EVALUATING MARKET-BASED POLICY INTERVENTIONS FOR HYDROGEN FUEL CELL TRUCKS: A TOTAL COST OF OWNERSHIP ANALYSIS

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Overview

This research investigates the Total Cost of Ownership (TCO) of hydrogen fuel cell trucks (HFCTs) and evaluates market-based policy interventions to enhance their economic viability in comparison to business-as-usual (BAU) trucks. The heavy-duty vehicle sector is still a hard-to-abate sector. Globally, it causes more than 40 % of NOx emissions and 50 % of PM2.5 emissions from the transport sector. It also contributes over 35% of direct CO2 emissions from road transport but only represents fewer than 8% of vehicles. Achieving the cost parity of zero-emission trucks is important to decarbonise the heavy-duty vehicle sector. Existing literature has explored the TCO projection for HFCTs and the time to reach the tipping point (e.g. Basma et al., 2022 and Mao et al., 2021), but little of the literature has discussed how the weights of trucks affect the time of achieving cost parity, and little research has considered trucks with various powertrains, and little research has investigated what are benefits of a combination of interventions, and little literature has considered the cost and benefit of interventions for the government.

This work is the first to explore how policy interventions close the TCO gaps between HFCTs of different weights and their counterfactuals using a novel Agent-based Model. This work is also the first to evaluate the effects of different market-based interventions to achieve cost parity for HFCTs and obtain a cost of the government. In this research, the analysis identifies TCO gaps between 3 HFCTs based on weights and two scenarios – diesel, battery electric. Policy scenarios explored include financial incentives/subsidies on CAPEX and OPEX, and taxation of conventional vehicles. The ABM was applied to simulate the impact of reducing capital expenditure (CAPEX) and operational expenditure (OPEX) related to the price of hydrogen, and both simultaneously, alongside the effect of increasing TCO for diesel vehicles via fossil fuel taxes. The model examines how these measures influence the timeline for achieving cost parity between HFCTs and diesel trucks. This research provides evidence of the effectiveness of demand-pull policy interventions and explores the synergies between policy mechanisms required to accelerate HFCT adoption.

Methods

Agent-Based Model (ABM): ABM is a model that is used to simulate behaviours of agents within a defined environment, allowing researchers to analyse and predict complex phenomena. It can contribute to the analysis of a case where there are several alternatives for BAU trucks with various weights in an environment where energy prices and other prices are variable. The ABM in our research simulates the cost evolution of heavy-duty trucks of varying weights (18t, 31t, and 49t) and powertrains (diesel, battery-electric, and hydrogen fuel cell) starting from 2020. In total, there are nine types of truck agents, which are a comprehensive representation of heavy-duty trucks in real life. The model’s dynamic is driven by the technology learning rate, which reduces the prices of zero-emission trucks and improves the fuel economy every year. Truck production is made on a yearly basis so the corresponding TCO of each truck is updated. In this research, we calculate 5-year TCO and consider no replacement of the fuel cell and the battery. The model applied a bottom-up method to construct the present values of TCO. The TCO function was adapted from the existing literature and we also separated TCO into CAPEX and OPEX to examine the details of interventions. The TCO function incorporates vehicle prices, fuel costs, and learning rates, annual mileage travel, maintenance costs, scrappage values derived from the literature and policy documents. We assumed that the fuel price, maintenance costs, and scrappage values remain the same in the baseline model without any interventions. Moreover, we had a more realistic assumption that zero-emission vehicle prices would reduce quicker from 2020 to 2025 and reduce slower afterwards, and the fuel economy improve more in the same period and have less improvement afterwards. In contrast, we assumed diesel trucks experience a slight price increase because of new and more expensive technologies aiming to improve fuel efficiency. The annual mileage travel was set to 100 thousand km per year and it was tested for sensitivity. Finally, we assumed there is no extra cost caused by the subsidies and extra benefit caused by taxes for the government.

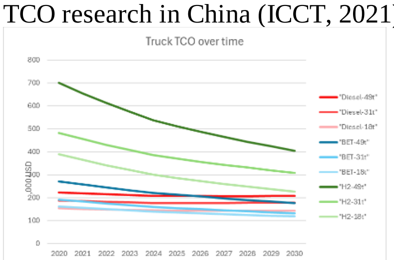
Scenario Analysis: (1) Reducing CAPEX by providing capital grants. The investigation started with a 1%, then to 100% CAPEX reduction and evaluated the effect of narrowing the TCO gap. (2) The hydrogen price may be important to achieving cost parity, hence we investigated the case of reducing OPEX by providing hydrogen refuelling subsidies. We reduced the hydrogen price by 20%, 40%, and 60% and evaluated the effect on the TCO. (3) Simultaneous CAPEX and OPEX reductions (20%, 40%) to explore combined effects. (4) There are several ways to penalise polluters, such as carbon pricing and diesel taxes. We generalised them into the change of diesel price. Therefore, we investigated

Basma, H., Zhou, Y., & Rodríguez, F. (2022). Fuel-cell hydrogen long-haul trucks in Europe: A total cost of ownership analysis. International Council on Clean Transportation: Washington, DC, USA.
Mao, S., Basma, H., Ragon, P. L., Zhou, Y., & Rodríguez, F. (2021). Total cost of ownership for heavy trucks in China: Battery-electric, fuel cell electric, and diesel trucks. *URL https://theicct. org/wp-content/uploads/2022/01/ze-hdvs-china-tco-FS-EN-nov21. pdf, Accessed on: Jan, 4,* 2023.

two stringent cases which increase the fossil fuel price by 20% and 40%, respectively, and have simultaneous CAPEX and OPEX reductions (40%). Our analysis examined scenarios with and without policy support to highlight the importance of governmental interventions in achieving economic viability for HFCTs. The model evaluated intervention impacts under varying conditions to determine robust pathways to cost parity under uncertainty. The parameter used for the sensitivity test is the annual mileage travel. We changed the annual mileage travel by 50% more and 50% less.

Results

Current TCO Analysis: Without any interventions, HFCTs at all three weights cannot reach cost parity by 2030, and our result shows the tipping point happens even after 2040 for the heaviest HFCTs (49t). The TCO gaps are 200 thousand USD for those lighter trucks and 480 thousand USD for the heaviest trucks in 2020. The gaps are still significant (77 thousand USD for lighter trucks and 200 thousand USD for the heaviest trucks) in 2030 As shown in the graph below. Notably, the CAPEXs of HFCTs and battery electric trucks are comparable to that of BAU trucks at the end of this decade, but it is the high OPEX gaps are still large. The reason is the high cost of hydrogen refuelling. The CAPEXs of the heaviest trucks and the lighter trucks are about 40% and 60% of their OPEXs. Interestingly, the TCO of battery electric trucks becomes competitive with the diesel trucks. Battery-electric trucks achieve cost parity by around 2027 across all weight categories, posing a competitive challenge for HFCTs. This finding aligns with a TCO research in China (ICCT, 2021).



Market-based Policy Intervention for the CAPEX and OPEX: (1) Reducing CAPEX by providing capital grants fails to obtain cost parity by 2030 and even if the capital grants funds all the CAPEX. The impact of the capital grant diminishes because the OPEX of HFCTs represents a too large proportion of the TCO (greater than 60%). The governmental cost is large, but may cannot fulfil the diffusion goal. This investigation also indicates the necessity to intervene in the OPEX. (2) By reducing 20% of the hydrogen price by providing a hydrogen refuelling subsidy, HFCTs still cannot achieve cost parity by 2030. By reducing 40% of the hydrogen price, HFCTs with a weight of 18t and 31t can almost achieve cost parity by 2030, while the TCO gap of the heaviest HFCTs is 70 thousand USD. By reducing 60% of the hydrogen price, the model shows an essential reduction in the TCO HFCTs. HFCTs at the weight of 49t, 31t and 18t reach cost parity by 2031, 2025 and 2028, respectively. The governmental cost to obtain cost parity for 18t trucks is 130 thousand and 100 thousand USD per truck in 2025 and 2030, respectively. In terms of the costs for 49t trucks, they are 240 thousand and 190 thousand USD. The cost is huge so the hydrogen subsidy cannot be the only intervention. (3) The third scenario Combined CAPEX and OPEX reductions (specifically at 40%) show HFCTs can achieve cost parity for lighter weight segments by 2030 but the heaviest HFCTs still have a 50 thousand USD gap with BAU trucks. (4) The fourth scenario showed the benefit of taxes on diesel trucks. With a 40% increase in diesel price due to taxation, the heaviest HFCTs can achieve cost parity by 2030, and the government can save 50 thousand USD per truck compared to the third scenario. This case implies that introducing carbon pricing may provide a robust mechanism to offset higher hydrogen fuel costs, enhancing the viability for the government. These above results are sensitive to the data of the annual mileage travel. The more mileage that a truck needs to cover every year, the larger the TCO gap between the HFCTs and diesel trucks and thus, the slower HFCTs can obtain cost parity with diesel trucks. In summary, to achieve cost parity by 2030, the intervention required is at a large amount but necessary.

Conclusions

The cost gap between HFCT and the BAU still remains a barrier to adoption indicating the need for policy and other interventions. A decrease in the price of HFCT over time due to technology learning is still not sufficient to achieve cost parity by 2030. This research develops a novel ABM for HFCT considering several weights, several truck alternatives, and the TCO over time to demonstrate the role of policy interventions in reducing the TCO of HFCTs and highlights the interplay between CAPEX and OPEX reductions, and taxation on diesel. Results show that Operational costs remain a barrier to achieving cost parity for heavier HFCTs (60% of the TCO). OPEX reductions are essential for long-term competitiveness, especially for larger and heavier vehicles, but leave a huge fiscal burden to the government. Shifting purchase subsidies to hydrogen refueling incentives is more effective as vehicle prices decline over time. A combination between hydrogen refueling subsidies and carbon pricing provide promising avenues to bridge this gap. Future research should explore optimized policy mixes to balance government financial burdens and market acceleration while incorporating behavioral insights into fleet operator decision-making.