

Article

Environmental Impact Assessment of the Transportation Sector and Hybrid Vehicle Implications in Palestine

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Abstract: During the last two decades, the development of sustainable transportation systems has been highlighted as a key element in solving environmental problems related to climate change and impacts on greenhouse gases. Globally, the transportation sector has become one of the main contributors to these environmental problems. Thus, the environmental impact assessment of this sector and the implications of new vehicle technologies have begun to be considered as first steps for any long-term future strategies in this sector. In Palestine, the lack of environmental data related to the transportation sector and the absence of studies that address the new vehicle technologies (such as hybrid vehicles) and their future implications make it difficult to set up any future strategies or plans. In this study, the current and the future environmental impacts of the transportation sector have been assessed, and the future implications of hybrid vehicles have been determined. The gross domestic product (GDP), population, and the number of vehicles for the period 1994–2018 have been used to develop an auto regressive integrated moving average (ARIMA) prediction model for the future number of vehicles. Then, the total traveled kilometers and the total consumed fuels (by diesel and gasoline vehicles) have been predicted. After that, the current and future (2020 and 2030) greenhouse gas (GHG) emissions, including CO₂, N₂O, and CH₄, have been estimated. Finally, the future implications of hybrid vehicles, based on two scenarios (10% and 20% hybrid vehicles) have been estimated. The results have showed that the estimated CO₂, N₂O, and CH₄ emissions from the transportation sector in 2020 are 4,842,164.5, 213.8, and 445.8 tons, which are very high, and even much higher than the total national emissions of 2014 (the only officially available data). Moreover, in 2030, replacing 20% of internal combustion engine vehicles (ICEVs) by hybrid vehicles would lead to 4.66% and 13.31% reductions in CO₂ and N₂O, respectively, as compared to 100% ICEVs, while the CH₄ emissions will increase. However, the overall CO₂-equivalent will decrease by 5%; therefore, a more sustainable transport system will be achieved.

Keywords: ARIMA; sustainable transportation; environmental impacts; Palestine emissions; impact assessment; prediction model; hybrid vehicles

1. Introduction

During the last two decades, the increasing awareness towards economic and environmental concerns related to fuel combustion by the transportation sector has led to increase the focus towards the development of sustainable transportation systems. The transportation sector is one of the highest consumers of fossil fuels and one of the main contributors to greenhouse gas (GHG) emissions. About 17% of all the consumed hydrocarbon fuel and 23% of all the carbon dioxide (CO₂) emissions into the atmosphere are accounted for by vehicles [1].

Recently, several sustainable techniques have been used in order to relieve the environmental impacts of the transportation sector. Electric vehicles (EVs) and hybrid vehicles are two of the main techniques that are used widely for this purpose. However, both techniques are used effectively in

order to reduce energy and GHG emissions. It is recommended that EVs could be promoted in the regions with higher proportions of hydropower and clean energy, while hybrid vehicles could be widely adopted in the regions with high fossil fuel-based energy [2]. Moreover, other factors such as topography and weather play a key role in choosing the most appropriate technique for each region.

Hybrid vehicles have been designed in order to overcome the disadvantages of both internal combustion engine vehicles (ICEVs) and EVs. Hybrid vehicles combine the conventional internal combustion engine (ICE) mechanical drivetrain with a motor propelled electric one. The electric power of the motor in a hybrid vehicle is usually provided by a battery. The presence of an electric motor allows optimized operations of the engine in its maximum efficiency region, thus, providing higher fuel efficiency than ICEVs. The use of the ICE to charge the battery allows a much more extended driving range than EVs [3].

Four main driving modes are available in hybrid vehicles in order to increase fuel efficiency and to reduce GHG emissions: (1) electric driving mode, (2) hybrid mode, (3) hold mode, and (4) charging mode [4].

In Palestine, vehicles are the main element in the transportation sector since there are still no airports, railways, or subways due to unstable political and economic conditions. Due to the high portion of coal and fossil fuel-based electricity, which is more than 63% of the total source of electricity [5], using EVs would not lead to a high reduction in GHG emissions. Furthermore, the mountainous topography and the weather conditions of this country reduce the driving range and the reliability of EVs. Thus, hybrid vehicles seem to be the most appropriate alternative to conventional ICEVs in order to reduce the energy consumption and GHG emissions. Moreover, the absence of EV electricity charging infrastructure and the instability of the electricity grid loads are other positive attributes for hybrid vehicles to be a better alternative for ICEVs rather than EVs in Palestine.

Based on several countries' cases, charging infrastructure is the key element in any EV market. In Norway, a study by Lorentzen et al. [6] concluded that well-developed fast charging infrastructure is needed as the EV becomes the only type of vehicle in a household. Another study by Foley et al. [7] indicated that if the deployment of EVs is to succeed, universal charging hardware infrastructure, associated universal peripherals, and user-friendly software on public and private property are necessary. Likewise, a study in Poland by Macioszek [8] indicated that there are many challenges for the development of the EV market, such as the purchase/lease of land for charging stations, optimized deployment, use of existing power infrastructure, and funding for the development of charging stations.

Recently, hybrid vehicles are used widely around the world as an alternative to conventional ICEVs in order to develop more sustainable transportation systems and to reduce energy consumption and GHG emissions. Globally, several studies have addressed the environmental impact of vehicles, and a fewer number of studies have addressed the implications of hybrid vehicles in different regions during the last 10 years.

In China, a study by Lang et al. [2] was conducted in order to determine the environmental implications of hybrid vehicles. The energy and environmental impacts of hybrid vehicles during 2010–2020 were evaluated using an energy conversion analysis. The results of the analysis showed that hybrid vehicles could reduce significantly the NO_x and CO emissions. Moreover, fewer reductions in SO₂ and CO₂ could be obtained as well.

Likewise, a study was conducted in Japan by Kato et al. [9], which aimed to evaluate the potential of hybrid vehicles to reduce CO₂ emissions based on real-world driving data. The data of 35 hybrid vehicles from April to August in 2011 were collected and analyzed. The results of the study showed that the gasoline consumption was reduced by 44% and the CO₂ emissions were totally reduced by up to 17%.

In Thailand, a study was conducted by Pitanuwat and Sripakagorn [10] in order to investigate the fuel economy performance and the GHG of hybrid vehicles in Bangkok by taking into account the effect of traffic conditions and driving styles. Statistical parameters, average speed, and acceleration noise were employed in order to determine the impacts of traffic conditions and driving styles. The results

showed that hybrid vehicles were capable of reducing energy consumption and GHG emissions in all the traffic conditions and driving styles.

In Canada, a study by Khan and Kar [3] was conducted to determine the amount of emissions that vehicle owners can save by driving hybrid vehicles instead of ICEVs in a lifetime of seven years with an annual mileage of 24,000 km. A comparative assessment of hybrid vehicles was performed with their equivalent ICEVs. The results showed that all tested hybrid vehicles showed lower CO₂ emissions by up to 31%.

In order to determine the GHG emissions cost of hybrid vehicles, a study was conducted by Mitropoulos et al. [11] such that the emissions of hybrid and ICEV light duty vehicles were determined. More specifically, CO, NO_x, VOC, SO_x, and PM₁₀ emissions were tested. The results showed that hybrid vehicles were the most environmentally friendly vehicles in terms of GHGs, with GHG emissions equaling 339 g per mile.

In order to determine the environmental implications of hybrid vehicles compared to EVs and ICEVs, a study was conducted by Hassouna and Al-Sahili [5]. The study indicated that there are no significant environmental benefits from using EVs in countries where the major source of electricity is fossil fuel, such as coal, due to an insignificant reduction in CO₂ emissions by EVs compared to ICEVs. Thus, hybrid vehicles are preferable as an alternative to ICEVs in these regions due to significant reductions in GHG emissions and the reliability of hybrid vehicles.

In Palestine, ICEVs constitute more than 99% of the number of registered vehicles, while hybrid vehicles still constitute less than 1% (officially neglected) and EVs are not used yet. The absence of future environmental impact studies, or studies that show the implications and benefits of using new vehicle technologies (such as hybrid vehicles), has contributed to creating many concerns about hybrid vehicles. Therefore, the main objective of this study is to assess the current and future environmental impacts of conventional vehicles, and the future environmental implications of hybrid vehicles in 2030. Future conditions will be assessed based on two assumed scenarios:

- Scenario 1: 10% hybrid vehicles;
- Scenario 2: 20% hybrid vehicles.

As petroleum fuel prices fluctuate and are unstable, and as the world is becoming more environmentally conscious, policies all over the world are promoting more environmentally friendly vehicles that rely on alternative fuels. Furthermore, some countries are even setting time limits to convert vehicles gradually to alternative fuels. Therefore, an optimistic percentage of 20% hybrid vehicles is used in this study, which goes along with the international trend and would serve as a tool to encourage Palestinian (and other countries') decision and policy makers to set and adopt policies that favor an alternative to petroleum-fuel vehicles based on the results of this study.

Since no previous studies addressed the future environmental impacts of vehicles or the implications of hybrid vehicles in Palestine, this study may be used by decision makers and planners, and it gives a better understanding to vehicle users about the environmental benefits of hybrid vehicles. Moreover, this would pave the way for future comprehensive studies.

The paper presents the objective and methodology showing the studied scenarios of ICEVs and hybrid vehicles. Then it presents an analysis of the data and results for these scenarios in terms of environmental impacts. The paper ends with a discussion of the results and conclusions of the study.

2. Methodology

The objective here is to assess the current and future environmental impacts of conventional and hybrid vehicles. The scope of this study includes passenger and commercial vehicles. More specifically, it is assumed that the hybrid vehicles will partially replace both gasoline and diesel ICEVs (passenger and commercial ICEVs) in the future.

The first step is to acquire the needed data for analysis. In this study, the data have been acquired from several resources. Number of vehicles, population, and the gross domestic product (GDP) for the

period 1994–2018 have been acquired from the Palestinian Central Bureau of Statistics (PCBS) [12], the total vehicle kilometers of travel in 2014 for gasoline and diesel ICEVs (the only officially available data) were obtained from the PCBS [13], and the average fuel efficiency factor (consumption rate) has also been acquired from the PCBS [14].

The next step is estimating the number of vehicles in the future. This has been determined based on the number of vehicles, the population, and the GDP for the period 1994–2018, using the autoregressive integrated moving average (ARIMA) prediction methodology. Then, the total traveled kilometers in Palestine in 2020 and 2030 have been determined. After that, the current and the future environmental impact assessments in terms of GHG emissions of the ICEVs and hybrid vehicles have been determined based on the two studied scenarios. Finally, the discussion and the expected implications of hybrid vehicles in 2030 have been determined for the two scenarios.

In the first scenario, 10% penetration of hybrid vehicles was used based on the assumption that the government will not have a clear strategy to encourage importing the more sustainable vehicle technologies (such as tax reduction on the more sustainable vehicle technologies). In the second scenario, 20% penetration of hybrid vehicles was used based on the assumption that the government will have a clear strategy to encourage importing the more sustainable vehicle technologies. The following sub-sections explain the used methodology for the prediction and calculations.

2.1. Number of Vehicles Prediction Model

The ARIMA model has been developed to predict the number of vehicles in 2020 and 2030. Two more variables (GDP and population) were used to develop the prediction model in addition to the number of vehicles for the past years, since these two variables have a direct effect on the number of vehicles. The GDP has a significant effect on the ability of people to buy their own vehicles, while population has a significant effect on the transportation demand in which vehicles form the key element. Then, the expected GHG emissions for 2020 (100% conventional ICEVs) and for 2030 (10% and 20% hybrid vehicles) have been determined. Currently, since there are two different authorities controlling the two parts of Palestine (Gaza Strip and the West Bank), there are no uniform records adopted by both authorities. Moreover, in the Gaza Strip there are no available records for the number of vehicles in 2019 and 2020, while such data is available only for the West Bank. Therefore, there is a need to predict the number of vehicles for 2020 at the country level.

The ARIMA method is one of the most widely used techniques in predicting time series data, developed by Box and Jenkins. During the last 20 years, numerous studies have used the ARIMA method for traffic accidents and number of vehicles prediction with reasonable accuracy. Furthermore, the ARIMA method could give higher accuracy prediction than any linear prediction method for data with high fluctuation (trends and seasonality), which is the case in Palestine. In addition, the ARIMA method was used successfully by researchers utilizing annual data for periods of 24 years or more with reasonable accuracy [15].

The ARIMA model is composed from three parts, and each one helps to model a certain type of pattern. The “AR”, or autoregressive part, attempts to account for the patterns between any period and the previous ones. The “MA”, or moving average part, (better understood as an error feedback term) measures the adaptation of new forecast errors. The “I”, or integrated component, connotes a trend or other “integrative” process in the data [15,16].

The ARIMA model has been expressed by ARIMA (p, d, q), where p, d, and q express the number of ordinary autoregressive, differences, and moving average parameters, respectively. p and q present the number of significant lags of the autocorrelation function (ACF) and the partial autocorrelation function (PACF) plots, respectively, and d is the difference order needed to remove ordinary non-stationarity in the mean of the error terms [17].

In order to implement the ARIMA method, several tests are required to develop the best-fit model. For this purpose, the following tests have been applied:

- Augmented Dickey–Fuller (ADF) test has been performed to check the stationarity of the time series, as recommended by Din [18].
- Mean absolute error (MAE) has been used in order to select the best-fit model. The model with the lowest values of MAE has been selected, as recommended by Mwenda et al. [19].
- Ljung–Box test has been applied in order to determine the normality of the residuals for the selected model. Moreover, the Shapiro–Wilk test has been used in order to confirm that the residuals follow the normal distribution.

The predicted values of GDP and population (2019–2030) were estimated by the Statistical Package for the Social Sciences (IBM SPSS 25) software using the ARIMA model for each. These values were used to predict the number of vehicles in the future.

2.2. GHG Emissions by Vehicles in 2020

Based on the estimated number of vehicles in 2020 and the estimated total traveled kilometers in 2014 (the only available data), the total traveled kilometers in 2020 for gasoline and diesel vehicles have been estimated. After that, using the average fuel efficiency factors (fuel consumption rates) for gasoline and diesel vehicles in Palestine, the expected total consumed amounts of fuels (gasoline and diesel) in 2020 have been estimated. Finally, the total consumed amounts of fuels by vehicles in 2020 and the average GHG emission per liter of fuel (kg/L of diesel, kg/L of gasoline) have been used to estimate the expected GHG emissions by vehicles (100% conventional ICEVs), as shown in Figure 1.

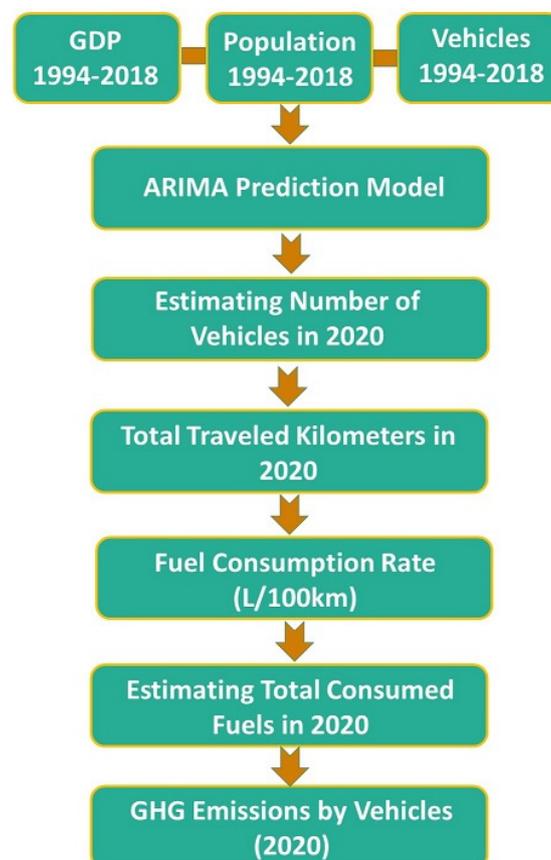


Figure 1. Implemented methodology to estimate the greenhouse gas (GHG) emissions by vehicles in Palestine, 2020.

2.3. GHG Emissions and Implication of Hybrid Vehicles in 2030

The total traveled kilometers in 2030 has been estimated by multiplying the total traveled kilometers in 2014 by the percent increase in number of vehicles between 2014 and 2030. After that, using the average fuel efficiency factors for gasoline, diesel, and hybrid vehicles (considering the increase in fuel efficiency due to engine improvement in the next 10 years), the expected total amounts of consumed fuels (gasoline and diesel) in 2030 have been estimated. Finally, the total amounts of the consumed fuels by vehicles in 2030 and the average GHG emission per liter of fuel have been used to estimate the expected GHG emissions by vehicles, as shown in Figure 2.

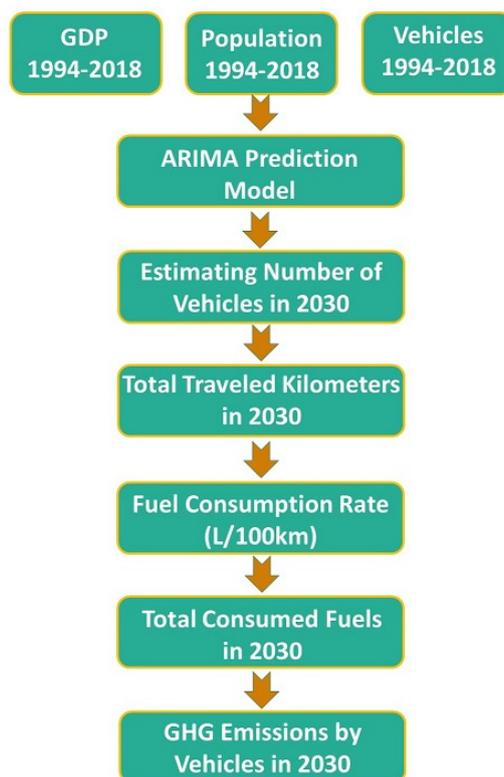


Figure 2. Implemented methodology to estimate the GHG emissions by vehicles in Palestine, 2030.

3. Results

The results of the ARIMA prediction models for number of vehicles and estimates of future GHG emissions resulted from the two scenarios are presented here.

3.1. Number of Predicted Vehicles

The number of vehicles in 2020 and 2030 has been estimated using the ARIMA prediction model based on previous records of number of vehicles, the GDP, and population, as described before. Initially, a time series for the number of vehicles of the subject period (1994–2018) has been plotted in order to determine the trend and the stationarity of the time series.

By applying the augmented Dickey–Fuller test using IBM SPSS 25 software, the results have showed that the second difference ($d = 2$) should be applied to the time series in order to have a stationary series. Then, all the possible models have been developed using the second difference ($d = 2$) in order to select the best-fit model. The model with the lowest value of MAE has been selected as a best-fit model, which was the ARIMA (3,2,2), as shown in Table 1. Despite that the value of MAE (14,709.581) for the selected model is relatively high, the values of R-squared and stationary R-squared (0.955 and 0.701, respectively) show an acceptable accuracy for the selected model. Therefore, the selected model could be used without any reservation.

Table 1. Comparison of statistical parameters for all tested models, in the order of increasing mean absolute error (MAE).

| Model | Number of Predictors | Model Fit Statistics | | |
|---------|----------------------|----------------------|-----------|------------|
| | | Stationary R-Squared | R-Squared | MAE |
| (3,2,2) | 2 | 0.701 | 0.955 | 14,709.581 |
| (3,2,1) | 2 | 0.680 | 0.955 | 14,747.995 |
| (0,2,3) | 2 | 0.679 | 0.955 | 15,320.930 |
| (2,2,2) | 2 | 0.504 | 0.931 | 15,663.812 |
| (0,2,2) | 2 | 0.546 | 0.937 | 15,750.507 |
| (1,2,2) | 2 | 0.539 | 0.936 | 16,173.592 |
| (1,2,3) | 2 | 0.574 | 0.941 | 16,266.604 |
| (1,2,1) | 2 | 0.560 | 0.939 | 16,287.114 |
| (2,2,1) | 2 | 0.599 | 0.944 | 16,401.343 |
| (2,2,3) | 2 | 0.590 | 0.943 | 16,415.115 |
| (0,2,1) | 2 | 0.538 | 0.936 | 16,695.548 |
| (3,2,0) | 2 | 0.504 | 0.931 | 17,697.454 |
| (2,2,0) | 2 | 0.366 | 0.912 | 18,994.078 |
| (1,2,0) | 2 | 0.259 | 0.897 | 20,228.233 |

In order to check the validity of the developed model, Ljung–Box and Shapiro–Wilk tests were used to determine the independency and the normality of the residuals. Finally, the developed model has been plotted (observed and fit values) and the equation of the developed model, including all statistical parameters has been set up, as shown in Figure 3 and Equation (1), respectively.

$$(Y_t, 2) = -22194.949 + 11.326V_t - 3.315Z_t - 0.373Y_{t-1} - 0.405Y_{t-2} - 0.571Y_{t-3} - 0.947\varepsilon_{t-1} - 0.041\varepsilon_{t-2} \quad (1)$$

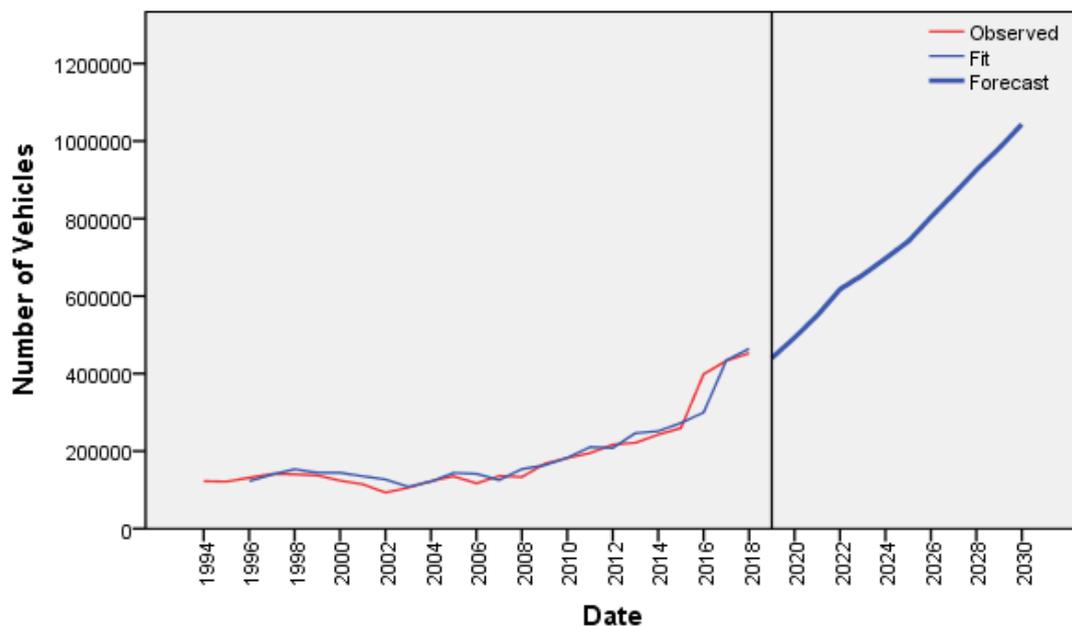
Y_t is the number of vehicles at time (year) t .

Y_{t-1} , Y_{t-2} , and Y_{t-3} are the number of vehicles at time lag $t - 1$, lag $t - 2$, and lag $t - 3$.

ε_{t-1} and ε_{t-2} are the error terms at time $t - 1$ and $t - 2$.

V_t is the population of Palestine (1000) at time (year) t .

Z_t is the gross domestic product of Palestine at time (year) t .

**Figure 3.** Observed and predicted number of vehicles.

By applying the developed ARIMA model, the expected numbers of vehicles for 2020 and 2030 were 492,913 and 1,042,999, respectively. Then, these data were used to determine the GHG emissions by vehicles in 2020 and 2030.

3.2. Estimating GHG Emissions by Vehicles in 2020

In Palestine, the total kilometers traveled by diesel and gasoline vehicles in 2014 were 4441 and 2553 million, respectively, and the total number of vehicles was 242,626 [13]. On the other hand, the estimated total number of vehicles in 2020 is 492,913.

The results have showed that there was a 103% increase in the number of vehicles between 2014 and 2020. Using the same increase rate, the estimated total traveled kilometers by diesel and gasoline vehicles in 2020 are 9015.23 and 5182.59 million kilometers, respectively.

The estimated total traveled kilometers by diesel and gasoline vehicles and the average fuel consumption rate (L/km) for diesel and gasoline vehicles have been used in order to determine the total amounts of fuel consumed by the vehicles. According to the Palestinian Central Bureau of Statistics [14], the average fuel consumption rates for diesel and gasoline vehicles are 0.129 and 0.107 L/km; therefore, the estimated consumed amounts in 2020 are 1162.96 and 554.54 million liters, respectively.

In order to determine the total amounts of GHG emissions for gasoline and diesel vehicles in 2020, the average rates (kg/L) of CH₄, N₂O, and the CO₂ emissions produced by gasoline and diesel combustion in ICEs (210,060 diesel and 282,854 gasoline ICEVs) have been used. The average amounts of CH₄, N₂O, and the CO₂ emissions produced by gasoline combustion in ICEs are 0.72, 0.05, and 2597.87 gm/L, respectively. On the other hand, the average rates of emissions produced by diesel combustion in ICVs are 0.04, 0.16, and 2924.90 gm/L, respectively [5,20]. Thus, the total estimated amounts of CH₄, N₂O, and CO₂ produced by diesel ICEVs in 2020 are 46.5184, 186.074, and 3,401,541.704 tons, respectively. The total estimated amounts of CH₄, N₂O, and CO₂ produced by gasoline ICEVs in 2020 are 399.269, 27.727, and 1,440,622.83 tons, respectively, as shown in Table 2. In other words, the total estimated GHG emission in 2020 is 4,917,021.907 tons of CO₂-equivalent.

Table 2. Total expected amounts of GHG emissions by diesel and gasoline vehicles in 2020.

| Gas Emissions | Diesel ICEVs | Gasoline ICEVs | Total | Total GHG (tons of CO ₂ -Equivalent) |
|------------------------|---------------|----------------|---------------|---|
| CO ₂ (ton) | 3,401,541.704 | 1,440,622.830 | 4,842,164.534 | 4,917,021.907 |
| N ₂ O (ton) | 186.074 | 27.727 | 213.801 | |
| CH ₄ (ton) | 46.518 | 399.269 | 445.787 | |

3.3. Estimating GHG Emissions by Vehicles in 2030

The estimated total number of vehicles in 2030, using the developed ARIMA prediction model, is 1,042,999. The results have showed that there was a 111.6% increase in number of vehicles between 2020 and 2030. Using the same increase rate, the total traveled kilometers by diesel and gasoline vehicles in 2030 could be estimated. Thus, the estimated total traveled kilometers by diesel and gasoline vehicles in 2030 are 19,076.227 and 10,966.361 million kilometers. Based on the Fuel Consumption Report [21], the average gasoline fuel consumption rate for hybrid vehicles (hybrid vehicles are gasoline-hybrid) is 0.055 L/km.

Due to the expected improvement in fuel efficiency for both ICEVs and hybrid vehicles during the next 10 years, the expected reduction factors (for fuel consumption rate) of 15% and 20% for ICEVs and hybrid vehicles, respectively, have been used. These were based on a study in China by Lang et al. [2], which concluded that the average fuel consumption rate for ICEVs and hybrid vehicles could be reduced by 15% and 20%, respectively, during a period of 10 years due to the continuous improvement in engine manufacturing. The summary of these rates is presented in Table 3.

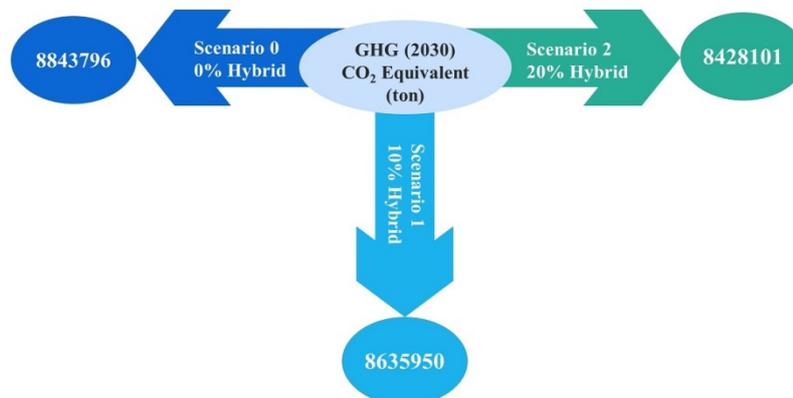
Table 3. Main assumptions and results summary.

| Year | Number of Vehicles | Total Traveled-Kilometers (million km) | | ICEVs Fuel Consumption Rate (L/km) | | Hybrid Fuel Consumption Rate (L/km) |
|------|--------------------|---|------------|---------------------------------------|----------|--|
| | | Diesel | Gasoline | Diesel | Gasoline | Gasoline |
| 2020 | 492,913 | 9015.230 | 5182.590 | 0.129 | 0.107 | 0.0551 |
| 2030 | 1,042,999 | 19,076.227 | 10,966.361 | 0.110 | 0.091 | 0.0441 |

For the first scenario (10% hybrid vehicles and 90% ICEVs), the estimated consumed amounts of fuels are 1882.54 and 1154.82 million liters of diesel and gasoline, respectively. Meanwhile, in the second scenario (20% hybrid vehicles and 80% of ICEVs), the estimated consumed amounts of diesel and fuel are 1673.37 and 1312.24 million liters, respectively. The corresponding amounts of fuel emissions and the total CO₂-equivalent for all tested scenarios are summarized in Table 4. Furthermore, the total estimated GHG emissions of CO₂-equivalent for the tested scenarios are shown in Figure 4.

Table 4. GHG emissions based on all tested scenarios, 2030.

| Scenarios | Total Diesel Consumption (million liter) | Total Gasoline Consumption (million liter) | GHG Emissions (ton) | | | Total GHG (ton of CO ₂ - Equivalent) |
|--|--|--|---------------------|------------------|-----------------------------|---|
| | | | CO ₂ | Diesel (ICEV) | Gasoline (ICEV + Hybrid) | |
| Scenario 0 (100% ICEVs + 0% Hybrid) | 2091.71 | 997.39 | CO ₂ | 611,8042.58 | 2,591,115.54 | 8,709,158.12 |
| | | | N ₂ O | 334.67 | 49.87 | 384.54 |
| | | | CH ₄ | 83.67 | 718.13 | 801.80 |
| Scenario 1 (90% ICEVs + 10% Hybrid) | 1882.54 | 1154.82 | CO ₂ | 5,506,241.25 | 3,000,072.20 | 8,506,313.45 |
| | | | N ₂ O | 301.21 | 57.74 | 358.95 |
| | | | CH ₄ | 75.30 | 831.47 | 906.77 |
| Scenario 2 (80% ICEVs + 20% Hybrid) | 1673.37 | 1312.24 | CO ₂ | 4,894,439.90 | 3,409,028.93 | 8,303,468.83 |
| | | | N ₂ O | 267.74 | 65.61 | 333.35 |
| | | | CH ₄ | 66.93 | 944.81 | 1011.74 |

**Figure 4.** GHG emissions in tons of CO₂-equivalent.

The results show that the CO₂ and N₂O emissions will be reduced in the first scenario, and will be further reduced in the second scenario, while the CH₄ emissions will be increased, as will be discussed. However, the total CO₂-equivalent will be reduced.

It should be noted here that the scrapping of old vehicles was not considered since there are no specific rules or period of time for vehicles to be scrapped in Palestine. Moreover, the average fuel consumption rate for ICEVs (for total new and old vehicles) in 2030 was assumed to be reduced by 15% compared to the average fuel consumption rate of ICEVs in 2020 (total current ICEVs).

4. Discussion and Conclusions

Despite developing a sustainable transportation system in Palestine becoming one of the highlighted topics by decision makers and planners in order to reduce the energy depletion and the GHG emissions, there are still no studies for current and future environmental implications of transportation systems. In order to have any long-term strategies, the current and future environmental impacts of the transportation sector should be assessed, which has been conducted in this study based on the gradual use of hybrid vehicles in the local market.

As a result of replacing 10% of ICEVs by hybrid vehicles in 2030, which was the first tested scenario in this study, 2.33% and 6.65% reductions in CO₂ and N₂O, respectively, are estimated. On the other hand, based on the second scenario (20% hybrid vehicles, 80% ICEVs), the expected reductions are 4.66% and 13.31%, respectively. Since hybrid vehicles use gasoline fuel only, there is an expected increase in the amount of gasoline fuel consumed, as part of the diesel ICEVs will be replaced by hybrid vehicles. This will lead to an increase in the amount of emitted CH₄ (13.10% and 26.18% for the first and the second scenarios, respectively), since the combustion of gasoline produces more CH₄ than the one produced by diesel combustion. However, the overall CO₂-equivalent will decrease; therefore, a more sustainable transport system will be achieved.

The results of this study confirmed results reported by other studies in the literature, such that the use of hybrid vehicles would significantly reduce the fuel consumption and GHG emissions; however, with different levels. This variation is related to the vehicle types, composition, and vehicle-kilometer traveled, as well as the type of fossil fuels used in different regions.

The unique situation of the high use of diesel fuel in the Palestinian market, which is used by all public transportation and commercial vehicles—these are vehicles that travel much longer distances (vehicle-kilometer traveled) than private vehicles—produces slightly different results than what was reported in the literature. Based on these conditions, the introduction of hybrid vehicles in the Palestinian market would increase the CH₄ emissions, which is different than other regions in the world.

In summary, the following conclusions are offered:

- In Palestine, the hybrid vehicle seems to be the best alternative to ICEVs, while the electric vehicles are expected to be kept close to 0% due to the mountainous topography and the weather conditions (air-conditioning and ventilation requirement). The absence of EV electricity charging infrastructure and the instability of the electricity networks and loads affect negatively on the reliability and range of the EVs. Moreover, due to the high portion of coal and fossil fuel-based electricity in Palestine, which is more than 63% of the total source of electricity, EV is not the preferable choice for decision makers due to an insignificant reduction in GHG emissions by EVs compared to ICEVs in this case.
- The estimated CO₂, N₂O, and CH₄ emissions from transportation in 2020 are very high; much higher than the total national emissions reported in 2014. As an example, the total CO₂ national emissions (including transportation, industry, communication, etc.) in 2014 were 3,180,300 tons, while the estimated CO₂ emissions from the transportation sector in 2020 are 4,842,164.5 tons. Furthermore, a huge increase in the estimated CO₂ emissions from the transportation sector is expected in 2030 compared to 2020.
- On the one hand, replacing 20% of ICEVs by hybrid vehicles in 2030 would lead to reductions in CO₂ and N₂O as compared to using 100% ICEVs (no hybrid vehicles). However, there is also an expected increase in the amount of CH₄ since the use of gasoline will increase at the expense of using diesel; the combustion of gasoline produces more CH₄ than the diesel combustion.
- The results of this study would promote the introduction of hybrid vehicles in the local market, and would encourage policy and decision makers to set policies to encourage their use; for example, through tax incentives. Furthermore, this study would pave the road for future comprehensive studies and would be a step towards a sustainable transportation system.

- It is recommended to consider PM₁₀, CO, and SO_x emissions in any future environmental assessment for the transportation sector in Palestine.

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