ECONOMICS OF SUSTAINABLE HYDROGEN-FUELS FOR TRUCKING, SHIPPING AND AVIATION

Jonas Martin, Norwegian University of Science and Technology, +47 463 36 350, jonas.martin@ntnu.no
Anne Neumann, Norwegian University of Science and Technology, +47 73 41 22 18, anne.neumann@ntnu.no
Anders Ødegård, SINTEF, +47 943 56 595, anders.odegard@sintef.no

Overview

In this paper we ask how the economics of long-haul trucking, short-sea shipping and short-haul aviation change over time while decarbonizing heavy-duty transport until 2050. We develop a dynamic cost model and apply it to Norway, which has a high potential of renewable energy generation and is considered an early adopter of sustainable transport. We investigate how the competitiveness in each transport mode changes when using sustainable hydrogen-fuels (SHF) instead of fossil fuels (fF) by comparing transport costs per tonne-kilometre. Also, we show how the competitiveness across transport modes changes due to the different impact of fuel costs in the mode's total cost of ownership.

SHFs are produced from renewable energy sources, water and optionally carbon dioxide or nitrogen captured from the atmosphere. The production process results in sustainable hydrogen (eH), hydrocarbon fuels (eF) or ammonia (eA) respectively, where "e" stands for electricity-based fuels. The produced gases and liquids have similar or identical characteristics as conventional fuels in transport regarding handling (distribution, storage) and applicability (vehicle refuelling and range). A disadvantage however is the required amount of energy in production due to low energy efficiencies resulting in high production costs. Thus, SHFs are primarily interesting to decarbonize applications where direct electrification and its infrastructure reaches technical limits.

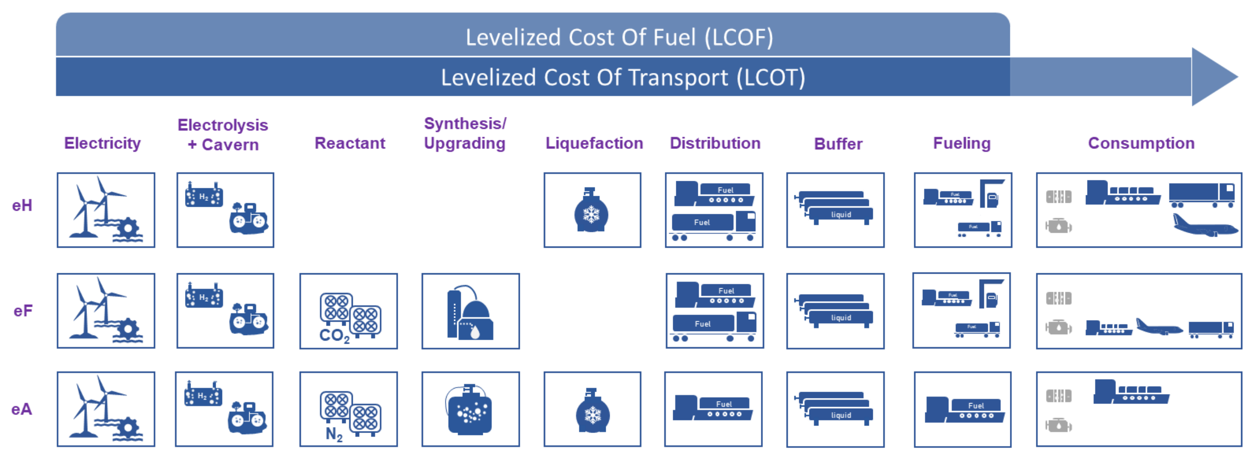

Figure 1: An illustration of the investigated value chains from electricity production to fuel consumption in transport
Adjusting the dynamic cost model to account for different sources of sustainable electricity generation, fuel production and distribution obtains the levelized cost of fuel (LCOF) and the levelized cost of transport (LCOT) for the trucking, shipping and aviation. (Source: own illustration)

Method

We estimate costs with a time resolution of five-year steps, from 2020 to 2050 based on publicly available data sources. Raw data for 140 parameters along the value chains (figure 1) were gathered from scientific articles in peer-reviewed journals, frequently cited grey literature including reports by consultancies, agencies and industry experts, and validated by practitioners.

In order to compare fuel and transport alternatives, we apply the common approach of levelized cost of energy, assigning total life-cycle costs to one unit of production output. We generalize the approach to calculate levelized cost of all process steps in the value chain, carrying out a bottom-up analysis. Uncertainties of future cost values are investigated and discussed in a detailed sensitivity analysis.

This paper contributes to the scientific discussion about sustainable transport with a holistic techno-economic path analysis including the process steps electricity production, hydrogen generation, fuel upgrading, distribution, fuelling and finally the consumption in the trucking, shipping and aviation sectors. It provides a dynamic cost model which can be adjusted to local conditions regarding energy production, distribution and transport needs, resulting in levelized costs of transport (LCOT).

Results

As shown in figure 2, for trucking sustainable hydrogen (eH) is the first choice for decarbonization, for shipping sustainable ammonia (eA) and for aviation a mix of sustainable hydrocarbon fuels (eF) and hydrogen (eH). However, all of these sustainable alternatives create cost disadvantages benchmarked against the current fossil fuel-based transport. The largest lever can be seen in the shipping sector with a cost increase of +232% in 2020 using eF and +41% in 2050 using eA, followed by aviation with +138% in 2020 using eF and + 33% in 2050 using eH, and trucking with +66% in 2020 and +8% in 2050 using eH respectively.

Among the transport modes, the introduction of alternative fuels does not change the economic ranking. Shipping stays the cheapest and aviation the most expensive freight transport alternative. However, additional criteria such as transport time, frequency, availability and flexibility requirements also impact the overall mode choice. A noticeable and asymmetric change in transport costs, can therefore lead to modal shifts for certain use cases.

Conclusions

Without any governmental support such as taxes or subsidies for fossil and sustainable alternatives, our results show that by using SHF there exist asymmetric cost gaps for all modes of transport towards 2050 compared to fossil fuels. Thus, decarbonizing long-haul trucking, short-sea shipping and short-haul aviation using SHF leads to changes in economic competitiveness of transport. The ambitious goals to reduce greenhouse gas emissions in freight transport require detailed knowledge about cost increases which trucking, shipping and aviation will face in the upcoming decades. Providing a dynamic cost model including electricity and fuel production, distribution and consumption, we define the cost gaps between sustainable transport and its fossil-based counterparts towards 2050. Based on this knowledge, decision makers are able to identify the economic challenges, transport will face inside and across each mode. In further work, optimal support schemes along the whole value chain can be defined to achieve an early and successful market integration of sustainable freight transport.

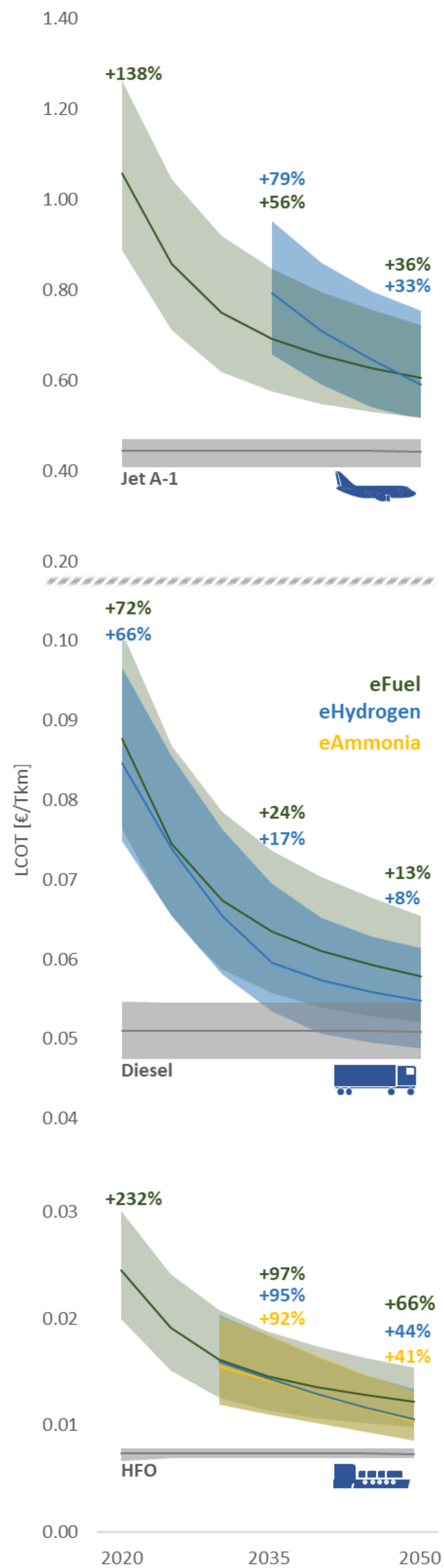

Figure 2: Levelized cost of transport for aviation, trucking and shipping (grouped from top) – case onshore wind power considering different fuel alternatives. Transport cost inside and across transport modes change over time. Economic competitiveness is out of reach. Percentages show the cost gap of alternatives benchmarked to the fossil fuel case. (Source: own illustration)