DECARBONISING THE EU FISHING FLEET

LESSONS FROM TODAY'S SHIPPING INDUSTRY

Our Fish

ClientEarth

INTRODUCTION

Fishing is an energy-intensive activity that produces vast amounts of greenhouse gas (GHG) emissions. In a recent scientific study published in *Marine Policy*, it was found that fishing vessels released approximately 207 million tonnes of CO2 into the atmosphere in 2016 alone (Greer et al., 2019).[1] And yet, marine fisheries are excluded from global assessments of GHG emissions.[2] To tackle this, decarbonising the fisheries sector must become a priority, as is currently the case for the shipping industry. The transition to cleaner energy required by the European Green Deal and the legislation being developed to make that transition possible (including the revision of the Energy Taxation Directive)[3] offer an opportunity to decarbonise the fisheries sector in the European Union (EU).

At the global level, in 2018, the International Maritime Organisation (IMO) adopted a set of targets to reduce GHG emissions from international shipping by 50% compared to 2008 levels. As part of this, the IMO sets out to reduce the carbon intensity of international shipping by 40% in 2030 and 70% in 2050.[4] Although these objectives only apply to the shipping industry, nothing is stopping decision makers and the fishing sector from adopting them for the global fishing fleet.

While the journey to decarbonisation is in its primary stages, progress already made within the maritime sector has provided momentum and offers an incremental pathway for the decarbonisation of the fishing fleet. In order to align itself with the objectives of the EU Green Deal and other relevant international agreements, the global fishing industry will need to switch to new sources of energy. The purpose of this briefing paper is to present a feasibility analysis of batteries, synthetic fuels and wind propulsion for fishing vessels by examining examples from the shipping industry, while also considering the advantages and challenges presented by each source of energy.

BACKGROUND

The world's fishing fleet is primarily powered by diesel engines that operate on distillate fuels. Burning these oils releases vast amounts of carbon emissions and air pollutants. Gases released, including carbon (CO2), methane (CH4), nitrous oxide and chlorofluorocarbons, linger in the atmosphere for long periods of time and contribute to global warming.

In a bid to reduce the EU's reliance on fossil fuels and to engage into an energy transition, the European Commission launched the Green Deal in 2020. The Green Deal calls for a 90% reduction in GHG emissions in transport and aims to safeguard ecosystems and biodiversity.[5] As part of this initiative, in December 2020 the European Commission launched the 'Sustainable and Smart Mobility Strategy. This strategy requires all modes of transport to be sustainable, including through the transition to low-carbon fuels and zero-emission vehicles.

Despite this very ambitious policy background, the fishing sector is still heavily dependent on fossil fuel as well as fossil fuel subsidies[6] and there is no decarbonisation strategy or road map to tackle the sector's heavy fossil fuel dependency. Even worse, the sector still relies on an indirect subsidy to operate: a fuel-tax exemption, made mandatory at the EU level, through the Energy Taxation Directive.

A report released by the European Court of Auditors on 31 January 2022[7] showed that energy taxation can support efforts to combat climate change. It underlined that current tax levels do not reflect the extent to which different energy sources pollute. It also highlighted that even though renewable-energy subsidies almost quadrupled over the 2008-2019 period, fossil fuel subsidies *"have remained relatively constant over the last decade despite commitments from the European Commission and some Member States to phase them out"*.

In this context, the revision of the Energy Taxation Directive foreseen in the European Green Deal offers the opportunity to align taxation of fishing fuel with the EU's climate objectives and the Polluter Pays Principle. Indeed, the EU agreed in its Green Deal and its Climate Law to transition to a sustainable Europe that achieves climate neutrality by 2050.[8] This will not happen without the elimination of all fossil-fuel subsidies (exemptions, tax advantages and rebates). Most recently, at the global level, Heads of State committed through the Glasgow Climate Pact to eliminate "inefficient" fossil fuel subsidies, recognising that if this does not happen, all other climate actions will be negated.

The need to introduce taxation in the fisheries sector goes hand in hand with the need to have a plan to decarbonise the fishing sector. This paper is meant to provoke a reflection on the use of alternative technology/fuels to propel fishing vessels by analysing the innovation that is taking place in the shipping sector and see if this can be replicated in the fishing sector.

PART 1: AVAILABLE ALTERNATIVE TECHNOLOGIES: INSPIRATIONS FROM THE SHIPPING SECTOR

1. BATTERIES

In the shipping sector, batteries can be used either as the only power propulsion system or as a hybrid propulsion system. For the moment they are mostly used to optimise the power use on vessels – both in terms of propulsion and auxiliary power alternative power systems that complement the traditional use of fossil fuels. Several projects have been developed to run ferries exclusively with batteries.[9] However, batteries are still limited in the amount of power they can generate. It is therefore still challenging to have vessels running on battery-only propulsion systems.

Considerations for the fisheries sector:

Fishing vessels that operate at low speeds for extended periods are the best candidates for alternative power systems. Electric and hybrid vessels with energy stored in batteries can deliver significant reductions in fuel consumption, maintenance and emissions.[10] Pure battery operation is most feasible for relatively short distances with opportunities for frequent charging.

Hybrid propulsion systems reduce emissions whilst at the same time optimising engine operation. They do so by combining battery power with combustion engines. Such hybrid propulsion systems are more appropriate for vessels that have running hours with differing power demands as well as flexible operation profiles. This solution, which is less ideal than battery-only propulsion from an emissions perspective, is more suitable for fishing vessels that go further out at sea and use more energy-intensive gears.

The use of batteries as the sole propulsion system is more suitable for fishing vessels that operate close to shore and navigate for shorter distances, as long as they operate at low speed. This is an alternative to fossil fuels that would be more suitable for small-scale, low-impact fishing vessels.

To summarise, propulsion systems running on batteries alone would be more suitable for small-scale fishing vessels that do not use too much power to fish; hybrid propulsion systems running partially on batteries seem to be more suitable for larger fishing vessels that need more power.

ADVANTAGES

- **Emission free**

CHALLENGES

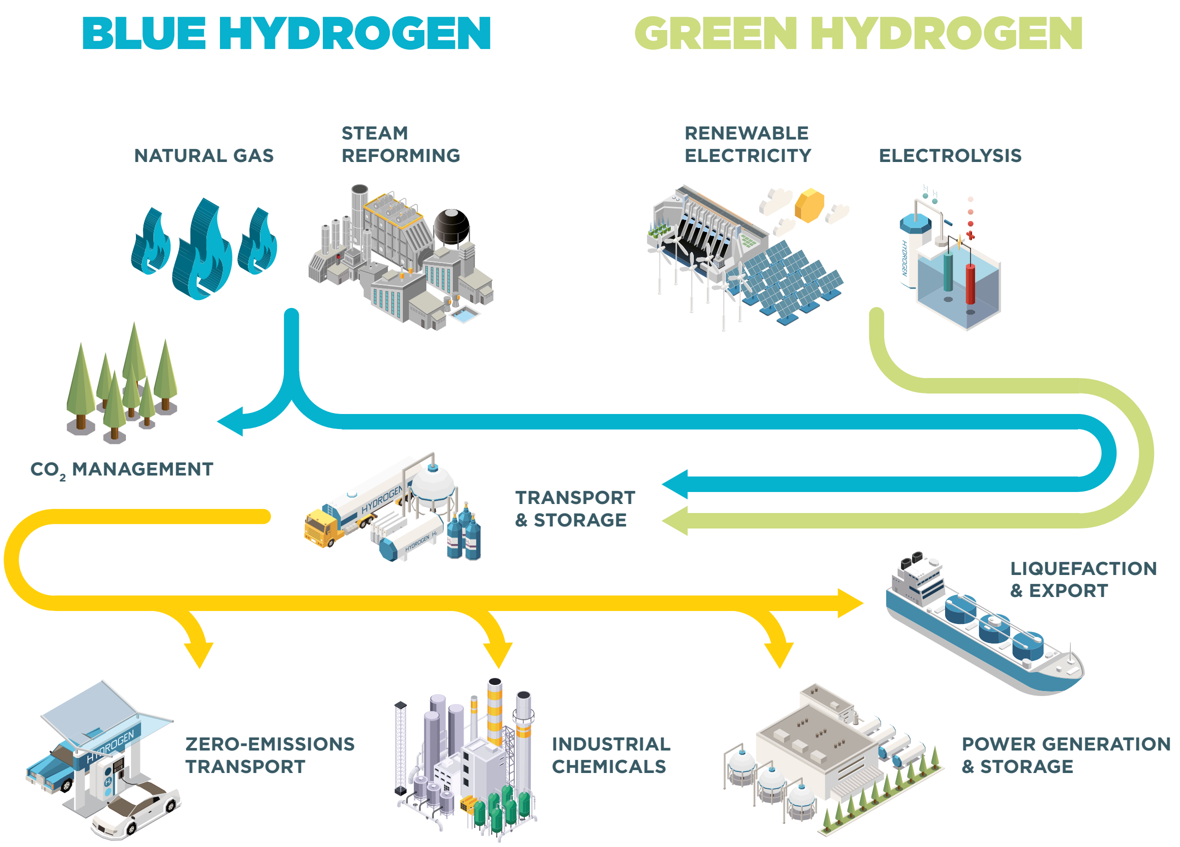
- **Cost and amount of energy for production**
- **Life cycle of batteries**
- **Weight**
- **Available only for short distances because of power generated**

2. GREEN HYDROGEN AND FUEL CELLS

Hydrogen is both the smallest and lightest of all gas molecules, resulting in the best energy to-weight storage ratio of all fuels.[11] For example, one kilogramme of hydrogen can produce the equivalent amount of energy as 3.2kg of petrol. Hydrogen offers a viable alternative to fossil fuels as an alternative energy that could contribute to the mitigation of climate change.[12] However, there are doubts surrounding its production, scalability, cost, storage, and flammability during its use.

The production of hydrogen also raises some environmental concerns.

There are two main hydrogen production routes: electrolysis and steam methane reforming.



Electrolysis is a process that splits hydrogen from water using an electric current, which does not release GHG emissions. Hydrogen produced through electrolysis is referred to as 'green hydrogen' only when the production is powered by renewable energy.

Production of hydrogen obtained by reforming steam methane is referred to as 'grey hydrogen'. This way of producing hydrogen requires natural gas to react with steam at high temperatures to create hydrogen but also carbon dioxide. The carbon dioxide needs then to be captured and stored to consider this process as carbon neutral. But this way of producing hydrogen is controversial as leakages of carbon emissions are inevitable during the process. In addition, capturing and storing carbon are not carbon-neutral processes. As the International Energy Agency (IEA) states: *"over 95 % of current hydrogen production is fossil-fuel based"*.[13]

Additionally, hydrogen can be costly and difficult to transport and store. To produce hydrogen at a scalable level, the cost of electrolysed hydrogen needs to decrease. The current rates of green hydrogen range from $2.5-$5.5/kg, which is likely to deter those wanting to invest in clean fuel. The cost of grey hydrogen is cheaper, at around $1.50/kg.[14]

Storing sufficiently large volumes of hydrogen has proved challenging. Storage of liquid hydrogen requires cryogenic storage at very low temperatures (-253°C). On board vessels, this means compromising space. For these reasons, it is not suited for large and long-distance vessels as they would need a substantial amount of hydrogen, meaning impractically large storage space onboard. Hydrogen would probably be better suited for small- to medium-sized vessels which travel shorter distances and would be able to refuel in port.

However, there is another very substantial concern about using hydrogen to decarbonise the shipping sector and therefore also the fishing sector: the wide flammability range of hydrogen. Hydrogen is very light and can react very quickly with other elements which makes it highly flammable. In addition, hydrogen fires disperse upwards, and this is incompatible with combustion in an enclosed space like the hull of vessel, especially as hydrogen combustion is colourless and odourless.

Considerations for the fisheries sector:

In the fisheries sector, Enova, a Norwegian Government Enterprise, decided to fund the world's first hydrogen-powered fishing vessel, in the hope of kickstarting the use of hydrogen to innovate in zero-emission technology. The vessel in question consists of two 185 kW fuel cells, a 2000 kWh battery and conventional diesel engines.[15] The success of dual-fuel engines also includes the 'Viking Lady': *"the fuel cell, generates an electric output of 330KW, and has successfully run for more than 18,500 hours"*.[16]

However, these are very localised attempts to introduce hydrogen as an alternative to fossil fuels in the fisheries sector. Given the flammability of hydrogen, its dependency on fossil fuels for production and the need for considerable storage space on board, this does not seem to be a viable alternative, either for large scale fishing vessels or small-scale ones.

ADVANTAGES

- **Offers the best energy to-weight storage ratio of all fuels**
- **Emission free**

CHALLENGES

- **Energy intensive production**
- **High dependency on carbon energies for production**
- **Storage**
- **Cost**
- **Scalability**
- **Flammability**

3. AMMONIA

Considering the challenges associated with hydrogen, ammonia may seem a better option for shipping vessels and possibly fishing vessels. As mentioned earlier, storing and transporting hydrogen is a challenge due to its inherent characteristics. Ammonia on the other hand has a higher volumetric energy density and takes on a liquid form at -33°c, making it easier to handle, store and transport without having to store it in high-pressure or cryogenic tanks, thus making on-board storage economically feasible. However, ammonia presents issues of scalability and costs.

Using ammonia comes with safety challenges. It is a highly toxic substance and can pose a risk to people and aquatic life. Exposure to high levels of ammonia may cause burns, respiratory issues and lung damage, which can be fatal.[17] When present in water, aquatic organisms face difficulty removing the toxicant, which often leads to death.[18] For such reasons, adopting ammonia as an alternative to fossil fuels is highly controversial because of its impacts on the environment and on human health. To reduce the likelihood of leaks, safety considerations linked to vessels infrastructure are vital. This can be achieved through accommodating ventilation, gas-handling and bunkering systems, to prevent and detect leaks. A final crucial consideration is that combustion of ammonia in engines releases nitrous oxide (N2O), a potent greenhouse gas that is 300 times more harmful than CO_2[19] and if inhaled can result in a lack of oxygen in the brain.

Considerations for the fisheries sector:

The inherent characteristics of ammonia such as its energy density and storage options, may suggest that ammonia is a better alternative to hydrogen. Ammonia is also widely used in refrigeration systems on fishing vessels, making many marine actors familiar with its use and handling. However, given the toxicity of this substance for human health and the marine environment, combined with the costs of production and the release of nitrous oxide, a potent greenhouse gas, ammonia does not offer a viable alternative to the use of fossil fuels in the fishing sector.

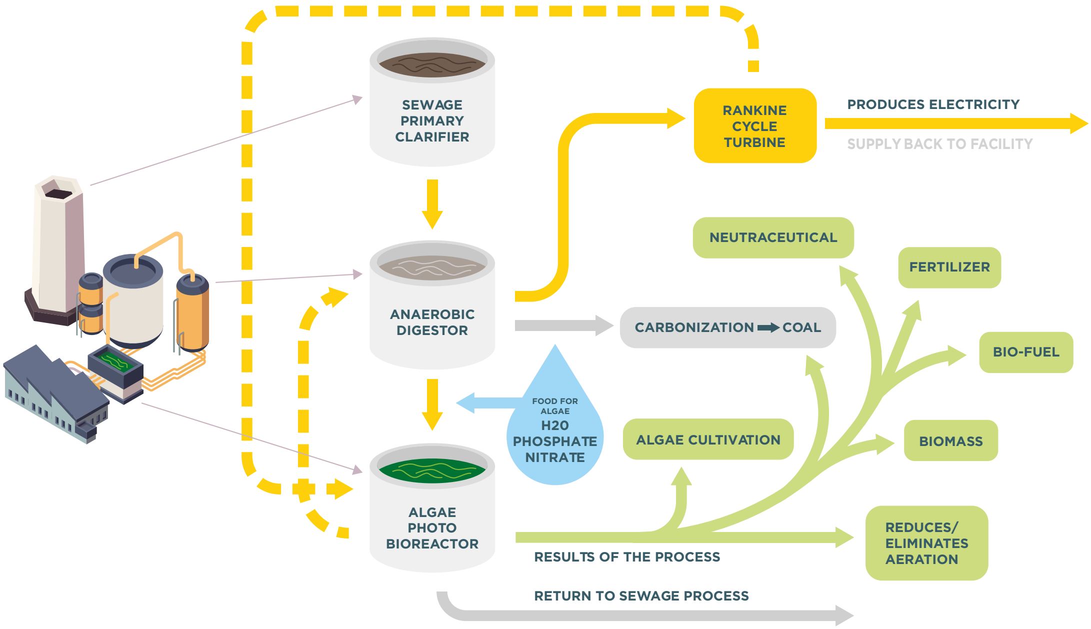
ADVANTAGES

- **Zero carbon emissions**
- **Easier to store in comparison to hydrogen**

CHALLENGES

- **Emission of nitrous oxide**
- **Toxicity for environment and human health**
- **Scalability**
- **Cost of production**
- **Risk of leaks**

4. BIOFUELS



Biofuel is an umbrella term encompassing a wide variety of liquids or gases derived from biomass or bio-waste. Biofuels are typically categorised in three categories:

- 1st generation biofuels or conventional biofuels are unprocessed, organic materials for fuel production. These are mainly sourced from consumable food items such as sugar, starch and oils, which are converted into biodiesel or bioethanol.
- 2nd generation biofuels, also known as advanced biofuels, are lignocellulosic (e.g. solid waste, agriculture residue).
- 3rd generation biofuels come from microorganisms such as algae.

Biofuels are potentially low-carbon fuels that could be used in the maritime sector. Depending on production rates and costs, by 2030 biofuels may play a larger role in the maritime sector.[20]

Due to the wide availability of biofuel feedstocks, biofuels have the potential to accommodate the needs of the maritime sector quite quickly if production rates and capacity are adapted. In addition, biofuels can be used in existing engines and fuel infrastructure with minor modifications.[21] This makes them cheaper, and more effective alternatives to fossil fuels but also to the alternatives listed above.

Disadvantages of conventional biofuels such as indirect land use change, could be tackled using 3rd generation biofuels derived from microbes and microalgae. The primary benefit of their use is avoiding competition with agricultural food production.[22] Algae diesel fuels are also safe to use and are energy efficient as long as used alone. But, given that algae have a lower heating value, 3d generation biofuels are also blended with petroleum diesel which increases performance while simultaneously reducing the sulphur content of regular diesel because of its mixture.[23] So using the blending solution does not eliminate completely emissions. This could be a short-term option until further research is done to ensure the use of algae is efficient without reliance on diesel. It is also important to note that there may be limited production capabilities to meet the demand of potential users, due to low biomass production rates.

BP and Maersk Tankers have successfully completed trials using biofuel-blended marine fuel in two tankers, without the need to modify engines or infrastructure.[24] In these two trials, each tanker was supplied with Marine B30 biofuel, consisting of 30% fatty acid methyl esters (FAME) blended with very low sulphur fuel oil (VLSFO). Maersk also successfully completed another trial in partnership with The Ocean Cleanup, blending 15% of hydrotreated vegetable oil (HVO) and 85% low sulphur MGO (Marine Gas Oil).[25] Other examples which piloted its use include ExxonMobil[26] and the US Navy.[27]

Considerations for the fisheries sector:

3rd generation biofuels, if proven economical and energy efficient without the need to blend them with diesel, might be an interesting alternative for the fisheries sector to fossil fuels. However, for the moment all trials done in the maritime sector blend biofuels with fossil fuels which means that emissions of greenhouse gases are still taking place. For 3rd generation biofuels to be a valid alternative, more research needs to be done to assess whether they can be used alone. The fact that engines can easily be converted is positive. This alternative, if proven viable, would be suitable both for large- and small-scale fishing vessels.

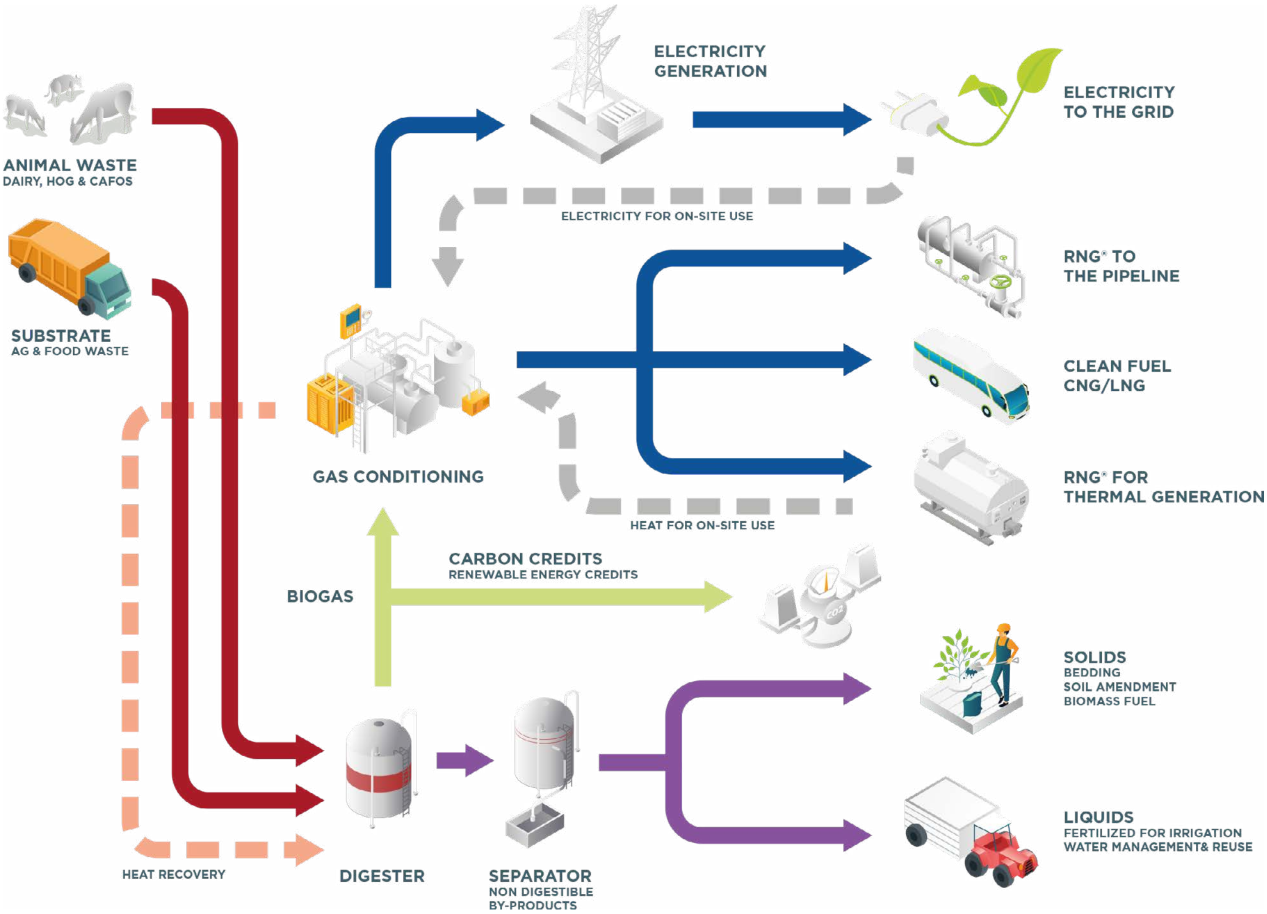
ADVANTAGES

- **Compatible with current vessel infrastructure and engine**
- **A widely traded commodity**
- **Easier to produce that fossil fuels**

CHALLENGES

- **Production lead to increase in competition with other sectors operating at sea;**
- **Cost of production is relatively high and is relatively energy intensive**
- **Energy efficiency not proven;**
- **No zero emissions if it is used together with diesel or other fossil fuels;**
- **Increased land or sea use;**
- **May not be scalable;**

5. BIOGAS



The use of biogas is also a possibility. It is an abundant source of renewable energy and has the potential to reduce the level of carbon, methane, and sulphur emissions released into the atmosphere.[28] Biogas is categorised as a 2nd generation biofuel and are naturally produced via the anaerobic decomposition of organic waste. It consists mainly of methane, the main combustible component, and carbon dioxide. The creation of biogas is a carbon neutral process as it does not release additional carbon emissions into the environment. Its use also reduces the amount of methane emitted into the atmosphere, through redirecting its use as an energy source. Studies are already underway to see whether biogas could be used on cruise ships.[29] Countries including Sweden have incentivised its use, as demonstrated through Sweden's proposal for a National Biogas Strategy. In addition, Sweden has tried its use on larger vehicles through the introduction of the world's first passenger train, powered solely by biogas.[30] Developments within the shipping industry are also happening. A 2017 review showed that half of Sweden's new built vehicles were designed to accommodate the use of gas, with the ability to run on blended biogas or biogas on its own.[31] In Norway, biogas is already used as an alternative to fossil fuels on vessels and it is considered to have huge potential in the maritime sector.[32] Denmark has also introduced biogas to run ferries.[33]

Considerations for the fisheries sector:

If biogas is further developed it could become a real alternative to fossil fuels both for large and small-scale fishing vessels.

ADVANTAGES

- **Does not produce further carbon emissions**
- **Reduces the amount of methane emissions released into the atmosphere**
- **Serves to maintain a healthy environment through redirecting the use of animal manure as a source of energy**

CHALLENGES

- **Cost of the biogas purification process**
- **Scale of production**
- **Limited infrastructure of biogas**

6. WIND ASSISTED PROPULSION

Considering the challenges associated with the alternative fuels discussed above, the use of wind power can serve as a viable solution for solving issues surrounding scalability, cost and efficiency. Of course, wind will not eliminate carbon emissions completely but wind power as an energy source is increasingly recognised as an effective way to reduce energy consumption, carbon emissions and fuel cost. Wind assisted technologies convert wind energy into propulsive force in combination with a vessel's engine. It currently represents a small fraction of the total fleet but the variety of wind-assisted technologies available today will certainly accommodate the needs of future fishing vessels, both large and small.

Available wind assisted technologies vary; here is a brief description of those that exist:

FLETTNER ROTORS

Flettner rotors are large vertical rotating cylinders mounted on the deck, which use the "magnus effect" to capture the energy of the wind and generate forward thrust.

Examples include E-Ship 1, where four large rotor scales 25 metres high and 4 metres in diameter were installed on deck were designed to cut down fuel costs by 30%.

TOWING KITES

Towing kites provide thrust to vessels via the high altitude of winds. Skysails have tested their use on a 55 metres, almost 800-tonnes testing ship. The results were impressive: using an 80-square metre towing kite, fuel savings of up to 1200 litres can be made.

SUCTION WINGS

Suctions wings create a lifting force.

WINGSAILS

Wingsails are like aeroplane wings except they are vertical and upright. They provide a lift and a better lift-to-drag ratio.

SOFTSAILS

Softsails are modernised versions of traditional sails.

Scientific research emphasises wind propulsion as an attractive technology which has the potential to play a significant role in achieving decarbonisation in the maritime sector.

In particular, the use of wind propulsion technologies can already save 5% to 20% of fuel. This in turn reduces the reliance on alternative and fossil fuels, making it cost effective. This will also prove useful in the foreseeable future where energy costs are expected to fluctuate due to demands from various other sectors.

Wind propulsion systems can easily be used by retrofitting existing vessels, thus offering an immediate reduction in GHG emissions. In the medium to long term, these technologies will offer further savings when deployed on newly built vessels.[34]

The challenges of wind propulsion systems are linked to the efficiency of those technologies as they are heavily dependent on the weather. It is therefore not a constant source of energy. Seasonal differences affect fuel efficiency and savings. For example, flettner rotors perform better in the winter while a Wingsail is more efficient in the summer.[35] However, weather routing software will help assess wind levels, storm probability and much more. Odfjell ships have used StormGeo's weather routing service[36] to assist the captains in choosing the safest and most efficient sailing route. Having these software's will ensure maximum efficiency.

Furthermore, the current costs of these technologies remain high. But with an increase in demand, this is predicted to be more affordable. In the meantime, tax incentives or government intervention may help overcome this barrier.

Considerations for the fisheries sector:

Technologies such as flettner rotors are large in scale, which will be more suitable for large-scale fishing vessels. Some innovative projects already exist in fisheries to use wind propelling systems. Although these technologies are only hybrid solutions and the sector still needs to rely on fossil fuels, they offer a possibility to immediately reduce emissions and can also be a hybrid solution for the future with other alternatives such as biogas or batteries.

ADVANTAGES

- **Fuel efficiency**
- **Reduced reliance on alternative fuels**
- **Ability to retrofit existing vehicles**
- **Use of renewable energy**

CHALLENGES

- **Reliance on weather**
- **Size**
- **Cost**
- **Hybrid propulsion system, so emissions are reduced not eliminated**

PART II: AVAILABLE FUNDING TO TRANSITION THE FISHERIES SECTOR TOWARDS ALTERNATIVE TECHNOLOGIES

Decarbonising the EU has become a priority under the EU Green Deal and all the legislation being adopted as part of it. The fishing sector should not be left behind, given the sector's significant emissions and its reliance on fossil fuels and fossil fuels subsidies for its business operating model. Several sources of EU funding are available to offer financial support for this transition.

The European Maritime, Fisheries and Aquaculture Fund[37] offers financial support to move towards more sustainable fishing. This includes support to increase the energy efficiency of fishing vessels or to innovate towards low impact fishing using gear that is less destructive and less energy intensive.

The EU has also set up a new funding instrument, the Just Transition Fund,[38] which is specifically designed to support Member States to achieve EU climate neutrality by 2050 in line with the EU Green Deal objectives.

The EU also recently launched "RePowerEU in 2022" [39] focusing on reducing dependency on fossil fuels and facilitating decarbonisation. Under this programme, EU Funds available as grants, loans and other financial instruments can be used specifically to decarbonise the EU.

The Horizon Europe research programme of the EU[40] also foresees grants to finance research on decarbonisation, including in the fishing sector.

At the national level, granting support is also possible through state aid. The EU's sector-specific state aids guidelines are being revised to increase the amounts that can be granted at national level to support economic operators as well as loosen the conditions for receiving state aid. Decarbonisation is at the heart of that thinking.

Finally, eliminating existing fuel-tax exemptions on fuel used in the fisheries sector through the revision of the Energy Taxation Directive will generate more than €1 billion of government revenue.[41] This public money could be redirected to decarbonising the fishing sector and support transition towards low impact fishing.

The financial tools exist to make decarbonisation of the fisheries sector happen.

CONCLUSION

This paper has considered batteries, synthetic fuels, biofuels and biogas, and wind-assisted technologies, to gain an understanding of their potential application in the fisheries sector. Although most options offer environmental benefits, there are challenges which need to be addressed before widespread deployment within the fishing sector can happen. In summary:

- Batteries are better for short distances;
- Hybrid systems are easy to implement in the short term;
- Hydrogen offers the best energy-to-weight storage ratio but raises concerns regarding scalability, expense, security and storage;
- Ammonia can help with storage issues, but it is so dangerous for the environment and human health that it cannot be considered as a viable alternative;
- Biofuels have great potential, but their efficiency still needs to be proven both in terms of production and energy generated;
- Biogas seem to be an interesting alternative both for large- and small-scale fishing vessels, but further large-scale use in the maritime sector is needed to rely on it on a larger scale;
- Wind-assisted technology looks promising as short-term solution to reduce GHG emissions but in the future it needs to be associated with an alternative to fossil fuels.

Overall, most sources of energy have potential that has been demonstrated through pilot studies and on-going further research. The shipping industry has taken steps to ensure a greener future, but the fishing industry falls short. There is no decarbonisation strategy to tackle the sector's dependence on fossil fuels and direct and indirect fossil-fuel subsidies. The removal of fossil fuel subsidies will not only help reach our climate goals; it will also deter overfishing and prevent excessive fuel use. In addition, the revenue from the removal of fuel subsidies can help finance new technologies and fuels, to help the fishing sector invest in and accelerate the path to decarbonisation.

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1 - Greer, K., Zeller, D., Woroniak, J., Coulter, A., Winchester, M., Palomares, M.D. and Pauly, D., 2019. Global trends in carbon dioxide (CO2) emissions from fuel combustion in marine fisheries from 1950 to 2016. Marine Policy, 107, p.103382.

2 - Parker, R.W.R., Blanchard, J.L., Gardner, C. et al. Fuel use and greenhouse gas emissions of world fisheries. Nature Clim Change 8, 333–337 (2018). https://doi.org/10.1038/s41558-018-0117-x

3 - Taxation and Customs Union. n.d. Revision of the Energy Taxation Directive. [online] Available at: <https://ec.europa.eu/taxation_customs/green-taxation-0/revision-energy-taxation-directive_en> [Accessed 2 June 2022].

4 - Imo.org. n.d. Initial IMO GHG Strategy. [online] Available at: <https://www.imo.org/en/MediaCentre/HotTopics/Pages/Reducing-greenhouse-gas-emissions-from-ships.aspx> [Accessed 11 May 2022].

5 - European Commission - European Commission. 2022. A European Green Deal. [online] Available at: <https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en> [Accessed 13 May 2022].

6 - Report: Climate Impacts & Fishing Industry Profits From EU Fuel Tax Subsidies - Stop Fossil Fuel Subsidies

7 - European Court of Auditor report, Review 01/2022: Energy taxation, carbon pricing and energy subsidies

8 - Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law'), OJ L 243, 9.7.2021, p. 1;

9 - Liang, L., 2019. Shipping takes aim at battery-powered future. [online] Seatrade Maritime. Available at: <https://www.seatrade-maritime.com/opinions-analysis/shipping-takes-aim-battery-powered-future> [Accessed 7 June 2022].

10 - Liang, L., 2019. Shipping takes aim at battery-powered future. [online] Seatrade Maritime. Available at: <https://www.seatrade-maritime.com/opinions-analysis/shipping-takes-aim-battery-powered-future> [Accessed 7 June 2022].

11 - DNV GL, Year One 150 Years, 2014.

12 - IEA. 2019. The Future of Hydrogen – Analysis - IEA. [online] Available at: <https://www.iea.org/reports/the-future-of-hydrogen> [Accessed 21 May 2022].

13 - Hydrogen from renewable power: Technology outlook for the energy transition (irena.org), p;13;

14 - European Commission, A Hydrogen Strategy for a Climate-Neutral Europe,2020, pp 4.

15 - ShipInsight. 2021. Enova funds world first hydrogen powered fishing vessel. [online] Available at: <https://www.shipinsight.com/articles/enova-funds-world-first-hydrogen-powered-fishing-vessel> [Accessed 20 May 2022].

16 - Wärtsilä. n.d. Offshore References. https://www.wartsila.com/marine/customer-segments/references/offshore/viking-lady

17 - Ammonia: general information, https://www.gov.uk/government/publications/ammonia-properties-incident-management-and-toxicology/ammonia-general-information.

18 - US EPA. n.d. Aquatic Life Criteria - Ammonia | US EPA. https://www.epa.gov/wqc/aquatic-life-criteria-ammonia;

19 - Tian, H., Xu, R., Canadell, J.G., Thompson, R.L., Winiwarter, W., Suntharalingam, P., Davidson, E.A., Ciais, P., Jackson, R.B., Janssens-Maenhout, G. and Prather, M.J., 2020. A comprehensive quantification of global nitrous oxide sources and sinks. Nature, 586(7828), pp.248-256.

20 - Panoutsou, C., Germer, S., Karka, P., Papadokostantakis, S., Kroyan, Y., Wojcieszyk, M., Maniatis, K., Marchand, P. and Landalv, I., 2021. Advanced biofuels to decarbonise European transport by 2030.

21 - Eriksson, T., 2020, Ways to Decarbonize Shipping, pp 19.

22 - ABS, Sustainability Whitepaper Biofuels as a Marine Fuel, 2021, pp 23.

23 - European Commission, Joint Research Centre, Moirangthem, K., Alternative fuels for marine and inland waterways, Baxter, D.(editor), Publications Office, 2017, https://data.europa.eu/doi/10.2790/227559

24 - 2021. bp and Maersk Tankers Carry Out Successful Marine Biofuel Trials. [online] Available at: <https://www.bp.com/en/global/corporate/news-and-insights/press-releases/bp-and-maersk-tankers-carry-out-successful-marine-biofuel-trials.html> [Accessed 24 May 2022].

25 - Palmer, H., n.d. Successful biofuel trial on Maersk Tender - Feature Story Maersk Supply Service. Maersk Supply Service. https://www.maersksupplyservice.com/2021/09/27/successful-biofuel-trial-on-maersk-tender/

26 - Exxonmobil.com. n.d. Marine Bio Fuel Oil | ExxonMobil Marine. [online] Available at: <https://www.exxonmobil.com/en/marine/technicalresource/press-releases/marine-bio-fuel-oil> [Accessed 26 May 2022].

27 - Reuters. 2016. 'Great Green Fleet' using biofuels deployed by U.S. Navy. [online] Available at: <https://www.reuters.com/article/us-usa-defense-greenfleet-idUSKCN0UY2U4> [Accessed 22 May 2022].

28 - Dimensions and characteristics of biogas policies – Modelling the European policy landscape - ScienceDirect

29 - Biogas potential of organic waste onboard cruise ships — a yet untapped energy source | SpringerLink

30 - Cordis.europa.eu. 2005. CORDIS | European Commission. [online] Available at: <https://cordis.europa.eu/article/id/24046-sweden-unveils-biogas-train> [Accessed 9 June 2022].

31 - Scandinavian Biogas. 2022. The shipping sector has increased its use of biogas - Scandinavian Biogas. [online] Available at: <https://scandinavianbiogas.com/en/the-shipping-sector-has-increased-its-use-of-biogas/> [Accessed 10 June 2022].

32 - Available at: Gasum delivers renewable biogas for the first time to an offshore supply vessel from Lundin Energy - Biofuels Central;

33 - Available at :faerdig_pressemeddelelse_makeenenergy_version_en.pdf

34 - Schinas, Orestis. (2020). REDUCTION OF GHG EMISSIONS FROM SHIPS Wind propulsion solutions. 10.13140/RG.2.2.18835.02081.

35 - Comer, B., Chen, C., Stolz, S., Rutherford, D., Rotors and Bubbles: Route-Based Assessment of Innovative Technologies to Reduce Ship Fuel Consumption and Emissions, ICCT Working Papers 2019-11, ICCT, Washington, DC, USA, 2019, pp. 1-19.

36 - StormGeo N.D, Ten Years of Weather Routing with Storm Geo, available at: https://www.stormgeo.com/solutions/shipping/articles/ten-years-of-wheather-routing/.

37 - Regulation (EU) 2021/1139 of the European Parliament and of the Council of 7 July 2021 establishing the European Maritime, Fisheries and Aquaculture Fund and amending Regulation (EU) 2017/1004, OJ L 247, 13.7.2021, p. 1.

38 - Regulation (EU) 2021/1056 of the European Parliament and of the Council of 24 June 2021 establishing the Just Transition Fund, OJ L 231, 30.6.2021, p. 1.

39 - Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions, REPowerEU Plan, COM/2022/230 final.

40 - Council Decision (EU) 2021/764 of 10 May 2021 establishing the Specific Programme implementing Horizon Europe – the Framework Programme for Research and Innovation, and repealing Decision 2013/743/EU, OJL 167, 12.05. 2021, p. 1.

41 - Borrello, Motova, & de Dentes Carvalho, 2013.