Preliminary research
Name: Katumwesigye Anthony
Research field: Transition Pathways for hard-to-abate sectors.
University: Abo-Akademi University Turku.

PhD Proposal: Techno-Economic Assessment of Transition Pathways for Hard-to-Abate Sectors: Alternative Fuels for Marine and Agricultural Industries

Transitioning to sustainable energy sources is imperative for sectors traditionally reliant on fossil fuels. Both marine and agricultural industries are pivotal in global trade and food production respectively, yet they contribute significantly to greenhouse gas emissions. To achieve sustainable energy systems, it is necessary to consider and evaluate a range of transition pathways. These pathways may include options such as electrification, intensified energy efficiency, LNG, biofuels, and e-fuels. Embracing technology pathways like electrification and alternative fuels is vital to combat environmental degradation and promote a greener future.

Background and Literature Review

The maritime and agricultural sectors hold paramount importance as key industries in the current global scenario, particularly given the pressing need to transition towards sustainable practices. These shifts are fuelled by a necessity driven by the traditional reliance on fossil fuels, championing the exploration and implementation of sustainable alternatives such as biomethane, biohydrogen, e-fuels, and electrification in a bid to decarbonize these crucial industries (Helge, Holger, and Laurids, 2020).

The Renewable Energy Directive (RED[1] II) of the European Union has a crucial role in promoting eco-friendly transportation and agricultural practices. Its goal is to incentivize the use of alternative fuels and electric propulsion systems in both agricultural and marine transportation. Deniz and Zincir (2016) highlight the importance of this benchmark in driving the initiative forward. Moreover, regions like the Nordic countries are setting a remarkable pace, pushing towards more stringent decarbonization targets compared to other counterparts in the EU. The current global challenge at hand demands a comprehensive approach that incorporates both regional and international strategies. As noted by Helge, Holger, and Laurids (2020), the complex nature of this challenge requires a diligent and well-coordinated effort.

Highly regarded organizations such as the United Nations Environment Programme (UNEP[2]), the United Nations Framework Convention on Climate Change (UNFCC[3]), and the International Transport Forum (ITF[4]) play significant roles in moulding a global movement towards reduced carbon emissions through collaborative efforts combining policy and tax incentives to sculpt a roadmap for a sustainable future.

One of the distinguished front-runners in this green revolution, the Nordic countries, are leveraging a wide array of raw materials including wind energy sources, rapeseed, and forest residues in the production of biofuels, E-fuels and have embraced biogas produced from organic waste as an eco-friendly alternative (Fan et al., 2021a). Recognizing the considerable contribution of water transport to global CO2 emissions, there is an intensified focus on adopting cleaner fuel options to substantially reduce its carbon footprint (Schwartz, Gustafsson and Spohr, 2020; Korberg *et al.*, 2021).

The International Maritime Organization (IMO[5]) has embarked on ambitious undertakings to curtail ship-induced emissions globally. This journey began with strategies such as imposing strict regulations on sulphur content in marine fuels since 2020 and initiating the meticulous logging of fuel oil

---

[1] https://joint-research-centre.ec.europa.eu/welcome-jec-website/reference-regulatory-framework/renewable-energy-recast-2030-red-ii_en
[2] https://www.unep.org/technical-highlight/unep-benelux-countries-partner-address-triple-planetary-crisis
[3] https://unfccc.int/climate-action/tracking-and-recognition
[4] https://www.itf-oecd.org/tcad
[5] https://www.energy.gov/eere/maritime-decarbonization

consumption data to foster transparency and data accessibility (Korberg *et al.*, 2021). In a groundbreaking move in 2018[6], the IMO adopted a strategy targeting a reduction of GHG emissions from shipping by at least 50% by 2050, using 2008 as a reference point (IMO2). While the detailed roadmap remains under formulation, the global anticipation builds for a holistic approach integrating short and long-term measures, wherein the embracement of alternative fuels takes centre stage.

Thus, it is apparent that the marine and agricultural sectors are on a transformative trajectory steered by a concerted effort from global organizations and directed by stringent policies and goals (Schwartz, Solakivi and Gustafsson, 2022). These efforts are heightened by the pioneering initiatives in the European regions, promoting a sustainable future that hinges significantly on the decarbonization of these hard abatement sectors through innovative transitions to cleaner and more sustainable fuel options and electrification pathways (Korberg *et al.*, 2021). This collaborative global endeavour underscores a hopeful and sustainable vision for the future, where critical sectors operate harmoniously with environmental conservation priorities. It is a pathway sculpted through international cooperation, policy-driven initiatives, and the relentless pursuit of sustainable technological innovations (Afionis and Stringer, 2012; Paris *et al.*, 2021; Breuer *et al.*, 2022). The achievement of a sustainable future necessitates a cooperative effort and an innovative, environmentally conscious approach.

Questions and Methodologies to investigate the objectives:

In light of the provided Work Package project roles (CPTII, Decatrip, FUSE), the investigation seeks to unearth critical insights into the techno-economic and environmental aspects of adopting alternative pathways including fuels and electrification in the marine and agricultural sectors. The synthesis of these insights will be instrumental in shaping future policy and technological directions, thereby fostering a more sustainable industrial landscape. The following research questions and their associated objectives emanate from the identified gaps and thematic areas within the Working Package projects.

Research Question 1: What alternative fuels are potentially suitable for the marine and agricultural sectors, considering their technological and economic viability?

Objective 1: Investigate Potential Alternative Fuels

Evaluate the technological and economic feasibility of farm-based fuels and E-fuels (such as hydrogen, e-methanol, and E-LNG) in the marine and agricultural sectors. This involves analyzing their production, handling, storage, and utilization while considering the CO2 abatement costs through robust methodologies like Life Cycle Assessment (LCA) and techno-economic assessments. Furthermore, the compatibility of these fuels with existing machinery and infrastructure will be critically examined, culminating in the development of guidelines for the safe and efficient handling of these fuels.

Research Question 2: What are the technical modifications required in internal combustion engines to adapt to sustainable advanced biofuels, and what are the implications of these modifications on the techno-economic feasibility of the fuels?

Objective 2: Analyze Techno-Economic Implications of Engine Adaptations

Examine the adaptations needed in internal combustion engines for the utilization of alternative fuels, considering advanced combustion concepts and new handling and aftertreatment systems. The objective seeks to understand how these modifications influence the techno-economic feasibility of adopting alternative fuels and inform other work packages about the most feasible fuel options, their emissions, usage, and associated costs.

[6] https://www.imo.org/en/MediaCentre/HotTopics/Pages/Reducing-greenhouse-gas-emissions-from-ships.aspx

Commented [MH1]: Perhaps you could start by arguing a bit for what kind of questions should be posed.

Commented [MH2R1]: When you write this, pelase keep in mind that a) you already have the Wasaline study and b) the tasks we should do in CPT II (i.e. Future CTP = FCTP).

Commented [MH3R1]: You could e.g. refer to different applications and segments and motivate it with the fact that there is no "one size fits all" solution, but that we need application/segment-specific solutions.

Preliminary research
Name: Katumwesigye Anthony
Research field: Transition Pathways for hard-to-abate sectors.
University: Abo-Akademi University Turku.

Research Question 3: How can Carbon Capture and Utilization (CCU) technology be integrated with After Treatment Systems (ATS) to convert CO2 back into a fuel compound, and what are the sustainability implications of this integration?

Objective 3: Explore CCU Integration and Sustainability

Investigate practical solutions to integrate CCU technology with ATS, focusing on the processes to separate, concentrate, purify, and convert CO2 back into a fuel compound. Additionally, evaluate the sustainability of CCU technology through Multicriteria Analysis (MCA) and LCA, comparing scenarios where CCU is utilized against cases where it is not used or used solely for capturing and storing CO2.

Research Question 4: How do fuel blending and electrification, as transitional methods towards sustainable energy, interact with emerging battery technologies to influence combustion efficiency, emissions, and system adaptability in hard-to-abate sectors?

Objective 4: **Assess the Synergistic Impacts of Fuel Blending, Electrification, and Battery Integration**

Evaluate the combined implications of fuel blending, electrification, and battery technology integration on combustion efficiency, emissions, and system adaptability. Delve into the feasibility of blending renewable fuels with conventional ones and understand how battery technologies can enhance or challenge these strategies. Additionally, explore the technical requirements for storage, handling, and energy supply, considering both in-cylinder and pre-introduction blending. Lastly, assess the broader challenges and opportunities presented by this multifaceted approach to decarbonization in the marine and agricultural sectors.

Research Question 5: By 2050, what are the anticipated comprehensive environmental, economic, and social impacts of transitioning to alternative fuels, electrification, and integrating battery technologies in the marine and agricultural sectors?

Objective 5: Holistic Projection of Impacts from Energy Transition Pathways

Undertake a comprehensive evaluation to project the environmental, economic, and social ramifications of embracing alternative fuels, electrification, and battery technologies in the marine and agricultural domains by 2050. This involves a multifaceted approach incorporating comparative Life Cycle Assessments (LCAs), Total Cost of Ownership assessments, and socio-economic analyses. The objective aims to provide a holistic understanding of the transition pathways, assessing not only their environmental sustainability but also their economic viability and social equitability across various applications and scenarios within these sectors.

Working Projects under which these questions will be investigated:

There are three projects that have specific goals related to sustainable shipping and agriculture: Clean Propulsion Technologies (CPT), Decatrip, and FUSE. CPT is focused on identifying and refining technical approaches for sustainable shipping using a variety of power trains, including diesel engines. Decatrip aims to create a business case for reducing carbon emissions in the Turku-Stockholm transport corridor, while FUSE is working on developing a case study for the use of batteries in the shipping industry.

Preliminary research
Name: Katumwesigye Anthony
Research field: Transition Pathways for hard-to-abate sectors.
University: Abo-Akademi University Turku.

References

1. Afionis, S. and Stringer, L.C. (2012) 'European Union leadership in biofuels regulation: Europe as a normative power?', *Journal of Cleaner Production*, 32, pp. 114–123. Available at: https://doi.org/10.1016/j.jclepro.2012.03.034.

2. Breuer, J. *et al.* (2022) 'An Overview of Promising Alternative Fuels for Road, Rail, Air, and Inland Waterway Transport in Germany', *Energies*, 15(4), p. 1443. Available at: https://doi.org/10.3390/en15041443.

3. Deniz, C. and Zincir, B. (2016) 'Environmental and economical assessment of alternative marine fuels', *Journal of Cleaner Production*, 113, pp. 438–449. Available at: https://doi.org/10.1016/j.jclepro.2015.11.089.

4. Korberg, A.D. *et al.* (2021) 'Techno-economic assessment of advanced fuels and propulsion systems in future fossil-free ships', *Renewable and Sustainable Energy Reviews*, 142, p. 110861. Available at: https://doi.org/10.1016/j.rser.2021.110861.

5. Paris, B. *et al.* (2021) 'Economic analysis of advanced biofuels, renewable gases, electrofuels and recycled carbon fuels for the Greek transport sector until 2050', *Renewable and Sustainable Energy Reviews*, 144, p. 111038. Available at: https://doi.org/10.1016/j.rser.2021.111038.

6. Schwartz, H., Gustafsson, M. and Spohr, J. (2020) 'Emission abatement in shipping – is it possible to reduce carbon dioxide emissions profitably?', *Journal of Cleaner Production*, 254, p. 120069. Available at: https://doi.org/10.1016/j.jclepro.2020.120069.

7. Schwartz, H., Solakivi, T. and Gustafsson, M. (2022) 'Is There Business Potential for Sustainable Shipping? Price Premiums Needed to Cover Decarbonized Transportation', *Sustainability*, 14(10), p. 5888. Available at: https://doi.org/10.3390/su14105888.