# Economic Prospects of Hydrogen Fuel Cell Vehicles

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The economic implications of public transportation powered by hydrogen fuel cell has been investigated. Due to the long working period and the high number of daily driven kilometers, the public transportation sector, especially the taxis sector, is considered one of the leading contributors to the energy and environmental problems related to transportation sector. Therefore, there is an urgent need to investigate the expected implications and feasibility of using hydrogen fuel cell technology as a new alternative in taxi fleets.

Keywords: hydrogen-powered vehicles ; FCEVs ; hydrogen fuel cell vehicles

## 1. Introduction

The increasing global demand for energy is considered one of the most significant challenges of the 21st century, due to the increase in population and industrialization coupled with an increased dependence on transportation. During the period 2015–2030, the amount of energy consumed by the road transportation sector is expected to increase by as much as one third [1][2]. Currently, around 65% of the global energy demand is produced by fluid forms of fossil fuels [3]. Moreover, this amount is expected to increase up to 75% in 2050 [4][5], which could lead to significant environmental problems and natural resources depletion.

The road transport sector is considered one of the main carbon dioxide ($CO_2$) pollutant sources. In this sector, fossil fuels are burned by internal combustion engines (ICEs), which leads to a chemical reaction of hydrocarbons and oxygen and, as a result, greenhouse gas (GHG) emissions are produced. More specifically, the road transport sector is responsible for nearly a quarter of global $CO_2$ emissions. For example, in 2017, the transport sector was responsible for about 27% of the European Union's (EU) total GHG emissions [6][7].

In order to mitigate these energy and environmental problems, improving the efficiency of road transportation modes by using new eco-friendly technologies has become a very urgent issue. Hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), and hydrogen fuel cell vehicles (FCEVs) are emerging technologies that could provide solutions to reduce the dependency on fossil fuel-based energy [8][9].

Despite the fact that BEVs emit zero emissions onboard and have no tailpipe, since the electric energy (grid electricity) that is stored in the battery is converted into tractive force, emissions are still produced at power plants [10][11] in order to produce the required electricity for vehicle operation. Furthermore, fossil fuels are still the main source of electricity in the majority of countries around the world. Moreover, BEVs have a limited range due to the cost and size of batteries, in addition to their long refueling time that can take several hours. Therefore, FCEVs have been developed in order to address the drawbacks of BEVs.

Generally, FCEVs use a traction system that is operated by electrical energy engendered by a fuel cell and a battery working together, instead of relying only on a battery to provide the required energy. Therefore, the magnitude of the hydrogen fuel tank determines the amount of energy that can be delivered. Thus, the size of the battery has no bearing on the amount of energy that is available and as a result, the vehicle range can be extended [12]. Furthermore, refueling FCEVs does not take more than few minutes. Moreover, using an advanced energy management strategy (EMS) for FCEVs could effectively improve the fuel economy [13]. Furthermore, in recent years, the optimal control of FCEVs' energy management strategy (EMS) has been extensively researched because of the huge application prospect of hydrogen fuel cell vehicles in the field of new energy vehicles [14].

Despite the recent focus on fuel cell technology, it cannot be considered a new topic. The fuel cell was invented in 1839 by William Grove, and the first time fuel cell vehicles were under the spotlight was in 1970, due to the oil crisis at that time. Later on, in 2014, the first commercialized fuel cell vehicle was introduced by Toyota [15]. Recently, the hydrogen fuel cell has been developed to be used on EVs in order to recharge the battery with the electricity that is produced by a fuel cell using the hydrogen which is stored in a tank [16]. This process could extend the vehicles' range and reduce their refueling time, among other expected environmental and economic implications that are still under study, since these implications vary from region to region based on fuel prices, the availability of hydrogen fuel, sources of electricity and hydrogen fuel, and other factors.

Usually, the fuel cell device uses a proton membrane in order to convert the chemical energy that is stored in fuel molecular bonds into electricity. In this process, positive (anode) and negative (cathode) electrodes are separated by an electrolytic medium. In hydrogen fuel cells, this process produces water, heat, and electricity [17].

Currently, hydrogen is classified into three types based on the production method: Gray hydrogen, which refers to hydrogen that is produced from fossil fuels, such as coal and natural gas; blue hydrogen, which is produced from fossil fuels, but with an additional process called carbon capture and storage (CCS) in order to reduce the associated $CO_2$ emissions; and green hydrogen, which is produced through a process called electrolysis by using different renewable energy sources, such as wind and solar energy [18].

Due to the long working period and the high number of daily driven kilometers, the public transportation sector, especially the taxis sector, is considered one of the leading contributors to the energy and environmental problems related to transportation sector. Therefore, there is an urgent need to investigate the expected implications and feasibility of using hydrogen fuel cell technology as a new alternative in taxi fleets.

## 2. Economic Prospects of Hydrogen Fuel Cell Vehicles

Since 2014, when the first commercialized hydrogen fuel cell vehicle was introduced, numerous studies have been conducted in order to investigate the applicability and the impacts of using FCEVs as a road transportation mode. The majority of these studies have been conducted in the United States, Europe, Japan, China, and Korea.

Focusing on the environmental impacts, a study by Dulau [19] was conducted in order to determine the expected $CO_2$ emissions of BEVs and FCEVs. The study considered different values for the mix of power generation and hydrogen production methods. The results of the study showed that the $CO_2$ emissions of FCEVs are lower than those of BEVs in cases in which the hydrogen is obtained from renewable energy sources or nuclear power. Similarly, another study was conducted by Usai et al. [20] in order to assess the life cycle of fuel cell systems for FCEVs based on different impact categories such as tank, catalyst, and fuel cell auxiliaries. Moreover, an assessment was performed for prospective technological development in order to determine the future impacts of these systems. The study concluded that there could be a potential reduction in the environmental footprint ranging from 25% to 70%. Likewise, a study by Lubecki et al. [21] was conducted in order to assess the environmental life cycle of diesel, electric, and hydrogen fuel buses. In this study, an environmental model was developed based on the life cycle assessment method, in order to test the impact of energy consumption during bus driving. Moreover, energy sources such as solar, wind, and grid electricity were investigated. The study showed that replacing conventional bus fleets with electrical and hydrogen-powered ones could provide significant environmental benefits, especially in terms of mitigating global warming. In the Maghreb countries, a study was conducted by Hafdaoui et al. [22] in order to evaluate the energy and environmental impacts of alternative fuel vehicles in Morocco, Algeria, and Tunisia. The study used the international standard in order to assess hybrid, electric, diesel, and FCEVs and to determine the expected benefits of transitioning to electric and FCEVs. The study concluded that the FCEVs are the best alternative for Morocco and Algeria, whereas electric vehicles are preferable in Tunisia. In the United States, a study was conducted by Iyer et al. [23] in order to analyze the life cycle of heavy-duty and medium-duty trucks. The study compared the impacts of class 6 and class 8 trucks' manufacturing cycles, which are powered by electric, diesel, hybrid, and fuel cell. The study concluded that the transition from diesel powertrain to fuel cell and electric powertrains caused an increase in vehicle-cycle GHG emissions.

In China, a study by Lan et al. [24] was conducted in order to determine the hydrogen consumption of FCEVs. The study evaluated actual hydrogen consumption based on the flowmeter and short-cut method, and by using the China light-duty vehicle test cycle and the new European driving cycle. The study concluded that compared with the run-out method, the short-cut method could save at least 50 percent of the test time. Moreover, the error of the short-cut method was less than 0.1% under new European driving cycle conditions, whereas the error in the China light-duty vehicle test cycle was 8.12%. Another study by Ferrara et al. [25] investigated the energy management and cost-optimal design of fuel cell electric trucks. Factors such as driving cycle, vehicle weight, powertrain, market prices, and component degradation have been considered. The study indicated that the total ownership cost is significantly influenced by market prices, component sizing, vehicle weight, and driving cycle. Moreover, predictive energy management is highly beneficial for challenging road topographies.

A study was conducted by Bethoux [26] in order to understand the FCEVs' assets, challenges, and current situation. The results of this study have concluded that FCEVs can contribute to the zero-emission vehicle trend. The main opportunity of FCEVs is the design versatility and the efficiency of fuel cell modules and the required hydrogen tanks. Moreover, delivery vehicles, long-distance heavy-duty vehicles, and fleets of taxis could be developed over the next few decades due to FCEVs' extended range and other factors. Focusing on consumers' preferences for FCEVs in Shanghai, China, a study was conducted by Yanan et al. [27]. Likewise, by using a choice experiment, the study investigated the factors that could affect consumers' preference for choosing FCEVs. Moreover, a conditional logit model was developed to estimate the attribute parameters. The study indicated that with an appropriate borrowing system or instalment payment plans over a period of 5 years, consumers could afford to purchase an FCEV. Therefore, the study recommended that the Chinese government promote a green loan program for purchasing FCEVs. In order to investigate the roadmap of the FCEVs industry in various countries, such as Japan, the United States, and Europe, a study by Yunzhe et al. [28] was conducted. In this study, the development of FCEVs and the hydrogen energy industry in the subject countries were quantified and compared to the development plans in China. The study concluded that China should increase its investment in research related to advanced technology in hydrogen energy production, transportation, storage, and refueling infrastructures.

The majority of the previous studies about FCEVs have addressed this topic based on the environmental and GHG emissions prospects only. Moreover, numerous studies have focused their analysis on heavy vehicles such as buses and trucks without considering public transportations modes such as taxis. Therefore, it is necessary to conduct a comprehensive study in order to investigate the applicability and implications of using hydrogen fuel cell technology in taxi fleets.

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