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Economic Prospects of Taxis Powered by Hydrogen Fuel Cells in Palestine

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Abstract: Recently, major problems related to fuel consumption and greenhouse gas (GHG) emissions have arisen in the transportation sector. Therefore, developing transportation modes powered by alternative fuels has become one of the main targets for car manufacturers and governments around the world. This study aimed to investigate the economic prospects of using hydrogen fuel cell technology in taxi fleets in Westbank. For this purpose, a model that could predict the number of taxis was developed, and the expected economic implications of using hydrogen fuel cell technology in taxi fleets were determined based on the expected future fuel consumption and future fuel cost. After analysis of the results, it was concluded that a slight annual increase in the number of taxis in Palestine is expected in the future, due to the government restrictions on issuing new taxi permits in order to get this sector organized. Furthermore, using hydrogen fuel cells in taxi fleets is expected to become more and more feasible over time due to the expected future increase in oil price and the expected significant reduction in hydrogen cost as a result of the new technologies that are expected to be used in the production and handling of hydrogen.

Keywords: penetration and fuel cost prediction; hydrogen fuel cell vehicles; sustainable transportation; sustainable taxis; Palestine; hydrogen-powered vehicles; FCEVs

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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. In this study, the expected future energy and the economic implications of using this technology in taxi fleets in Westbank, Palestine, have been determined.

2. Literature Review

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. In this study, the expected energy and the economic implications of using hydrogen fuel cell-powered taxi fleets in Palestine have been determined, during the future and up to 2050. This study could be helpful for decision makers and transportation planners setting future transportation policies and programs in the absence of such studies that address this emerging topic in Palestine.

3. Data and Methodology

In order to conduct this study, a large amount of data were acquired from several sources. These data included the annual number of registered taxis in Westbank, Palestine, for a 20 year-period (2002–2021), the average distance (in kilometers) traveled by taxis annually, the average fuel consumption rate of taxis, the average diesel and hydrogen fuel prices in 2021, and the predicted prices of diesel and hydrogen fuels in 2030 and 2050.

3.1. Prediction Model

A prediction model was developed using the annual number of registered taxis for 20-year period of 2002–2021. In countries with unsteady socioeconomic development or ineffective transportation polices over the past few decades, as is the case in Palestine, a sample size of 15 years or more can be used, and the developed prediction model will yield reasonably accurate results [29,30]. The Exponential Smoothing Method was used in order to develop the prediction model, which was used to determine the expected number of taxis in 2030 and 2050.

Exponential Smoothing is a statistical method used in time series in order to exponentially smooth the data over a period of time by assigning either exponentially decreasing or increasing weight to the values in the series. In this method, the predicted values are affected greatly by the recent time series data. Exponential Smoothing methods are mainly divided into three categories: Winters' Exponential Smoothing, Holt's Exponential Smoothing, and Simple Exponential smoothing. If the data have no trend or seasonal patterns, Simple Exponential Smoothing Method is appropriate; if the data exhibit a linear trend, Holt's Exponential Smoothing is appropriate; and if the data are seasonal, Winters' Exponential Smoothing is appropriate. Therefore, Holt's method was used in this study, as illustrated in Equation (1) [31,32].

$$\begin{aligned} F_{t+m} &= s_t + m b_t \\ s_t &= \alpha x_t + (1-\alpha)(s_{t-1} + b_{t-1}) \\ b_t &= \beta(s_t - s_{t-1}) + (1-\beta) b_{t-1} \end{aligned} \quad (1)$$

where s_t is the smoothed value for year t, F is an estimate of the x value at time t + m; m is a value greater than 0; b_t is the best estimated trend at specific time t; α is the smoothing factor, where α is between 0 and 1; β is the trend factor, where β is between 0 and 1; and x_t is the data sequence.

3.2. Energy and Economic Implications

Based on the average annual traveled kilometers for taxis in Palestine and the average diesel fuel consumption rate (Km/L) for taxis, the total annual diesel fuel consumption per taxi was determined. Next, using the average diesel fuel price in 2021 and the expected price for 2030 and 2050, the average annual diesel fuel cost per taxi was determined for 2021, 2030, and 2050.

Likewise, based on the average annual traveled kilometers for taxis in Palestine and the average hydrogen fuel consumption rate (Km/Kg) for hydrogen fuel cell taxis, the total annual hydrogen fuel consumption per taxi was determined. Next, using the average hydrogen fuel price in 2021 and the expected price for 2030 and 2050, the average annual hydrogen fuel cost per taxi was determined for 2021, 2030, and 2050, as illustrated in Figure 1.

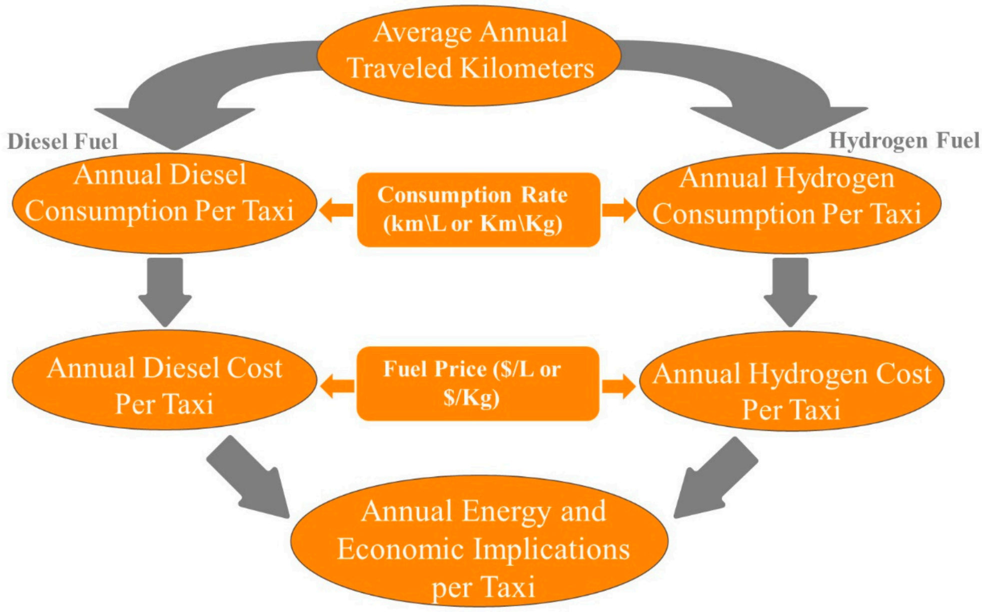

Figure 1. Applied methodology for determining the annual expected implications per taxi.

Using the annual number of registered taxis in 2021, the total annual diesel fuel consumption per taxi, and the average annual diesel fuel cost per taxi in 2021, the total annual diesel consumption for all taxis was determined.

Similarly, using the predicted number of taxis in 2030 and 2050 (using the developed prediction model), the predicted total diesel and hydrogen fuel consumption and the predicted total fuel cost for all taxis were determined for 2030 and 2050. As illustrated in Figure 2, in order to determine these values, different scenarios for 2030 and 2050 were envisioned by considering 10%, 30%, 50%, 70%, and 100% hydrogen fuel cell taxis penetration. These different percentages have been assumed to give an indication about the minimum percentage that could lead to a significant implication.

It is worth noting that the future number of taxis was predicted based on the historical data for the period 2002–2021, which were affected by governmental polices during that period of time, and therefore this prediction could require an adjustment in case of applying any new governmental polices. Additionally, the future diesel and hydrogen prices used are based on the global prediction reports, and these prices could be changed in the event of any future economic crisis or development of new fuel and hydrogen production methods, such as extracting white hydrogen from natural deposits, which is still under study and could significantly affect the future price of hydrogen.

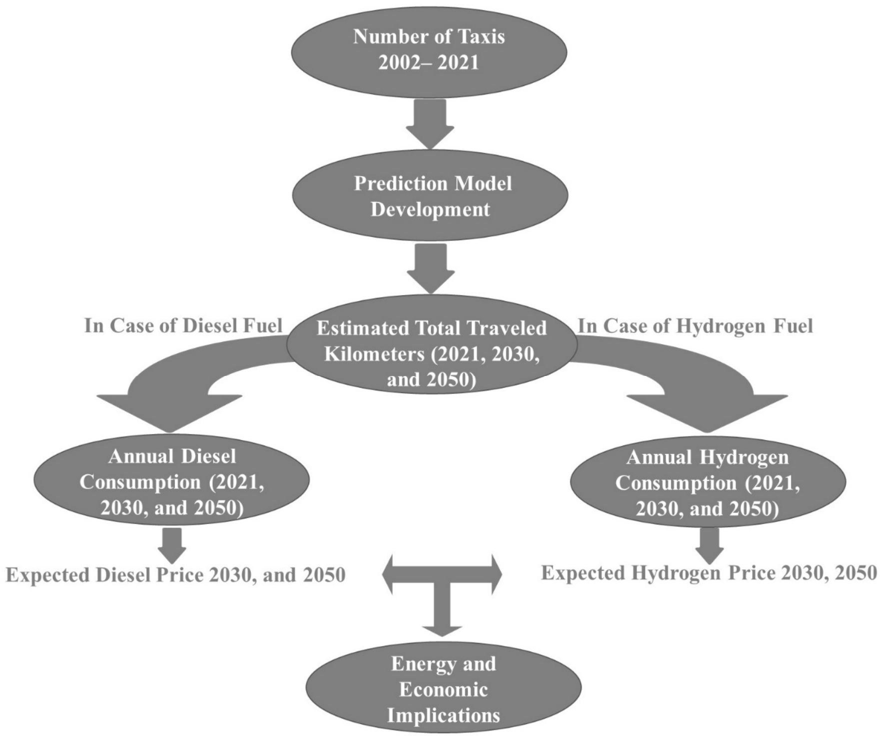

Figure 2. Applied methodology for determining the expected implications for total number of taxis in 2021, 2030, 2050.

4. Data Analysis and Discussion

In this study, the historical annual number of registered taxis in Westbank, Palestine, for the period 2002–2021 was analyzed and used to develop a prediction model in order to predict the expected number of taxis in 2030 and 2050. Next, the expected average annual fuel consumption and the fuel cost per taxi for diesel and hydrogen fuel cell taxis were determined. After that, the expected total fuel consumption and fuel costs for all taxis in 2030 and 2050 were determined by using different assumptions (10%, 30%, 50%, 70%, and 100% hydrogen fuel cell taxis penetration). Finally, based on each of these assumptions, the expected energy and cost implications were determined.

4.1. Prediction Model Development

In order to determine the expected number of taxis in 2030 and 2050, a prediction model was developed based on the annual registered taxis record for the period 2002–2021, which was acquired from the Palestinian Central Bureau of Statistics [33]. By using Statistical Package for the Social Sciences (SPSS) the best-fit Holt's Exponential Smoothing prediction model was developed, as illustrated in Figure 3.

Based on the model fit statistics of the developed model, which are illustrated in Table 1, the values of R-Squared, which is a measure of how a model fits a dataset, and the Mean Absolute Percentage Error (MAPE), which measures the average magnitude of error produced by the model, are 0.969 and 2.337, respectively. More specifically, these values indicate that the forecast is acceptably accurate (R-Squared greater than 90% indicates a good-fit model and an MAPE value less than 5% is considered an indication that the forecast is acceptably accurate). Therefore, the developed model can be used without reservation.

In order to predict the number of taxis in 2030 and 2050, the developed model was applied and the expected number of taxis for the subject years have been determined. More specifically, the expected numbers of taxis in 2030 and 2050 are 11,070 and 13,504, respectively.

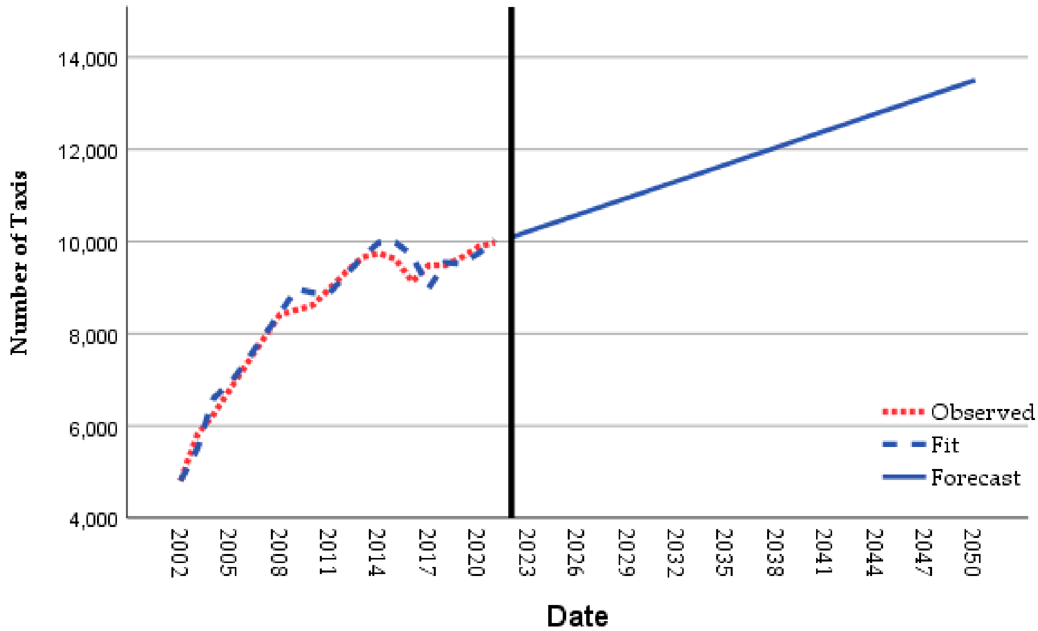

Figure 3. Observed, fit, and forecast values for developed prediction model.

Table 1. Taxis prediction model parameters and statistics.

Model	Model Fit Statistics		
	R-Squared	**MAE**	**MAPE**
Holt's Model	0.969	194.352	2.337
Prediction Model Parameters			
Parameters	Estimate	SE	t
Alpha (Level)	1.0	0.217	4.612
Beta (Trend)	0.4	0.232	1.728

4.2. Energy and Economic Implications

Based on the average annual traveled kilometers of taxis in Palestine (73,300 km per taxi) [34] and the average diesel consumption rate of 9.9 (L\100 Km) (8], the annual diesel consumption of a diesel taxi in 2021 was determined (7256.7 L). Next, by using the average diesel price in 2021 (1.55 USD\L) [35], the annual total diesel cost per taxi was determined, as shown in Table 2.

Table 2. Annual fuel consumption and fuel cost per taxi.

Type of Fuel	Annual Traveled Kilometers per Taxi (Km)	Average Consumption Rate (L or Kg/100 Km)	Annual Fuel Consumption (L or Kg)	Fuel Price (USD\Kg or L)	Annual Fuel Cost per Taxi (USD)
Diesel	73,300	9.900	7256.7	1.55	11,247.89
Hydrogen Fuel Cell	73,300	0.876	642.1	7.78	4995.54

Likewise, based on the average annual traveled kilometers by taxis in Palestine (73,300 km per taxi) [34] and the average hydrogen consumption rate of 0.876 (Kg\100 Km), the annual hydrogen consumption of a hydrogen fuel cell taxi in 2021 was determined (642.1 Kg). Next, using the average hydrogen price in 2021 (7.78 USD\Kg) [36], the annual total hydrogen cost per taxi was determined, as shown in Table 2. It is worth mentioning that the hydrogen consumption rate that was used in this study is the average of three values: the actual average consumption rate of hydrogen fuel passenger cars tested in China [37], a comprehensive study conducted by Zemo [38], and the consumption rate of the Hyundai Nexo passenger car [39], which is very popular in this category.

In order to determine the expected total fuel cost in 2030, different scenarios have been proposed using 10%, 30%, 50%, 70%, and 100% hydrogen fuel cell taxi penetration. Moreover, the expected fuel consumption rate and fuel price were determined. First, by assuming that the fuel efficiency rate increases by 15% every 10 years, based on a study conducted in Palestine by [8], the hydrogen and diesel consumption rates were determined. Next, the diesel price was determined based on a study by [40], which indicated that will be 3% decrease in the global fuel price compared to that in 2021. On the other hand, the expected hydrogen price for 2030 is USD 5.25 [36], as shown in Table 3.

Table 3. Expected total fuel price in 2030.

Type of Fuel	Total Number of Taxis	Fuel Price (USD\Kg or L)	Fuel Consumption Rate (L or Kg\100 Km)	Total Fuel Cost (Million USD)					
				0% FCEVs	10% FCEVs	30% FCEVs	50% FCEVs	70% FCEVs	100% FCEVs
Diesel	11,070	1.504	8.415	102.696	92.426	71.887	51.348	30.809	0
Hydrogen Fuel Cell		5.250	0.745	0	3.174	9.521	15.869	22.216	31.737
		Total		102.696	95.6	81.408	67.217	53.025	31.025

Similarly, in order to determine the expected total fuel cost in 2050, different scenarios have been proposed using 10%, 30%, 50%, 70%, and 100% hydrogen fuel cell taxi penetration. Moreover, the expected fuel consumption rate and fuel price have been determined. First, by assuming that the fuel efficiency rate increases by 15% every 10 years, based on a study conducted in Palestine by [8], the hydrogen and the diesel consumption rates were determined. Next, the diesel price was determined based on a study by [41], which indicated that there will be an 13.9% increase in the global fuel price compared to that in 2030. On the other hand, the expected hydrogen price for 2050 is USD 1.93 [42], as shown in Table 4.

Table 4. Expected total fuel price in 2050.

Type of Fuel	Total Number of Taxis	Fuel Price (USD\Kg or L)	Annual Fuel Consumption (L or Kg)	Total Fuel Cost (Million USD)					
				0% FCEVs	10% FCEVs	30% FCEVs	50% FCEVs	70% FCEVs	100% FCEVs
Diesel	13,504	1.713	6.135	104.025	93.623	72.818	52.013	31.208	0
Hydrogen Fuel Cell		1.930	0.538	0	1.028	3.083	5.139	7.195	10.278
		Total		104.025	94.651	75.901	57.152	38.403	10.278

As a result, the study showed that the total annual fuel cost of a taxi in Palestine can be reduced by up to 55.59% by using hydrogen fuel cell technology instead of the conventional diesel internal combustion engine vehicles, which form a significant part of taxi fleets. Moreover, in 2030, based on the expected number of vehicles, fuel consumption, and fuel price, the penetration of hydrogen fuel cell taxis by 10%, 30%, 50%, 70%, and 100% could lead to reductions in the total fuel cost by 6.91%, 20.73%, 34.55%, 48.37%, and 69.79%, respectively, whereas, in 2050, based on the expected number of vehicles, fuel consumption, and fuel price, the penetration of hydrogen fuel cell taxis by 10%, 30%, 50%, 70%, and 100% could lead to reductions in the total fuel cost of 9.01%, 27.04%, 45.06, 63.08, and 90.12% respectively.

Comparing the predicted total annual fuel cost of 2030 and 2050 revealed a significant fuel cost reduction in 2050 compared to 2030 as a result of using hydrogen fuel cell taxis.

For example, in case of 100% penetration of hydrogen fuel cell taxis, the expected reduction in 2030 is 69.79%, while the expected reduction in 2050 is 90.12%. This significant difference is attributed to the expected increase in oil prices due to the increasing demand and to the expected decrease in hydrogen production and handling cost resulting from the implementation of new technologies.

It is worth noting that the results of this study could be helpful for creating a roadmap for future policies and long-term strategies in order to create a more sustainable transportation system in Palestine, since the technology of FCEVs has not been used yet in Palestine due to the absence of clear and relevant governmental policies, the restrictions on imported vehicles in light of the Israeli occupation, and other socio-economic factors, while other countries and continents, such as the United States, Korea, Japan, and Europe, have come a long way in the past few years.

5. Conclusions

Using hydrogen fuel cell technology in transportations modes is considered an emerging issue, and the feasibility of using this technology in transportation systems varies among regions around the world based on different economic and environmental factors such as hydrogen sources, hydrogen production, and fuel costs in these regions. In this study, a prediction model for number of taxis in Westbank, Palestine, was developed, and the expected future economic implications of using hydrogen fuel cell technology in taxi fleets have been determined based on the future fuel consumption and fuel cost. After analyzing the results, the following findings can be offered:

- It is expected that there will be a slight annual future increase in the number of registered taxis in Palestine (from 9974 in 2021 to 11,070 in 2030 in Westbank), and this is attributed to the government restrictions on issuing new taxi permits in order to get this sector organized.
- In 2030, the penetration of hydrogen fuel cell taxis by 10%, 30%, 50%, 70%, and 100% could lead to reductions in the annual total fuel cost by 6.91%, 20.73%, 34.55%, 48.37%, and 69.79%, respectively, whereas in 2050, the penetration of hydrogen fuel cell taxis by 10%, 30%, 50%, 70%, and 100% could lead to reductions in the total fuel cost by 9.01%, 27.04%, 45.06, 63.08, and 90.12% respectively.
- Over time, using hydrogen fuel cell in taxi fleets becomes more and more feasible due to the expected future increase in oil prices (from 1.550 USD/L in 2021 to 1.713 USD/L in 2050) and the expected significant reduction in hydrogen cost (from 7.78 USD\Kg in 2021 to 1.93 in 2050) due to the new technologies that are expected to be used in the production and handling of hydrogen.
- In 2030, hydrogen fuel cell taxis penetration of 30% or more could lead to a significant economic benefit. More specifically, the expected reduction in total fuel cost by taxis in case of 30% penetration is 20.73%, whereas, in 2050, hydrogen fuel cell taxis penetration by 10% or more could lead to a significant economic benefit.
- It is recommended to consider the ownership cost of the taxis in any future comprehensive study, since this issue has not been addressed in this study due to the absence of data related to the expected hydrogen fuel vehicle price in Palestine, which depends mainly on future tax policies. Moreover, it is essential to assess the future environmental impacts of using hydrogen fuel cell technology in future works.

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References

1. IEA. *Technology Roadmap-Fuel Economy of Road Vehicles*; IEA: Paris, France, 2012.
2. Kosai, S.; Matsui, K.; Matsubae, K.; Yamasue, E.; Nagasaka, T. Natural resource use of gasoline, hybrid, electric and fuel cell vehicles considering land disturbances. *Resour. Conserv. Recycl.* **2021**, *166*, 105256. [CrossRef]
3. Hosseini, S.E.; Butler, B. An overview of development and challenges in hydrogen powered vehicles. *Int. J. Green Energy* **2019**, *17*, 13–37. [CrossRef]
4. Eriksson, E.L.V.; Gray, E.M.A. Optimization and integration of hybrid renewable energy hydrogen fuel cell energy systems–A critical review. *Appl. Energy* **2017**, *202*, 348–364. [CrossRef]
5. Manoharan, Y.; Hosseini, S.E.; Butler, B.; Alzhahrani, H.; Senior, B.T.F.; Ashuri, T.; Krohn, J. Hydrogen Fuel Cell Vehicles; Current Status and Future Prospect. *Appl. Sci.* **2019**, *9*, 2296. [CrossRef]
6. Tsakalidis, A.; Krause, J.; Julea, A.; Peduzzi, E.; Pisoni, E.; Thiel, C. Electric light commercial vehicles: Are they the sleeping giant of electromobility? *Transp. Res. D Transp. Environ.* **2020**, *86*, 102421. [CrossRef]
7. Hassouna, F.M.A. Urban Freight Transport Electrification in Westbank, Palestine: Environmental and Economic Benefits. *Energies* **2022**, *15*, 4058. [CrossRef]
8. Hassouna, F.M.A.; Assad, M. Towards a Sustainable Public Transportation: Replacing the Conventional Taxis by a Hybrid Taxi Fleet in the West Bank, Palestine. *Int. J. Environ. Res. Public Health* **2020**, *17*, 8940. [CrossRef] [PubMed]
9. Baptista, P.; Ribau, J.; Bravo, J.; Silva, C.; Adcock, P.; Kells, A. Fuel cell hybrid taxi life cycle analysis. *Energy Policy* **2011**, *39*, 4683–4691. [CrossRef]
10. Hassouna, F.M.A.; Al-Sahili, K. Future Energy and Environmental Implications of Electric Vehicles in Palestine. *Sustainability* **2020**, *12*, 5515. [CrossRef]
11. Feng, Y.; Yang, J.; Dong, Z. Fuel Selections for Electrified Vehicles: A Well-to-Wheel Analysis. *World Electr. Veh. J.* **2021**, *12*, 151. [CrossRef]
12. Waseem, M.; Amir, M.; Lakshmi, G.S.; Harivardhagini, S.; Ahmad, M. Fuel Cell-Based Hybrid Electric Vehicles: An Integrated Review of Current Status, Key Challenges, Recommended Policies, and Future Prospects. *Green Energy Intell. Transp.* **2023**, *2*, 100121. [CrossRef]
13. Jia, C.; Zhou, J.; He, H.; Li, J.; Wei, Z.; Li, K. Health-conscious deep reinforcement learning energy management for fuel cell buses integrating environmental and look-ahead road information. *Energy* **2024**, *290*, 130146. [CrossRef]
14. Jia, C.; He, H.; Zhou, J.; Li, J.; Wei, Z.; Li, K. Learning-based model predictive energy management for fuel cell hybrid electric bus with health-aware control. *Appl. Energy* **2024**, *355*, 122228. [CrossRef]
15. Deloitte and Ballard. In *Fueling the Future of Mobility Hydrogen and Fuel Cell Solutions for Transportation*; Deloitte: Shanghai, China, 2020.
16. Dash, S.K.; Chakraborty, S.; Roccotelli, M.; Sahu, U.K. Hydrogen Fuel for Future Mobility: Challenges and Future Aspects. *Sustainability* **2022**, *14*, 8285. [CrossRef]
17. Wong, E.Y.C.; Ho, D.C.K.; So, S.; Tsang, C.-W.; Chan, E.M.H. Life Cycle Assessment of Electric Vehicles and Hydrogen Fuel Cell Vehicles Using the GREET Model—A Comparative Study. *Sustainability* **2021**, *13*, 4872. [CrossRef]
18. Albatayneh, A.; Juaidi, A.; Jaradat, M.; Manzano-Agugliaro, F. Future of Electric and Hydrogen Cars and Trucks: An Overview. *Energies* **2023**, *16*, 3230. [CrossRef]
19. Dulău, L.-I. CO_2 Emissions of Battery Electric Vehicles and Hydrogen Fuel Cell Vehicles. *Clean Technol.* **2023**, *5*, 696–712. [CrossRef]
20. Usai, L.; Hung, C.R.; Vásquez, F.; Windsheimer, M.; Burheim, O.S.; Strømman, A.H. Life cycle assessment of fuel cell systems for light duty vehicles, current state-of-the-art and future impacts. *J. Clean. Prod.* **2021**, *280*, 125086. [CrossRef]
21. Lubecki, A.; Szczurowski, J.; Zarębska, K. A comparative environmental Life Cycle Assessment study of hydrogen fuel, electricity and diesel fuel for public buses. *Appl. Energy* **2023**, *350*, 121766. [CrossRef]
22. El Hafdaoui, H.; Jelti, F.; Khallaayoun, A.; Jamil, A.; Ouazzani, K. Energy and environmental evaluation of alternative fuel vehicles in Maghreb countries. *Innov. Green Dev.* **2024**, *3*, 100092. [CrossRef]
23. Iyer, R.K.; Kelly, J.C.; Elgowainy, A. Vehicle-cycle and life-cycle analysis of medium-duty and heavy-duty trucks in the United States. *Sci. Total. Environ.* **2023**, *891*, 164093. [CrossRef]
24. Lan, H.; Wang, X.; Hao, W.; Hao, D.; He, Y.; Xu, N. Research on the hydrogen consumption of fuel cell electric vehicles based on the flowmeter and short-cut method. *Energy Rep.* **2022**, *8*, 40–50. [CrossRef]
25. Ferrara, A.; Jakubek, S.; Hametner, C. Cost-optimal design and energy management of fuel cell electric trucks. *Int. J. Hydrogen Energy* **2023**, *48*, 16420–16434. [CrossRef]
26. Bethoux, O. Hydrogen Fuel Cell Road Vehicles: State of the Art and Perspectives. *Energies* **2020**, *13*, 5843. [CrossRef]
27. Yanan, H.; Dmitriy, L.; Hwan, B.J. Analysis of Consumers' Preferences for hydrogen Fuel cell Vehicles in Shanghai by using a choice experiment. *Korea Energy Econ. Rev.* **2023**, *22*, 429–448.
28. Yunzhe, J.; Bowei, Z.; Feifei, W.; Mengmeng, L. Research on Hydrogen Energy and Fuel Cell Vehicle Roadmap in Various Countries. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *512*, 012136. [CrossRef]
29. Hassouna, F.M.A.; Al-Sahili, K. Practical Minimum Sample Size for Road Crash Time-Series Prediction Models. *Adv. Civ. Eng.* **2020**, *2020*, 6672612. [CrossRef]

30. Hassouna, F.M.; Pringle, I. Analysis and Prediction of Crash Fatalities in Australia. *Open Transp. J.* **2019**, *13*, 134–140. [CrossRef]
31. Hassouna, F.M.A. Sustainability assessment of public bus transportation sector in westbank, palestine. *Environ. Res. Commun.* **2023**, *5*, 015001. [CrossRef]
32. Makridakis, S.; Wheelwright, S.C.; Hyndman, R.J. *Forecasting Methods and Applications*, 3rd ed.; Wiley: New Delhi, India, 2008.
33. Palestinian Central Bureau of Statistics. *Transport Sector Statistics*; Palestinian Central Bureau of Statistics: Ramallah, Palestine, 2021.
34. Karaeen, M.; Akel Hasan, A.; Abu Hanieh, A.; Zorba, M.; Abuhomos, M. On-Road Vehicular Emissions Case of Palestine. In Proceedings of the 2021 12th International Renewable Engineering Conference (IREC), Amman, Jordan, 14–15 April 2021; pp. 1–6.
35. The Fuel Price. The Fuel Price Database. Fuel Prices in Palestine. 2021. Available online: https://www.thefuelprice.com/Fps/en (accessed on 29 November 2023).
36. Szałek, A.; Pielecha, I.; Cieslik, W. Fuel Cell Electric Vehicle (FCEV) Energy Flow Analysis in Real Driving Conditions (RDC). *Energies* **2021**, *14*, 5018. [CrossRef]
37. Duan, Z.; Mei, N.; Feng, L.; Yu, S.; Jiang, Z.; Chen, D.; Xu, X.; Hong, J. Research on Hydrogen Consumption and Driving Range of Hydrogen Fuel Cell Vehicle under the CLTC-P Condition. *World Electr. Veh. J.* **2021**, *13*, 9. [CrossRef]
38. Zemo Partnership. *Hydrogen Vehicle Well-to-Wheel GHG and Energy Study*; Zemo Partnership: London, UK, 2021.
39. H2 Live. Hydrogen Vehicles All Models at a Glance. 2023. Available online: https://h2.live/en/fcev/ (accessed on 11 December 2023).
40. World Bank. *Commodities Price Forecast*; World Bank: Washington, DC, USA, 2021.
41. Amadeo, K. *Oil Price Forecast 2023–2050*; The Balance: New York, NY, USA, 2023.
42. Zhou, Y.; Searle, S. *Cost of Renewable Hydrogen Produced Onsite at Hydrogen Refueling Stations in Europe*; Washington, DC, USA, 2022.