within mitigation hierarchies to account for the entire environmental impact of dredging operations. Dredging operations encompass many aspects including ecological, technological and social components. This amplifies the importance of holistic approaches, inducing the need to think of innovative ways to address CO_2 emissions during the transition. In conjunction, I recommend that the sector implements small-scale change, where possible, and prioritizes active engagement. Several representatives deemed scalability as crucial. As a player within the industry, dredging companies can stimulate small-scale change by engaging with governments, clients and suppliers, even in countries where conventional operations are leading. The interviews namely showed that every company has a certain amount of agency they can exert. Thus, to increase environmental awareness and impact, active engagement is needed for implementation of cleaner alternatives. While the sector does largely depend on international development to ensure competitiveness, policies such as Fit For 55 would create an even playing field in the EU. This creates opportunity to test out new technologies. A final recommendation is to increase internal and external transparency. Representatives from the sector deemed that a lack of awareness is, among other things, slowing down the energy transition in the sector. By increasing communication and the exchange of knowledge the sector can further a progressive mindset, increase cooperation and help drive intrinsic motivation to invest in cleaner alternatives. In addition, external transparency could facilitate more nuanced discussions in relation to decarbonization.

Limitations

Representation

Fuel choices will vary per type of dredging vessel. Thus, further research should explore which alternative options are best suited based on the vessel's operational profile. Moreover, I held interviews with stakeholders within the sector and thus opinions will partially be biased, as an inside view on the decarbonization issue was given.

Sustainability

Creating a sustainable business model is not exclusively about decreasing carbon emissions. Sustainability within the sector should also address other emissions, as well as ensure that materials of dredging equipment are sustainable and operations create as little damage to the environment as possible. As this thesis focused on carbon emissions, it is thus important to keep in mind these are also areas that require attention.

Time

Some of the sources used for the meta-analysis date back a couple of years. Given the rapid changes happening in terms of sustainable technology, certain information could therefore be outdated and not give an accurate representation of the current situation. Moreover, this thesis was conducted over a time period of 8 months, which is a short time period to tackle an issue as encompassing as decarbonization. More time might have led to new and/or additional insights.

Chapter 8: Conclusion

This thesis aimed to explore how the Dutch dredging sector determines carbon reduction measures against climate policy by conducting literature reviews and interviews with stakeholders. The results show that the sector embarked on several initiatives to research cleaner alternatives, with advanced biofuel, methanol, hydrogen and batteries/electrification (mainly for hybrid solutions and/or smaller near-coast vessels) deemed as favorable options. While the sector is notably motivated to decarbonize, it is still hesitant to invest in cleaner alternatives on a large scale. Interviewees deem the transition to alternative fuels technologically feasible, yet the worldwide availability of fuels and infrastructure, the legislation and policy needed to facilitate the latter and the ambiguity of the market are challenging. A lack of intrinsic motivation by governments to prioritize the environment over cost benefits (especially internationally), a lack of long-term clarity, and complexity of the emission scopes facilitate the latter. My findings conclude that the energy transition in the sector involves a mutual effort of influence and impact. Therefore, both extrinsic and intrinsic drivers are needed to facilitate the effective implementation of decarbonization in the Dutch dredging sector. Extrinsic drivers are most important as investment in sustainable alternatives by dredging companies largely depends on the influence of the client which is mediated by government mechanisms. I give the following recommendations:

- **Policy makers** should include the dredging sector in climate policy that implements CO_2 prizing in a well thought-out manner.
- **Governments** should give long-term clarity on alternative fuels and invest in infrastructure to make the investment in cleaner technology more logical for the dredging sector.
- **Clients** should stimulate companies to address decarbonization by the means of comprehensive approaches.

Intrinsic drivers could facilitate a less hesitant approach towards cleaner investment:

- The Dutch dredging sector should ensure holistic approaches within mitigation hierarchies to account for the entire environmental impact of dredging operations.
- The Dutch dredging sector should implement small-scale change, where possible, and prioritize active engagement with suppliers, clients and governments.
- The Dutch dredging sector should increase internal as well as external transparency to boost cooperation and create more nuanced discussions in relation to decarbonization.

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Appendix I: Sources Meta-Analysis

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Appendix II: Fit For 55

Green Deal & Fit For 55

The EU commission adopted the EU Green Deal in 2019 to reach the climate goals set out under the Paris Agreement, a legally international binding agreement on climate change (Peeters, 2021). The Green Deal is a set of policy goals that aim to achieve climate neutrality by 2050 (European Green Deal, 2022). Climate neutrality refers to a target of net zero greenhouse gases (Hainsch et al., 2020). The Fit For 55 Plan was introduced to realize the goals set out in the Green Deal (European Green Deal, 2022). The target is a baseline of a net 55% reduction of emissions as compared to 1990 by 2030. Several of the measures within this package affect the maritime industry, as shown in Figure 8.

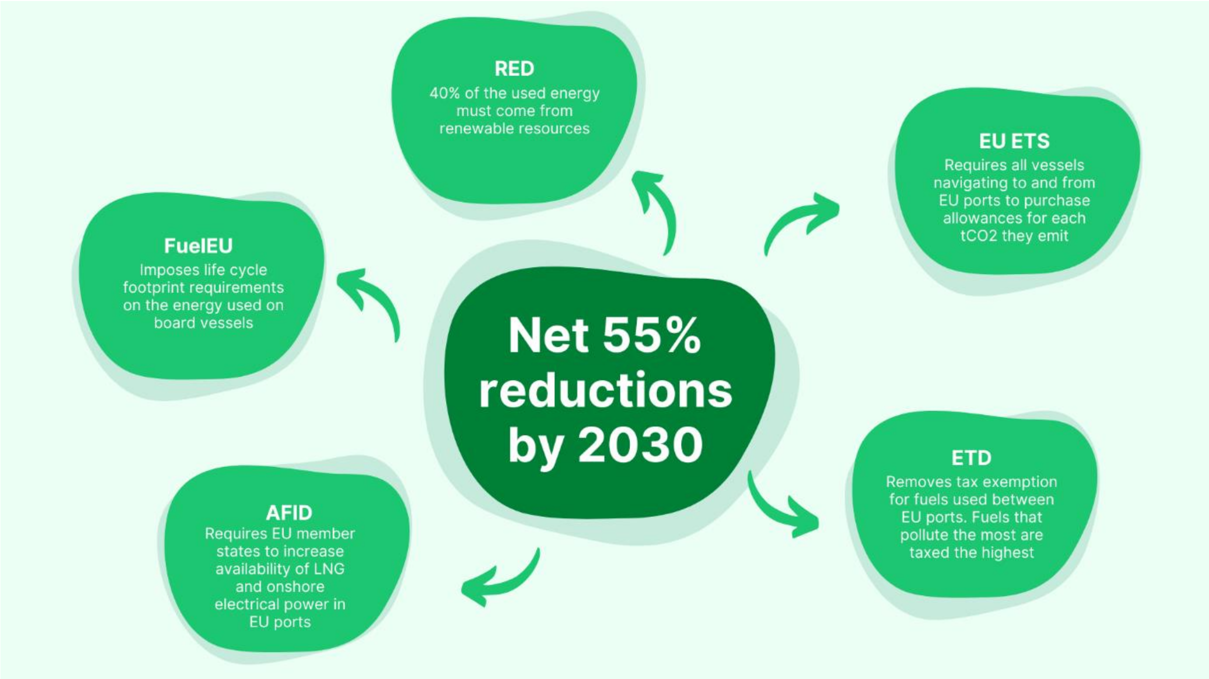

Figure 8: Fit For 55 Regulations affecting the Maritime Industry (RED: Renewable Energy Directive; EU ETS: European Union Emission Trading System; ETD: Energy Tax Directive; AFID: Alternative Fuels Infrastructure Directive; FuelEU: Maritime Fuel Directive (European Green Deal, 2022))

EU ETS

One of the measures of Fit For 55 is the EU ETS (European Union Emission Trading System) which is a ‘cap and trade’ system (Cariou et al., 2021). A cap refers to the overall emissions allowed to be emitted which is re-determined yearly. These are distributed to the companies involved through an auction (Wu et al., 2022). Emissions can be traded and are given a price by supply versus demand. If a company emits less than its ‘cap’, it can sell its surplus to other companies. However if it were to exceed its ‘cap’, it would have to buy allowances to comply with the regulations. This cap and trade system is known as the Emission Trading System and is a form of market-based measures (Wu et al., 2022). The ETS defined by the EU covers CO2, nitrous oxide, perfluorocarbons emissions from power, oil refineries, combustion plants, airline sectors and now also the maritime transport sector.

ETD

Another measure set by Fit For 55 is the Energy Taxation Directive (ETD), which with the adoption of Fit For 55 now also extends to maritime transport (Ovaere & Proost, 2022). It sets minimum tax rates for non-sustainable fuels, i.e. fuels that emit a lot of pollutants such as carbon. This means that vessels traveling to and from EU ports have to pay tax over the fuels used for their voyages (Fit for 55: how the EU plans to revise energy taxation, 2022). Over a ten year transition period the tax rates will increase annually.

RED

Moreover, imposed onto the maritime industry by the adoption of Fit For 55, is the Renewable Energy Directive. The revision of RED (RED II) sets the goals that items such as the ETD, ETS and FuelEU are aspiring to realize (Furustam, 2022; Searle, 2021). The revision in 2021 of this directive required that 40% of the total energy comes from renewable energy by 2030 ("Fit for 55": Council agrees on higher targets for renewables and energy efficiency, 2022). In respect of the targets for transport, the EU Member States have the possibility to opt for either a binding target of 13% GHG intensity reduction by 2030, of which a separate target could be set for maritime transport provided that the overall target is reached, or a binding target of a minimum of 29% renewable energy within the final consumption of energy.

FuelEU

Another measure set by Fit For 55 is FuelEU. It encourages the use of sustainable fuels within the maritime industry by setting a limit to the carbon intensity of the energy used on board of vessels (Marketa, 2022). This implicates that maritime fuels used by vessels, including those by non-EU flagged ships trading with EU ports, must comply with EU standards in terms of their carbon content. It applies to all energy used between EU ports and to half of the energy between EU ports and third countries (Searle, 2021). The carbon emission factors are calculated following the methodology in RED II (Searle, 2021). All food- and feed-based biofuels are not qualified to contribute towards the CO2 reduction target (Searle, 2021). A reward factor (0.99-0.95) can be granted if wind is used as an alternative source of energy by multiplying it with the fuel emissions intensity of a vessel (Searle, 2021). Surpluses of fuel emissions allowed can be saved up for the following years (Searle, 2021). If there is a deficit of fuel emissions, it cannot surpass 2% and must be made up the next year +10% extra; additionally FuelEU does not allow deficits two years in a row. Moreover, as of 2030, vessels have to use on-shore power for energy needs when anchored at a port (Searle, 2021). The enforcement mechanisms to assess whether a vessel applies with FuelEU is likely to be imposed through commanding the minimum proportion of a vessel's fuel that should consist of biofuels (Marketa, 2022). It is the International Maritime Organization 's (IMO), which was founded by the UN and oversees the safety and security of shipping and works on the prevention of marine and atmospheric pollution by vessels, role to determine the carbon factor of fuels used by vessels (Rothwell & Stephens, 2016). As they have not yet come with specific guidelines it could be that the EU introduces its own life cycle guidelines for fuels purchased beyond its jurisdiction (Marketa, 2022).

AFID

Moreover, an Alternative Fuels Infrastructure Directive (AFID) is implemented to reduce emissions within the maritime industry. This directive includes proposals to set up a Trans-European Transport Network. It would be able to grant vessels access to LNG across ports of EU member states and to allow vessels access to electricity, from renewable energy, in ports of EU member states. Additionally, it obliges EU member states to establish national policies and set targets to deploy the infrastructure for the alternative fuels for vessels (European Commission, 2021).

Appendix III: Alternative Fuels: Details

Combustion Engines

The most conventional engine is an internal combustion engine. It produces mechanical work by the expansion of hot gases due to the combustion of fuel, such as Marine Diesel Oil (MDO), and an oxidizer, usually oxygen or air (Gharehpetian & Mousavi, 2017). There are several types namely compression ignition engines, dual-fuel engines and spark ignited engines (Mestemaker et al., 2019). Compression ignition engines are suitable for fuels which quickly achieve complete combustion due to their relatively high number of cetane whereas spark ignited engines are suitable for fuels with lower cetane numbers (Mestemaker et al., 2019). Dual-fuel engines are engines which can operate on two different types of fuels (Mestemaker et al., 2019). They provide dredging companies greater flexibility, as they accommodate for variations in the vessel's operating conditions. For instance, in areas where certain alternative fuels are not yet available (Mestemaker et al., 2020).

Fuel Cells (FC)

Fuel cells are environmentally more advantageous because the only by-product is water. Within a fuel cell energy is produced by converting chemical energy of hydrogen and oxygen into electricity (Benet et al., 2022). Since they are energy converters they determine the maximum power (Haxhiu et al., 2021). This means that the energy content is limited by the fuel used within the fuel cell. There are two main types of fuel cells used for maritime application namely the proton exchange membrane fuel cell (PEMFC) and the solid oxide fuel cell (SOFC) (Benet et al., 2022). PEMFCs generate electrical energy and operate on low temperatures (Silaa et al., 2022; Mestemaker et al., 2019). It converts the chemical energy of pure hydrogen into electrical energy with the use of a catalyst. SOFCs generate electrical energy in the same way as PEMFCs do, but they can operate on light hydrocarbon fuels to produce electricity (Mestemaker et al., 2019).

Batteries

Batteries are electric energy sources with an unregulated dc voltage output (Haxhiu et al., 2021). They are often used in combination with a combustion engine as a hybrid system. In such systems batteries mainly fulfill the role of dynamic support and spinning reserve (Haxhiu et al., 2021).

Appendix IV: Alternative Fuel Options Work Vessels

Table 2: Alternative Fuel Options (Mestemaker et al., 2020) (CI : Compression Ignition Engine ; DF : Dual Fuel Engine ; SI : Spark Ignited Engine ; FC: Fuel Cell)

Fuel	TRL	Prime mover	TCO	Emissions
GTL (syn. diesel)	8	CI/FC	−−	++
LNG/CNG	9	DF/SI/FC	++	+
LPG	9	DF/SI/FC	+	+
MeOH	8	DF/SI/FC	++	−
DME	6	CI/FC	++	−
HVO (biodiesel)	8	CI/FC	++	−−
Biogas (NG)	8	DF/SI/FC	++	−−
BioMeOH	7	DF/SI/FC	++	−−
BioDME	6	CI/FC	+	−−
BioEtOH	9	SI/FC	++	−−
Ren. MeOH	7	DF/SI/FC	+	−−
LH_2	9	DF/SI/FC	−	0
NH_3	5	FC	+	0
$NaBH_4$	3	DF/SI/FC	−−	0
Fe	3	n/a	−−	0
Li-ion	9	n/a	−−	0

Appendix V: MKI & CO_2 Performance Ladder in the Netherlands

On a national level clients often use two guidelines in projects of the Dutch dredging sector. Rijkswaterstaat, which is the executive agency of the Ministry of Infrastructure and Water Management in the Netherlands, uses the MKI (Milieu Kosten Indicator) as an incentive to measure environmental performance of Dutch dredging companies (MvI & Waterstaat, 2020). Additionally clients often use the CO_2-prestatieladder (Scholl & Gotjé, 2014). When companies score well, on either the MKI or CO_2-prestatieladder, they are more likely to get a contract for a project and/or can even get a fictive discount, which means the offer of the company will be viewed as if it would cost 5% less than it actually does, thus providing them an economic advantage (Interviewee 7).