HYDROGEN MOBILITY FOR QATAR: A COMPARISON BETWEEN CONVENTIONAL, ELECTRIC AND HYDROGEN FUEL CELL VEHICLES USING LIFE CYCLE COST ANALYSIS

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ABSTRACT

Qatar's road transport is dominated by private vehicles, which leaves a substantial environmental footprint. Seeking to counter this impact, the nation is targeting an increase in public and private transport electrification. Nonetheless, due to its associated emissions, the dependence on hydrocarbon-based power plants to satisfy said electricity demand remains an issue. Hence, the present study analyses the potential incorporation of hydrogen fuel cell vehicles (HFCVs) into the mix. To do so, this technology is compared with conventional and electric cars, using a life cycle cost (LCC) approach, which considers economic and environmental aspects. For the latter, Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation is adjusted to mimic Qatar's context, obtaining emissions associated with each technology. These values are merged with economic parameters in Python, obtaining the cost per kilometre travelled. In a one-to-one comparison, HFCVs are the least viable option, constantly decreasing their gap with other technologies over time. Furthermore, to quantify policy instruments that aim to influence HFCV adoption, over 600 scenarios are modelled and compared, considering different fuel production methods, HFCV-related incentives, as well as technology-specific and environmental taxes. As a result, while considering a combination of the most aggressive approach for purchase price incentive (20%) and H2 subsidy (80%), HFCVs' LCC is transformed into the lowest among the analysed technologies. Moreover, by disincentivizing the use of internal combustion engines via 40% and 30% purchase and emission taxes, electric vehicles have become more feasible since the initial year, while HFCVs' LCC outperforms internal combustion engine vehicles a decade faster compared to the non-taxed scenario.

Keywords: hydrogen fuel cell vehicle, life cycle cost, sustainable transport, alternative vehicles.

1 INTRODUCTION

Population growth and its associated anthropogenic infrastructure expansion have originated, among many aspects, a rise in transportation demand. This expansion is generally met via conventional technologies, which, considering that said sector's CO_2 emissions are just 13% lower than industry, its footprint is not negligible [1]. Moreover, road transport is responsible for 74% of the transport sector's emissions, especially in countries and regions like Qatar and the Gulf Cooperation Council where personal vehicles are the main mean of transportation, representing up to 67% of the modal split [2], [3]. To address this issue, countries and regions have originated initiatives targeting the reduction use of conventional vehicles, such as the USA that will limit the sale of this technologies by 2030, while the EU will completely ban their sales by 2035. Qatar, in particular, is leaning towards electrification with its green car initiative which aims to have an electric vehicle (EV) representing 10% of the nation's car stock by 2030. Despite reducing tailpipe emissions, the country's national grid relies heavily on natural gas power plants for electricity production meaning that this environmental

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footprint remains; hence, the deployment of alternative technologies like hydrogen fuel cell vehicles (HFCVs) should be contemplated.

Considering the discussion above, the present study considers both environmental and economic aspects to carry out a life cycle cost (LCC) comparison between conventional, electric and hydrogen fuel cell vehicles within a Qatar context. Furthermore, the influence of policy instruments to enable HFCV deployment and their impact on the LCC trend is also analysed.

2 METHODOLOGY

To develop the LCC approach a Python code was generated and its environmental-related parameters were originated using Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model. The latter was adjusted to mimic a Qatar context, by detailing elements such as the technologies used for electricity and hydrogen production; while its outputs were used as one of the inputs of eqn (1) which represents the LCC's governing expression.

$$LCC = \frac{\frac{\left(PC_i - RV_{ij}\right)}{(1+r)^{j-1}} + \sum_{j=1}^{n}\left(\frac{FC_{ij} + MC_{ij} + EC_{ij} + WT_{ij}}{(1+r)^{j-1}}\right)}{n.ADT_i} \quad (1)$$

where:
PC = vehicle purchase cost;
RV = salvage price;
FC = fuel cost;
MC = maintenance and repair cost;
EC = environmental cost;
WT = water cost;
n = maximum service life;
ADT = annual distance travelled;
r = discount rate;
i = individual vehicle;
j = particular year of service.

To carry out calculations national and regional input sources were used such as WOQOD (national gasoline distribution company), the Middle East's hydrogen from natural gas production and distribution cost and Qatar's General Electricity and Water Corporation (Kahramaa) electricity prices. With this approach, blue hydrogen costs gradually decrease from 8.60 US$/kg in 2023 to 1.21 US$/kg in 2050, while electricity from natural gas power plants increase from 0.030 US$/kWh in 2023 to 0.11 US$/kWh in 2050. Regarding green fuel and electricity, these present the same trend, however, green H_2 cost decline from 8.73 to 1.23 US$/kg, while electricity cost from a centralized solar photovoltaic power plant rise from 0.049 to 0.068 US$/kWh [4]–[7].

Moreover, aiming to incentivise HFCVs, disincentivise the purchase of internal combustion engine vehicles (ICEVs) over 600 scenarios were built based on the application of potential policy instruments and their combinations (see Table 1).

3 RESULTS AND DISCUSSIONS

The results indicate that without applying any policy instrument, HFCVs present the highest LCC value, while conventional ICEVs yield the bet outcome (as reflected in Fig. 1).

Table 1: Policy Instruments and their values.

Instrument	Value
HFCV purchase incentive	0%, 5%, 10%, 20%
H_2 subsidy	0%, 40%, 60%, 80%
ICEV purchase tax	0%, 20%, 30%, 40%
Emission tax	0%, 10%, 20%, 30%

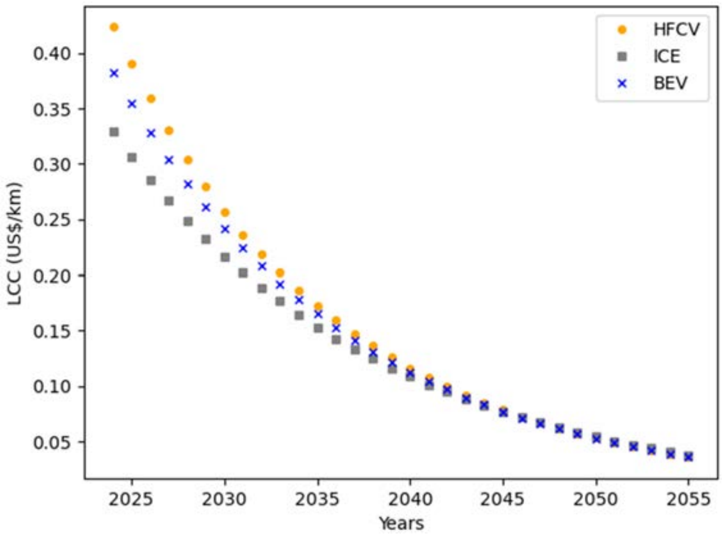

Figure 1: LCC comparison without incentives or taxes.

However, the gap between HFCVs and the other technologies decreases over time, gaining parity and eventually yielding a lower LCC value than EVs and ICEVs by 2046 and 2050, respectively.

One way to facilitate HFCV acceptance is to implement incentives that are associated with the purchase of these vehicles, its fuel (hydrogen) cost or both. Hence, Fig. 2 reflects how purchase price incentives present a higher impact than fuel subsidy; all of which decrease the gap between HFCVs and the other technologies accelerating the moment when its LCC value becomes the lowest.

Fig. 2(a) reflects how despite lowering HFCV's LCC, the most aggressive hydrogen subsidy approach is not as influential as purchase price incentives which generates a greater impact (see Fig. 2(b)).

To close the gap with ICEVs more quickly, HFCV-associated policy instruments can be merged. As reflected in Fig. 2(c), this approach has the potential to make this technology immediately more appealing than any the other analysed options.

Another approach is to disincentivise ICEV via a purchase tax. As shown in Fig. 3, this route increases ICEV's LCC, intensifying the sustainable technologies appeal. More specifically, while implementing the most aggressive tax, conventional cars' LCC is higher than EVs and the intersection with HFCVs is accelerated by over 10 years.

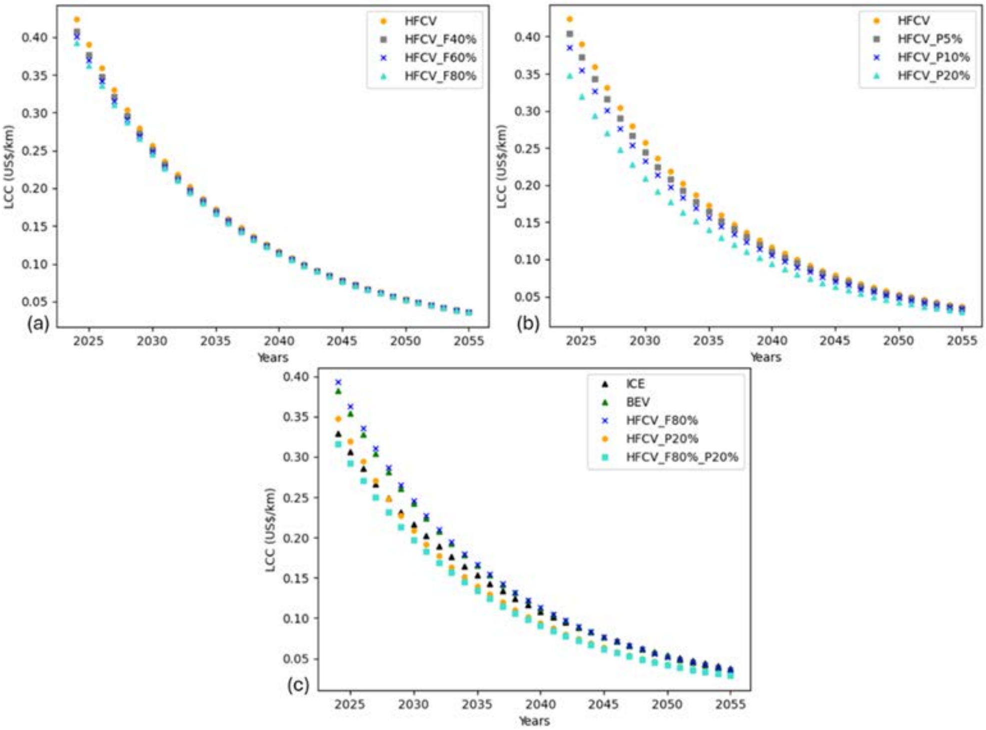

Figure 2: Incentives influence. (a) Fuel discount impact on HFCVs; (b) Purchase price incentive's impact on HFCVs; and (c) ICE and BEV vs HFCV with 80% fuel discount, 20% purchase price, and their combination.

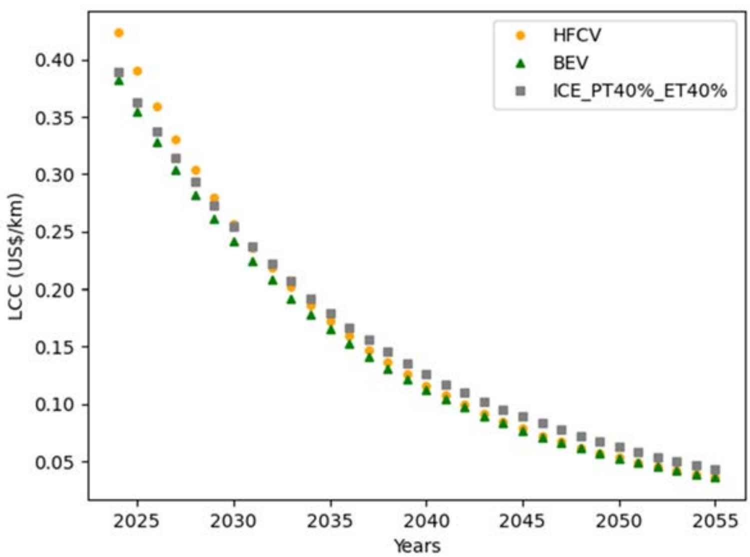

Figure 3: HFCV and BEV vs ICE with 40% purchase tax and 40% emission tax.

4 CONCLUSIONS

This study carries out an LCC comparison between electric, conventional, and hydrogen fuel cell vehicles and the influence that policy instruments may have on increasing the appeal of HFCVs. Before incentives, ICEVs presented the lowest LCC, followed by EVs; however, over time, HFCVs decreases the difference. Moreover, the implementation of incentives proved to be a viable option to increase the competitiveness of HFCVs, with the purchase price incentives more influential than hydrogen subsidy; more so, while merging the most aggressive of these approaches, HFCVs immediately yield the lowest LCC. Lastly, while disincentivising the use of ICEVs via a purchase tax, the gap with the alternative vehicles decreases, reaching a point where EV is the most appealing option, while HFCVs will yield a lower LCC value than ICEV over 10 years sooner.

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