DETAILED MODELING OF INLAND TRANSPORT OF SYNTHETIC FUELS

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Overview

Countries around the world are transforming their energy systems to increase the share of renewable energies, making their energy mixes greener. This energy transition, coupled with the ever-increasing global energy demand, necessitates the expansion of these renewable energies. To address its complexity, scientists have been modeling future energy systems to analyze the costs, emissions, and materials associated with the various steps of the renewable energy supply chain. In this supply chain, renewable energy sources are used to generate green electricity, which is later electrolysed into green hydrogen and further processed into its derivates, including liquid hydrogen, ammonia, methanol, liquid organic hydrogen carriers, and synthetic fuels.

As the production of these energy carriers represents a significant share of the total energy supply costs, many studies have projected the cost of producing green energy in detail. In these studies, however, the transport cost calculations were simplified via assumptions; the costs were computed for estimated distances (not accounting for the detour – difficulty in the path imposed by the transport network) traversed using pre-existing transport infrastructure. These transport costs reportedly accounted for only 1-2% of the total energy costs [1]. These studies ignore the cost of other infrastructure elements, which become highly relevant considering the expansion of renewable energies, especially to produce energy carriers, including synthetic fuels.

Renewable energies have significantly lower energy densities compared to fossil-based fuels. Owing to these low energy densities, setting up renewable energy power plants requires large amounts of land. The energy source further limits the sites for the power plants. This results in optimal sites not necessarily being closer to the existing transport infrastructure. Despite these limitations, the energy generated has to be brought to the demand centers. Thus, new transport infrastructure has to be built, and the costs have to be accounted for.

While the shipping transport of these energy carriers has been extensively explored, inland transport, especially infrastructure, has not been largely considered so far. The inland transport also represents a crucial and unavoidable portion of the energy supply chain; the path from the power plant, the path to the demand site, or both will be on land. Thus, this paper aims to explore the major inland cargo transport modes, road and rail, considering predominantly the near-future transport of trucks and trains. It aims to first calculate the specific future transport costs, analyze the impact of detours on these costs, and further estimate the associated infrastructure costs. To overview the infrastructure costs, which are expected to be negligible compared to total energy costs, countries with good renewable energy sites and expansion potential but poor inland transport infrastructure were considered. Further, the impact of autonomous vehicles on the far-future transport costs is also discussed.

Methods

Based on existing trends, battery electric trucks and trains run on 100% electrified lines are considered for the near-future scenario. Techno-economic parameters such as vehicle cost, lifetime, labour costs, maintenance costs, insurance costs, truck/train-trailer capacity, fuel demand, speeds, charging costs, and loading time are collected from the literature and other sources. Using these values and simple equations, the specific future transport costs of transporting synthetic fuels from the power plant to a demand site are calculated for a range of distances and given in €/MWh.

The range of detours for countries, specifically with good transport infrastructure, was collected from the literature to analyse the effect of detours. These values were used to calculate the increase in the previously calculated costs.

The infrastructure costs of inland transport include either the construction of roads or railroads and other additional infrastructure components, wherever required. The costs mainly factor in labour and material expenses. For the chosen countries, the costs of constructing roads or railroads were obtained from multiple recent infrastructure projects involving a range of distances. A range of costs was obtained in €/km-a.

Finally, techno-economic parameters related to autonomous vehicles were calculated to comment on their impact on far-future specific costs. The previously defined equations were used.

Results

The near-future specific transport costs for transporting synthetic fuels using battery-powered trucks and electrified trains were calculated for a range of distances from 100 to 500 km. The costs were 0.40 – 1.12 €/MWh and 0.08 – 0.28 €/MWh for truck and train transport respectively. A detour factor for travel distance of 1.10 to 1.40, identified from the literature [2–4], increased the specific costs by 4 to 36%.

While near-future transport costs and detour costs are predominantly based on travel distance, the transport infrastructure costs are case-specific; one solution does not fit all countries. To choose case studies, first, only countries with good renewable energy potential, namely open-field photovoltaic and onshore wind, were considered. The countries were further filtered based on land availability for renewable energy expansion. Finally, countries where inland transport infrastructure is not extensively developed, such as Algeria, Chile, Kazakhstan, Australia, and Canada, were chosen as exemplary cases. The infrastructure costs were computed for different case studies. For instance, in Chile, considering over 15 new road infrastructure project offers involving the new construction or expansion and maintenance of roads [5], an annual specific infrastructure cost ranging from 150,000 to 1,850,000 €/km-a was obtained with a lifetime of 20 years and a rate of interest 5%/a. In contrast, at a 40-year lifetime and 5% rate of interest, the annual specific infrastructure cost amounted to 4080000 €/km-a for an upcoming rail project.

Conclusions

The specific transport, detour, and infrastructure costs of transporting synthetic fuels via roads and rails using battery electric vehicles were calculated. The specific transport costs increased with increasing distances. The costs for transport via train were relatively cheaper than trucks as trains carry significantly higher capacities of fuel per trip compared to trucks. The detour linearly affects the distance and, in turn, the specific transport costs. The infrastructure costs associated with the new roads and railroads for new power plant projects present additional costs that have been previously ignored.

Future research on near-future transport infrastructure costs can consider other countries as further case studies. The different stakeholders responsible for bearing this cost of transport infrastructure can be identified, and the share per stakeholder can be calculated. In the far future, autonomous vehicles are expected to revolutionise the freight transport industry. These autonomous systems will reduce labour and technology costs due to their inherent nature and expected technological maturity but at a very high capital investment. Understanding such energy economics at different stages of the energy supply chain for different future scenarios is crucial in preparing for a green and sustainable future energy system.

References

[1] Patrick Buchenberg *et al.*, “Global Potentials and Costs of Synfuels via Fischer–Tropsch Process,” *energies*, vol. 16, 2023. [Online]. Available: 10.3390/en16041976

[2] Ronald H. Ballou, Handoko Rahardja, Noriaki Sakai, “Selected country circuity factors for road travel distance estimation,” *Transportation Research Part A*, vol. 36, pp. 843–848, 2002.

[3] Frédéric Héran, “Des distances à vol d'oiseau aux distances réelles ou de l'origine des détours,” *Flux*, 76/77, 2009.

[4] Borut Zgonc, Metka Tekavčič, and Marko Jakšič, “The impact of distance on mode choice in freight transport,” *European Transport Research Review*, vol. 11, 2019. [Online]. Available: 10.1186/s12544-019-0346-8

[5] P. P. Santiago Barba, *Infrastructure Insights - Tender Schedule PPP Projects Dirección General de Concesiones Chile*.