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

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Overview

In this paper we ask how the economics of aviation, shipping and trucking change over time while decarbonizing freight transport by 2050. We apply our methodology to Norway, a country which is an early market for launching sustainable transport and thus, provides first insights into issues the world will face in the upcoming years. We investigate how the competitiveness in each mode of transport 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 between transport modes changes due to the different impact of fuel costs in the share of total life-cycle costs.

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.

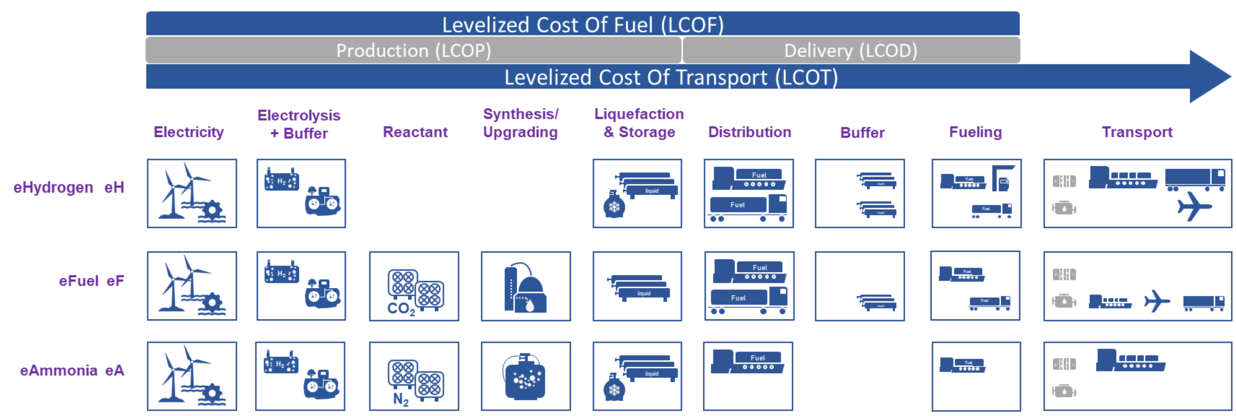

Figure 1: An illustration of the investigated value chains from electricity production to fuel consumption in transport
The dynamic cost model can be adjusted to several sources for sustainable electricity production, capacities in fuel production and delivery ranges, resulting in levelized cost of fuel (LCOF) and fuel consumption in the trucking, shipping and aviation sector, resulting in levelized cost of transport (LCOT). (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 chain (figure 1) were gathered from scientific articles in peer-reviewed journals, frequently cited grey literature including reports by consultancies, agencies and industry experts, 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 process output. We generalize the approach to calculate levelized cost of all process steps in the value chain, carrying out a detailed 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 pure 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 +217% in 2020 using eF and +26% in 2050 using eA, followed by aviation with +160% in 2020 using eF and + 37% in 2050 using eH, and trucking with +88% in 2020 and +5% 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 change in transport costs, can therefore lead to shifts in the preferred transport mode for certain use cases.

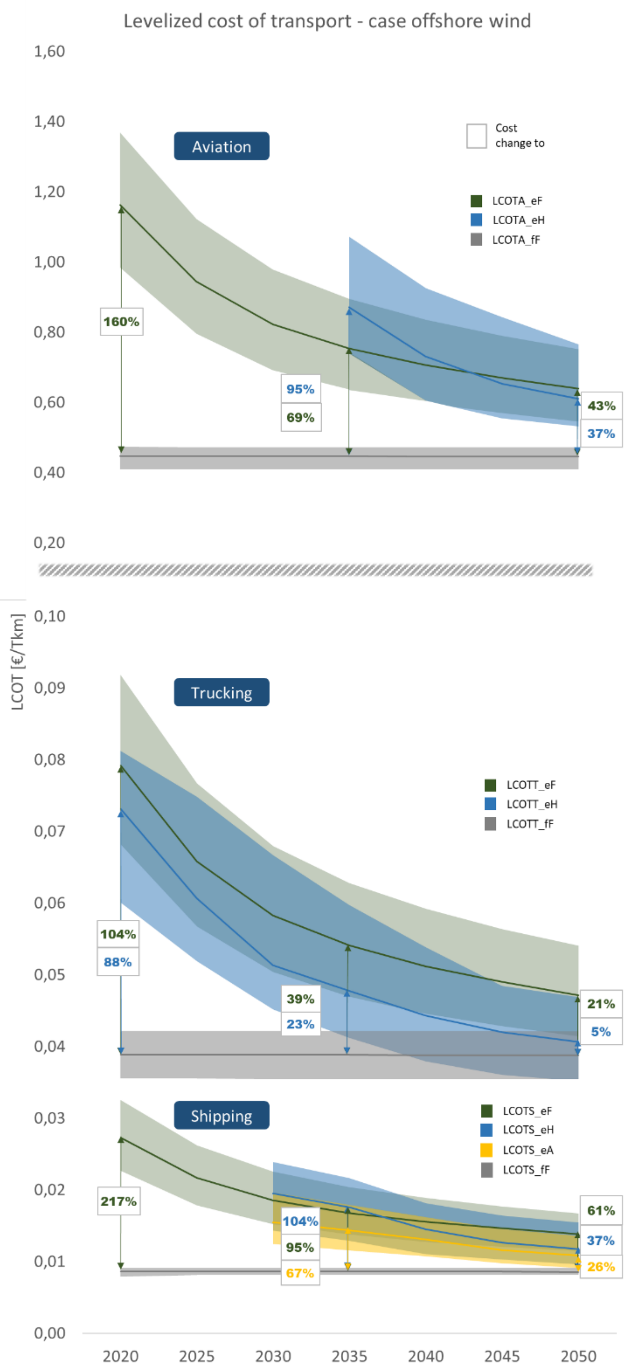

Figure 2: Levelized cost of transport for aviation, trucking and shipping (grouped from top) – case offshore wind considering different fuel alternatives. Transport cost inside and between transport modes changes over time. Boxes show the percentage in cost change of the average scenario benchmarked to the fossil fuel case. (Source: own illustration)

Conclusions

Without any governmental support such as taxes or subsidies for fossil and sustainable alternatives, our results show that by using SHF there exists a cost gap for all modes of transport towards 2050 compared to fossil fuels. Thus, decarbonizing trucking, shipping and 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 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.