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Energy Use and CO_2 Emissions of Passenger Vehicles in Bahrain - A Case Study

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Abstract. Although there has been rapid growth in the number of passenger vehicles in Bahrain accompanied by an increase in energy demand, the CO_2 emissions per vehicle has remained unexplored. This paper contributes to closing the information gap with regard to CO_2 emissions, fuel economy, and distance travelled. A bottom-up approach developed by the Global Fuel Economy Initiative that utilizes the vehicles' specifications is used to calculate the missing indicators. Analysis shows that fuel economy of passenger vehicles has improved by an average annual rate of 0.7 % between 2000 and 2010. This rate is lower than that of many developed and developing countries. We conclude by emphasizing the need for policy intervention through introducing fuel economy standards in Bahrain. Although the focus of this paper is on Bahrain, the methodology is readily applicable in other countries where similar data deficiencies can be found.

Keywords: Passenger vehicles, CO_2 emissions, Bahrain

1. Introduction

The transport sector is responsible for 27 % of the world energy consumption [1].This proportion has increased from 23 % in 1973 [2] and contributes to 22 % of the total CO_2 emissions [3]. Intergovernmental Panel on Climate Change (IPCC) scenarios suggest that global emissions must peak by 2020 followed by a 5 % annual reduction to avoid dangerous climate changes. Therefore, a reduction in transport emissions is required in all countries.

In Bahrain, as in most other countries, the road transport sector is one of the highest energy-consuming sectors. It consumes approximately 22 % of its total energy [1] and is responsible for a significant share of the CO_2 emissions (100 % of the CO_2 emissions from the transport sector and 11.7 % of the total emissions) [4]. Management of the road transport sector is of particular importance in Bahrain; this arrangement is due to the rapid increase in the number of passenger vehicles (7.3 % per year on average) [5], which resulted in an accelerated rise in the fuel consumption (5.7 % per year on average) [6] and consequently an increase in the carbon emissions (5.5 % per year on average) [4]. Another significant point is that Bahrain's oil field is approaching the end of its life after almost eighty years of production. In light of this fact, Bahrain is seeking to extend the life of the field and to improve its energy efficiency.

Furthermore, Bahrain faces challenges in data availability and quality. It should be noted that reliable and accurate data are crucial to the development of desired transport policies. This matter might be taken for granted in some countries, while other countries are still struggling with data availability, including Bahrain and some other Gulf Cooperation Council (GCC) countries. Therefore, this paper primarily aims to close the information gap with respect to passenger vehicle data in Bahrain. A bottom-up methodology suggested by

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the Global Fuel Economy Initiative (GFEI) has been utilized to address the limited availability of transport data, focusing on passenger vehicles data in particular. This method can be easily transferred to other GCC countries where similar data deficiencies could exist.

Hence, this paper aims to achieve two main objectives: first, it depicts the profile of the passenger vehicle fleet in Bahrain, with particular emphasis on the technical aspects in addition to the existing knowledge gaps and deficiencies. Second, it supplies information on a number of missing data indicators for the first time for Bahrain, such as the average CO_2 emissions, fuel economy and vehicle-use intensity per passenger vehicle.

This paper consists of five sections. Section 2 outlines the related work and available methodologies that are used to calculate CO_2 emissions and fuel economy from the literature. Subsequently, section 3 explains the research methodology steps, the data collection, and the tasks that are involved with the data processing and management adopted in this research. The computed results are presented in section 4. Finally, section 5 states the main conclusions along with a number of recommendations.

2. Related Work

Schipper [7] described the identification of vehicle fuel use and fuel economy as a '*complex matter'*. This description could be due to a number of different factors that determine the total energy use of any given vehicle population. The list of factors includes the number of vehicles, the average distance travelled and the average fuel economy. In addition to these factors, a vehicle's carbon emission is also determined by its energy consumption, fuel type, the carbon content of the fuel, and the vehicle's technical performance while accounting for its engine size, efficiency, power, weight, automatic transmission and air conditioning [8], [9].

The literature cites a number of different attempts and methods to calculate CO_2 emissions or fuel economy per vehicle. According to the United States Environmental Protection Agency (US EPA) [10], GHG emissions from passenger vehicles can be calculated through multiplying the total gasoline consumption by the CO_2 emissions factor for gasoline (i.e., 8887 grams CO_2 per gallon). The same calculation was adopted by the IPCC to prepare the GHG emissions inventory reports [11].

US EPA [10] adopts another approach to calculate CO_2 emissions per mile driven by using the fuel economy data (Miles per Gallon - MPG) (1). The total CO_2 emissions per vehicle can be obtained by multiplying the result by the annual miles driven (2).

$$CO_2 \text{ emissions per mile} = CO_2 \text{ per gallon / MPG} \quad (1)$$

$$CO_2 \text{ emissions per vehicle} = (CO_2 \text{ per gallon / MPG}) * \text{miles per vehicle} \quad (2)$$

GEFI in its online toolkit suggest using a number of websites to obtain estimations for the per passenger vehicle CO_2 emissions rates [12]. The same approach is recommended by the Arab Forum for Environment and Development **(**AFED**)** [13], in its Energy Efficiency Handbook, acknowledging the existing information gaps in Arab countries. This suggestion appeared to be applicable to the case of Bahrain, and further work was conducted to take it to the implementation stage.

3. Methods and Data Set

Throughout the literature review and the use of the vehicle data set, we identified three main information gaps, specifically: CO_2 emissions, fuel economy, and vehicle-use intensity (vehicle kilometres travelled - VKT) per passenger vehicle.

We followed the steps below to perform the calculations:

- The data set was split into 22 subsets, which represent both the new passenger vehicles and the total passenger vehicle population within the observation period of 11 years (2000 - 2010).
- The passenger vehicles were grouped based on their engine size, to select representative samples. Because there is no classification system for passenger vehicles based on their size, we consider those that have an engine capacity of more than 3000cc to be large vehicles.

- Random stratified samples were drawn from each subset by using SPSS. We took the first set of samples based on the engine size groups from the newly registered vehicles from 2000 to 2010. We took another set of samples that represent the on-road registered vehicles during the same period. Cochran's sample size formula for categorical data [14] was used to determine the minimum sample size, as follows:

$$n = (t^2 * pq) / d^2 \quad (3)$$

Where: t is the value for the selected alpha level, in this case, 1.96 for 95 % confidence

pq is the estimate of variance, assuming a heterogeneous population that is more or less 50 % - 50 %

d is the acceptable margin for error, which is 0.05 in this case

Four main elements of the data set were utilised to obtain fuel economy and CO_2 emissions per passenger vehicle, namely, the vehicle make, model, manufacturing year, and engine size. We used the US fuel economy website[1] to obtain the fuel economy and CO_2 emissions per passenger vehicle data. We then calculated the average CO_2 emissions and fuel economy per passenger vehicle using the following equations [12]:

$$\textit{Harmonic average annual fuel economy} = \textit{Total sale} / \sum_1^n (sales\ model\ i\ /\ Fuel\ economy\ model\ i) \quad (4)$$

$$\textit{Average annual emission} = \sum_1^n (sales\ model\ i\ *\ emission\ model\ i)\ /\ \textit{Total sales} \quad (5)$$

- We then indicated the dominant vehicle manufacturers for the 2010 model year. The CO_2 emissions were then calculated from representative samples that were drawn from each of the major car companies' sales in Bahrain. This step was taken to determine any differences in the carbon emissions of new models sold in Bahrain and some selected countries
- We calculated the average annual distance travelled per passenger vehicle through solving the following equation backwards [15]. The total emissions published in the 2nd communication report to the UNFCCC, the number of vehicles, and the calculated CO_2 emissions per vehicle were all used to calculate the distance travelled.

$$\textit{Total emissions} = \textit{number of vehicles} * \textit{distance travelled} * \textit{emissions per vehicle-distance travelled} \quad (6)$$

- Because there were no previous surveys on vehicle mileages, we conducted a limited survey in different ministries, universities, and markets. We calculated the sample size using equation (3) and we used the simple random sampling technique to validate our calculation results. From our survey, the total mileage was recorded and then divided by the vehicle's age, to derive an estimate of the annual average distance travelled per passenger vehicle in Bahrain. In the survey, the respondents were asked if their vehicles have ever travelled abroad or not.
- The findings were then compared to the published numbers and to those of selected countries worldwide.

4. Results and Discussion

Following the methodology steps mentioned in section 4, analysis revealed that the average CO_2 emissions per passenger vehicle for the entire on-road passenger vehicle fleet registered in Bahrain in 2010 is 241 gCO_2/km (Table I). This number has been fluctuating during the observation period, ending with a decrease in 2010 of 5.1 % compared to the year 2000.

Table I: Average CO_2 emissions from the passenger vehicle fleet registered in Bahrain between 2000 and 2010 (gCO_2/km)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Bahrain	254	234	237	239	240	240	240	240	242	242	241

[1] http://www.fueleconomy.gov/feg/findacar.shtml

Further investigations were conducted to explore the carbon emissions level of the new models of passenger vehicles in Bahrain. The calculated number amounted to 238 g CO_2/km for the 2010 models, which indicates a decrease compared to the year 2000 (254 g CO_2/km), as shown in

Table II.

Table II: A comparison between the average CO_2 emissions from new models of passenger vehicles in the EU and Bahrain between 2000 and 2010 (g CO_2/km)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Bahrain	254	260	250	244	243	237	237	236	247	242	238
EU	172.2	169.7	167.2	165.5	163.4	162.4	161.3	158.7	153.6	145.7	140.3

Source: our calculations; [16]

Once again, as shown in Table III, the calculated numbers for Bahrain are higher than that of the EU. A noticeable difference appears between the decreasing pattern of carbon emissions in the EU and that of Bahraini vehicle emissions. Surprisingly, the least CO_2 emission per vehicle from the 2010 models in Bahrain (182.6 g CO_2/km) is higher than the EU average for the year 2000 (172.2 g CO_2/km).

We also calculated the average fuel economy per passenger vehicle for the whole fleet, which is equal to 9.6 km/litre for passenger vehicles in 2010 in Bahrain. This number indicates a relatively higher fuel economy than the figure given by the General Directorate of Traffic, which was 7 km/litre in 2007. The average fuel economy of new vehicles in Bahrain has fluctuated over the period 2000-2010, with an average annual increase of 0.7 %. However, it demonstrates low energy economy for passenger vehicles when compared to that of the USA's, Kenya, the Organisation for Economic Co-operation and Development (OECD) countries, and non-OECD countries (

Table) [17], [18].

Table III: A comparison between the average fuel economy of new passenger vehicles registered in Bahrain and selected countries between 2000 and 2010 (km/litre)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Bahrain	9.1	8.9	9.2	9.5	9.5	9.7	9.7	9.8	9.3	9.5	9.7
Kenya	-	-	-	-	-	14.7	-	-	15.3	-	-
Non-OECD	-	-	-	-	-	14.7	-	-	14.4	-	-
OECD	-	-	-	-	-	13.6	-	-	14.4	-	-
USA	12.1	12.2	12.3	12.5	12.5	12.9	12.8	13.3	13.4	14.0	14.4

Source: our calculations; [17], [18]

To locate the exact differences between the passenger vehicle specifications in Bahrain and those in the EU and Australia, some additional analysis was conducted by using the 2010 model year vehicles. We performed a comparison between the dominant manufacturers' sales in Bahrain, EU and Australia for that purpose. The results show that the Bahraini market is dominated by three major vehicle manufacturers, namely, Toyota, Honda, and Nissan. The sales of these three main manufacturers make up more than 50 % of the 2010 model sales. When compared to the same manufacturers' sales in the EU, substantial differences can clearly be seen (Table), whilst the numbers from Bahrain are closer to those from Australia. This finding could be the result of a number of factors, including dissimilar weather, consumption patterns, alternative modes of transportation, vehicle age, and fuel economy standards.

Table IV: Average CO_2 emissions for a number of vehicle makes in Bahrain, EU and Australia in 2010 (g CO_2/km)

Make	Bahrain	Australia	EU
HONDA	226	194	144
NISSAN	216	231	147
TOYOTA	234	222	129

Source: our calculations; [19]

We calculated another important transport-related indicator for the passenger vehicle fleet in Bahrain. Unlike the previous indicators, the vehicle-use intensity can be found in official reports that were published before 2008. This indicator was calculated based on the fuel consumption data, assuming 7 km/litre for fuel efficiency. Modifications to the calculation method were suggested[2] but have not been implemented yet.

Nevertheless, the last published number for vehicle-use intensity was estimated at 19,836 kilometres per vehicle for the year 2008. When compared to the calculated number for the same year using equation (6) [15], we obtained an approximate 8.4 % difference (18,164 kilometres per year, assuming 240 g CO_2/km emissions, and a total number of 342,547 gasoline vehicles). Regardless of this small difference, the published number was calculated based on a lower fuel economy (7 km/litre), whilst our calculated efficiency number for the passenger vehicles in that year equals 9.6 km/litre.

Table demonstrates the average annual distance that was travelled per passenger vehicle in Bahrain. A declining trend is clearly shown in the calculated figures, while the published figures are almost unchanged. Although it is surprising to find that the distance travelled is decreasing by an average of 1.5 % per year, the gasoline consumption per gasoline vehicle is decreasing as well during the same period. There are many factors that explain this trend, for example, the fuel economy of the passenger vehicles could have significantly improved (which is not the case here), the distance travelled could have decreased, or there is an issue of fuel tourism (especially because the Saudi Arabians sell gasoline at a lower price). However, further research is recommended to explore this trend.

Table V: The average annual distance travelled per passenger vehicle in Bahrain between 2000 and 2010 (km/vehicle/year)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
The calculated distance	20,665	22,056	21,753	21,028	20,418	19,577	19,597	18,327	18,164	17,873	17,751
The Published distance	19,971	19,600	19,739	19,954	19,563	20,681	19,772	-	19,837	-	-

Source: [20]; our calculations

Nevertheless, the limited survey results validate the results of our calculations. The survey reveals that the average annual distance travelled by a passenger vehicle that has never travelled abroad equals 17,276 km. This number is only 2.7 % less than the calculated number. It is worthwhile noting that the majority of the surveyed vehicles have travelled abroad (63.4 %).However, a considerable number of vehicles (203 vehicles) have not travelled abroad and, subsequently, they are used to calculate the average.

When compared to a number of selected countries, the average annual distance travelled per passenger vehicle in Bahrain is relatively higher; however, it is slightly lower than that of the USA (VI). This finding could be due to the different passenger transport modes that are available in those countries, whilst private passenger vehicles represent the main transport mode in Bahrain. Other factors that affect the average distance travelled include geography, patterns of urban planning, and consumer behaviour.

Table VI: Distance travelled in selected countries

Country	Average distance travelled per passenger vehicle (km/yr)
Australia	13,743a
Japan	8,830 a
New Zealand	14,134 a
United Kingdom	14,078 a
United States	19,096 b
Bahrain	17,751 c

Source: [21], [17] our calculations
a Calculated from IRF data
b Obtained from [17]
c This number is the average distance travelled by a gasoline vehicle regardless of being a passenger vehicle or not.

In this context, an interesting and noteworthy point is related to the comparison between transport-related indicators in Bahrain and that in the USA. Although the passenger vehicle ownership and the average annual distance travelled are relatively higher in the USA, the average fuel economy of new passenger vehicles is

[2] The General Directorate of Traffic suggested recording the distance travelled during the annual car test, to provide more accurate numbers for the vehicles' fuel economy and distance travelled. However, no further actions have been taken yet.

considerably lower in Bahrain. Consumption patterns and lifestyle definitely contribute to vehicle model selection; however, another factor controls the situation in the USA, which is the fuel economy standards. Fuel economy standards are set at 11.7 km/litre for 2010 models in the USA. This setting is the impetus behind the more efficient new passenger vehicles compared to the case of Bahrain. Accordingly, policy intervention through setting fuel standards is not a luxury any more in Bahrain. The new vehicles will most likely be larger and less efficient in fuel consumption. Therefore, we developed future mitigation scenarios that assumed fuel economy improvements regardless of any other factors in this study.

5. Conclusions

This paper aims to provide a clear picture of the current status and future trends of the passenger vehicles in Bahrain, in which the findings are presented for the first time. The passenger vehicles problem in Bahrain is not solely about the increasing number of vehicles; it is also about vehicle specifications, size, and fuel economy, as demonstrated in this study. One implication that can be drawn is that the increase in the vehicle engine size and weight has offset the potential of gaining significant savings from the wide distribution of small and more efficient vehicles. Although this pattern could be a common problem that can possibly be found in other countries, it is of special importance to Bahrain. There are no restrictions in Bahrain on new vehicles with respect to fuel economy or CO_2 emissions. Furthermore, environmental labelling, emission reduction targets and action plans have yet to be developed for the country. Hence, this arrangement denotes abundant objectives for focusing policy framing and research, to encourage the use of more efficient vehicles and the introduction of fuel economy standards.

The findings of this research show where Bahrain stands compared to selected countries. The results reveal that Bahrain is still far away from a number of developed and developing countries including the USA, the OECD countries, non-OECD countries, Kenya. More in-depth analysis shows that the new vehicle models and specifications in Bahrain differ significantly from those sold in the EU, especially considering that the same manufacturing companies are the source of the vehicles. Based on the current CO_2 emissions and fuel economy of the new models in Bahrain, it is evident that policy intervention is not a luxury any more, especially in that similar figures for other world countries articulate substantial fuel efficiency improvements.

This research is the first-ever attempt at calculating the fuel use and carbon emissions of passenger vehicles in Bahrain. The utilized approach in this paper identifies the development trends of the CO_2 emissions and fuel economy of new vehicle models in the Bahraini market. Moreover, it indicates some of the information and policy gaps that require more attention. Furthermore, this bottom-up methodology could be transferred to other GCC countries in which similar situations could exist.

Bahrain will need to take the initiative toward achieving sustainability in the transport sector. Following the footsteps of other countries in the international community, learning from their experiences, considering different options, and obtaining benefit from global initiatives will all help to put Bahrain on the right track.

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