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December, 2013
No. 53

SRI PAPERS

SRI Papers (Online) ISSN1753-1330

First published in 2013 by the Sustainability Research Institute (SRI)

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CO_2 emissions and fuel consumption of passenger vehicles in Bahrain: Current status and future scenarios

2013

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Contents

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 and fuel economy per vehicle had remained unexplored due to insufficient data. This paper has three objectives. First, it aims to present the passenger vehicle profile in Bahrain during the period 2000-2010. Second, it attempts to close the information gaps with regard to: (1) CO_2 emissions, (2) fuel economy, (3) and vehicle-use intensity. Third, it develops future scenarios for the first time for this sector in Bahrain. The paper also develops a simplified bottom-up approach that utilises the limited data available on passenger vehicles. The vehicles' specifications are used to calculate the missing indicators using information published on an official website. Descriptive analysis indicates a continuing trend towards buying large passenger vehicles, which may offset any significant savings gained from smaller vehicles. Further in-depth analysis indicates a fluctuating trend in the new models' fuel economy, which is translated into an increasing rate of CO_2 emissions. The Business-As-Usual (BAU) scenario shows that CO_2 emissions and energy demand of passenger vehicles will double by 2030 compared to 2010. While assuming all other factors constant, setting fuel economy standards can achieve up to 27% reduction in CO_2 emissions. We conclude by emphasizing the need for policy intervention through introducing fuel economy standards in Bahrain. The consideration of other options including vehicle ownership, usage restrictions, and public transportation are also recommended. Although the focus of this paper is on Bahrain, the proposed methodology is readily applicable in other Gulf Cooperation Council (GCC) countries where similar data deficiencies may be found.

Key words: Passenger vehicles, CO_2 emissions, Fuel economy, Future scenarios, Bahrain

Submission date 12-09-2013; Publication date 02-12-2013

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1. Introduction

The transport sector is responsible for 27% of the world energy consumption (IEA, 2012a).This proportion has increased from 23% in 1973 (IEA, 2011) and contributes to 22% of total CO_2 emissions (IEA, 2012b). Intergovernmental Panel on Climate Change (IPCC) scenarios suggest that global emissions need to peak by 2020 followed by a 5% annual reduction to avoid dangerous climate change. Therefore, a reduction in transport emissions is required in all countries.

This has attracted a significant amount of interest in developing different strategies and methods to measure and mitigate CO_2 emissions from the road transport sector as found in the literature. These options range from fuel and vehicle technologies to regulatory and economic instruments, and also planning and information techniques. International experience shows a considerable number of success stories and lessons learnt worldwide (e.g. EEA, 2008; Mckinsey and Company, 2009; Santos *et al*., 2010a; Santos et al., 2010b).

In Bahrain, as in most other countries, road transport sector is one of the highest energy consuming sectors. It consumes around 22% of its total energy (IEA, 2012a) and is responsible for a significant share of the CO_2 emissions (100% of the CO_2 emissions from transport sector and 11.7% of the total emissions) (PMEW, 2012). Management of the road transport sector is of particular importance in Bahrain. This is due to the rapid increase in the number of the passenger vehicles (7.3% per year on average) (General Directorate of Traffic, 2011) which resulted in an accelerated rise in fuel consumption (5.7% per year on average) (CIO, 2012) and consequently an increase in the carbon emissions (5.5% per year on average) (PMEW, 2012). Another significant point is that Bahrain's oil field is approaching the end of its life after nearly eighty years of production. In light of this fact, Bahrain is seeking to extend the life of the field[1] and to improve energy efficiency.

Furthermore, Bahrain faces challenges in data availability and quality. It should be noted that reliable and accurate data is crucial to the development of desired transport policies. Additionally, modelling CO_2 emissions and energy consumption requires many parameters. This matter might be taken for granted in some countries and yet, 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 gaps with respect to passenger vehicles data in Bahrain. A simplified bottom-up methodology has been developed to cope with the limited availability of transport data, focusing on passenger vehicles data in particular. This method that has been developed can easily be transferred to other GCC countries where similar data deficiencies may exist.

[1] Through Tatweer Petroleum Company (established 2009), in an attempt to extend the field's life using a number of recovery techniques (Tatweer Petroleum, 2013)

Hence, this paper aims to achieve three main objectives: firstly, it depicts the profile of the passenger vehicle fleet in Bahrain, with particular emphasis on technical aspects, in addition to existing knowledge gaps and deficiencies. Secondly, it supplies information on a number of missing data indicators for the first time for Bahrain, such as average CO_2 emissions, fuel economy[2] and vehicle-use intensity[3] per passenger vehicle. It should be noted that these indicators are needed to develop effective transport policies and action plans. Thirdly, this paper gives projections of carbon emissions and fuel demand of passenger vehicles for the first time in Bahrain[4], and tests the impact of imposing fuel economy standards.

This paper consists of six sections. The Bahraini national context offers insights into passenger vehicles and some related factors in Bahrain. Section 3 outlines the related work and available methodologies used to calculate CO_2 emissions and fuel economy from the literature. The subsequent section 4 explains the research methodology steps, data collection, and tasks involved with the data processing and management adopted in this research. The computed results are presented in section 5 along with predictions of possible future scenarios. Finally, section 6 states the main conclusions along with some recommendations.

2. National context

2.1. Socio-economic characteristics

Bahrain has a rapidly increasing population with an average growth rate of around 7.1% per year. Economic development and diversification have created many employment opportunities that resulted in an increase of the number of non-Bahraini workers in the country during the last decade. The number of non-Bahrainis has grown by an average of 16.2% annually, compared to the population growth of Bahrainis at only 3.8%. The total population size has increased dramatically from 0.63 million in 2000 to more than 1.23 million in 2010 (CIO, 2011; CIO, 2012). With its limited area (760 km^2), Bahrain is highly populated with a population density that exceeds 1,600 people per km^2, with the northern and central areas of the country being the most densely populated parts of the country due to urbanization.

Bahrain has a prosperous economy. The real Gross Domestic Product (GDP) has been growing at an average annual rate of 6% (11% for the nominal GDP) over the period between 2000 and 2010 (MOF, 2011). However, the picture looks different for the per capita GDP. The official figures show a declining rate for the GDP per capita during the same period on account of the high population growth rate (MOF, 2011). Nevertheless, both the population and economic growth rates have contributed to a substantial increase in the passenger vehicle number over the last decade. Figure 1 provides a significant, positive and very strong correlation[5] between the passenger vehicle number,

[2] This number was randomly estimated in Bahrain based on fuel economy average in other countries without any documented methodology. The estimated number equals 7 km/litre.
[3] Published estimations for this indicator are available until 2008, based on the estimated fuel economy.
[4] Except for an on-going and unpublished consultancy report on sustainable transportation in Bahrain
[5] The correlation is significant at the 0.01 level (2-tailed)

the population size (R^2=0.99) and the real GDP (R^2=0.94) in Bahrain during the period between 2000 and 2010.

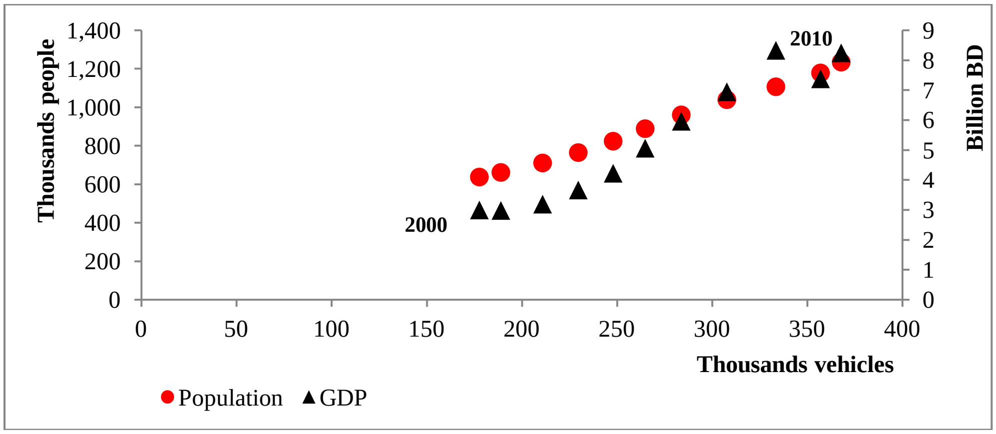

Figure 1: Passenger vehicle number vs. population size and real GDP in Bahrain between 2000 and 2010.

Source: CIO, 2011; CIO, 2012; MOF, 2011

2.2. Passenger vehicle population

Since 2000, the passenger vehicle number has grown dramatically to reach 367,000 vehicles in 2010 with an average annual growth rate of 7.3% (General Directorate of Traffic, 2011). The total number of passenger vehicles is not often given in the national transport statistics. The vehicle registration system classifies the vehicles into 18 different categories based on the type of registration plate. Therefore, we had to collect and compile the published data to derive the total number of passenger vehicles.

Despite the upward trend in passenger vehicle ownership (337 passenger vehicles per 1000 population), this is relatively low when comparing this statistic to that in countries worldwide (e.g. Australia 550, UK 460, USA 750 passenger vehicles per 1000 population) (IRF, 2011; RITA, 2013). However, this trend in Bahrain is higher than that of some neighbouring countries (e.g. Saudi Arabia 139, and Oman 166 passenger vehicles per 1000 population).

In addition to the Bahraini-registered vehicles, a considerable number of vehicles enter the country through King Fahad Causeway that connects Bahrain to the Saudi Arabia, (1.7 million vehicles in 2011) (CIO, 2012). Published statistics provide only the total number of vehicles entering the country with no further details on vehicle technical specifications or fuel consumption. Furthermore, there are no available data or estimations[6] on the issue of fuel tourism in Bahrain or in the Saudi Arabia where the gasoline price is lower[7].

[6]The National Oil and Gas Authority (NOGA) assumes that the amount of gasoline sold locally is consumed by Bahraini vehicles only based on the observations. No surveys were conducted to verify this assumption.
[7]The Gasoline price is 0.16 US $ per litre in Saudi Arabia and 0.27 US $ per litre in Bahrain (The World Bank, 2013)

One should note that all vehicles in Bahrain have to pass an annual car inspection. The inspection is compulsory[8] in order to ensure the safety measures of the on-road vehicles. However, it is not mandatory during the inspection to collect transport data, such as the distance travelled and vehicle engine power.

2.3. The regulatory framework and plans

Bahrain is not currently bound by any Greenhouse Gas (GHG) reduction targets. It has prepared and submitted two national communication reports to the United Nations Framework Convention on Climate Change (UNFCCC) in 2000 and 2012. Post-Kyoto agreements are continuing to cut global emissions of GHG's and further commitments are expected to include developing countries in 2020.

On the national level in Bahrain, sustainability and energy efficiency issues have been stated in the National Environment Strategy, the Economic Vision 2030, and the second communication report to the UNFCCC. However, no specific targets or action plans have been developed yet. There is no car manufacturing industry in the country, and Bahrain still has not introduced any CO_2 emissions or fuel economy standards yet. This implies that there is no control over the imported vehicle specifications except for the regional requirements of the Standardization Organization for GCC.

On a positive note, strategic plans towards sustainable transportation are being discussed in depth. Future plans aim to increase the public transport share of the passenger transport mode from 11% today up to 25% by 2030. However, these plans are not yet finalized.

2.4. Fuel consumption and CO_2 emissions

Passenger vehicles in Bahrain rely heavily on gasoline. In 2010, more than 93% of the total vehicles, including 99.5% of passenger vehicles, have gasoline engines whilst the remaining percentage uses diesel. Therefore, gasoline usage has experienced an increase in local consumption with an average annual growth rate of 5.7% during the last decade. This increase was a result of the dramatic increase in the number of passenger vehicles, as shown in Figure 2 (CIO, 2012). The local gasoline consumption share of the total production has also steadily increased during the same period. This consumption share was at 77% in 2010 compared to only 43% in 2002. Consequently, Bahrain's exports of gasoline have decreased due to this increasing trend of local gasoline consumption. If this trend continues, concerns over transport fuel security and availability may increase. By then, Bahrain will no longer have gasoline exports nor the benefit of its revenues.

[8] Except for the first four years of the newly-manufactured vehicles

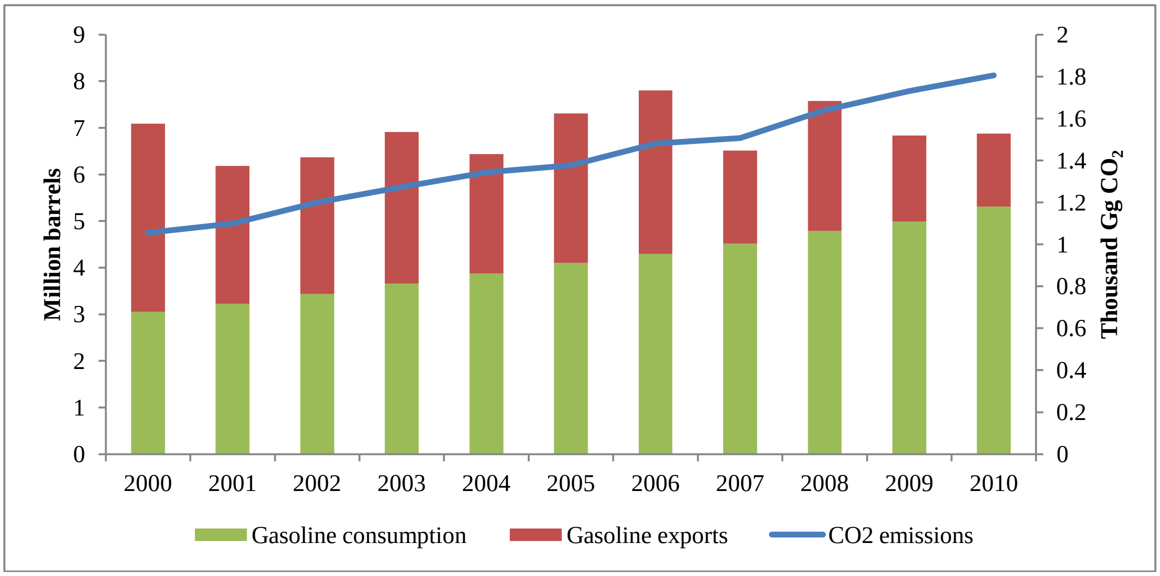

Figure 2: Development of gasoline consumptions, exports and CO_2 emissions from passenger vehicles between 2000 and 2010

Source: CIO, 2012; PMEW, 2012; our calculations

Note: G gCO_2= Giga gram CO_2

In terms of CO_2 emissions from passenger vehicles, our own calculations show that more than 60% of the CO_2 emissions from the road transport sector in 2010 were from passenger vehicles. These calculations were based on statistics from the Second National Communication Report to the UNFCCC (PMEW, 2012). The nearly complete reliance on gasoline has resulted in an average annual increase of 5.5% in CO_2 emissions between 2000 and 2010 (PMEW, 2012). Despite the relatively low share of the carbon emissions from passenger vehicles at 6.8% of the country's total emissions in 2000 (PMEW, 2012), this rate has been gradually increasing since 1994 when it was 4.9% of the country's total emissions (PMEW, 2005). Therefore, this emissions rate is one of a high priority to be controlled and managed.

Mitigating CO_2 emissions from passenger vehicles in Bahrain goes beyond saving the environment. It correlates with oil security issues as well as human health. Additionally, heading towards a more sustainable transport sector ensures the country's compliance with any future legally binding international agreements and obligations.

In summary, we can say that the CO_2 emissions issue from passenger vehicles in Bahrain is framed within the context of a number of factors. The current practices, socio-economic situation, and the legislative framework all contribute to this matter. On one hand, notable increases with respect to passenger vehicles, gasoline consumption, and carbon emissions have occurred between 2000 and 2010. On the other hand, major gaps exist in transport-related indicators required to design carbon mitigation strategies and scenarios.

3. Related work

Schipper (2009) described the identification of vehicle fuel use and fuel economy as a '*complex matter'*. This 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, average distance travelled and the average fuel economy (He et al., 2005). 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 taking into account engine size, efficiency, power, weight, automatic transmission and air conditioning (Schipper, 2011; Meyer and Wessely, 2009; Scholl et al., 1996). The travel time and any controlling vehicle usage policies may also contribute to the vehicle's carbon emissions.

The Global Fuel Economy Initiative comes as an effort of five organizations[9] to promote improvements in vehicle fuel economy. This initiative aims to achieve 50% improvements by 2050 in all cars globally compared to that in the year 2005. This initiative's main activities include data development and analysis, policy support, and awareness raising (GFEI, 2013a).

A literature review has been conducted to shed light on different available approaches that deal with transport data limitations, in particular those that have gained experience in their own context.

According to Schipper (2011), there are three bottom-up approaches that can be adopted to close knowledge gaps with regard to traditional transport data. The first approach is to conduct national surveys to document fuel consumption and vehicle use. This method has been applied in a number of countries including Australia, USA and France (Schipper, 2011). Surveying a representative sample can provide accurate and reliable data. However, a number of concerns had arisen when this approach was considered in terms of sample size, the time available, and budget required to obtain the data. The second approach is to develop different models that calculate transport data using available resources and observations. Examples of the application of this approach can be found in Germany and Japan (Schipper, 2011). Although this process might be less time-consuming with fewer requirements, the results need to be calibrated through surveys. Missing the surveys will lead to circularity when performing the calculations. The third approach is a combination of modelling and surveying, as some indicators can be collected during national surveys while the others can be obtained from computer modelling (Schipper, 2011).

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) (2011), GHG emissions from passenger vehicles can be calculated through multiplying the total gasoline consumption by the CO_2 emissions

[9]FIA Foundation, International Energy Agency (IEA), International Transport Forum (ITF), United Nations Environment Programme (UNEP), and the International Council on Clean Transportation (ICCT).

factor for gasoline (i.e. 8887 grams CO_2 per gallon). The same calculation was adopted by the IPCC to prepare GHG emissions inventory reports (IPCC, 2006).

US EPA (2011) adopts another approach to calculate CO_2 emissions per mile driven using the fuel economy data (Miles per Gallon - MPG) (Eq. 1). The total CO_2 emissions per vehicle can be obtained by multiplying the result by the annual miles driven (Eq. 2).

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

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

In China, He et al. (2005) had calculated the vehicle miles travelled (VMT) for the different types of vehicles. They utilised available data published in the Statistical Yearbook including load capacity and total passenger traffic volume. They also considered findings of relevant research and fuel economy inputs compiled by governmental authorities and consultant companies. A similar approach that used modelling was employed to portray passenger transport and its energy use in India (Singh, 2006; Singh et al., 2008), Indonesia (Atabani et al., 2012), Malaysia (Ong et al., 2011), Mexico (Sheinbaum-Pardo and Chavez-Baeza, 2011; Solis and Sheinbaum, 2013), South Korea (Eom and Schipper, 2010), and Thailand (Pongthanaisawan and Sorapipatana, 2013).

Kelly et al. (2009) carried out another study that estimated the annual vehicle mileage and emissions in Ireland. The study utilised empirical vehicle data obtained from national car tests. The data sets included vehicles' technical characteristics and distance travelled. In Jennings et al. (2013), a simple linear regression was used to examine the relationship between vehicle mileage and adult car ownership rates prior to the introduction of the national car inspections.

A different approach was used to validate modelling results in Japan (Kudoh et al., 2004). The actual fuel consumption data was collected from volunteer drivers through an '*internet-connected mobile-phone system*' and were compared to the modelling results. In Austria, another method was developed by Meyer and Wessely (2009) to calculate the fuel economy of passenger vehicles. The technical specifications of a selected sample were collected from published reports and then utilised in the technical performance trend analysis.

Kennedy et al. (2010) used three different approaches to quantify the GHG emissions from ten global cities. They found out that the fuel sales amount was appropriate in cities where there was a '*commuter shed*' and most of the trips occurred within the city boundaries. The second approach was to estimate the gasoline consumption by using the total mileage and vehicle fuel economy. The total mileages were either obtained from computer modelling or surveys. The third approach was to scale down the regional gasoline consumption to the city's level.

In summary, three main approaches are used to close the information gaps with regard to transport data: computer modelling, surveys, or a combination of both. All of the above-mentioned research approaches have specific data requirements that are not readily available in the case of Bahrain. All of these approaches have benefited from and access to (some) published data, previous research or surveys. None of these has suffered from a lack of data (expect in Meyer and Wessely, 2009). Therefore, we had to look for other methods developed for situations that were similar to ours.

The Arab Forum for Environment and Development *(*AFED*)* (2011) in its Energy Efficiency Handbook, acknowledged the existing information gaps in Arab countries. Therefore, it suggested using a number of websites[10] to obtain estimations for the per passenger vehicle CO_2 emissions rates. This suggestion seemed to be applicable to the case of Bahrain, and further work was carried out to take it to the implementation stage.

The only relevant research study was from Alnaser (1995) pertaining to the national level. In his study, Alnaser developed an empirical equation that related the vehicle fuel consumption to vehicle weight, distance travelled, and time taken for the trip. He used 13 gasoline vehicles[11] with weights less than 1500 kg to carry out the measurements and calculations.

4. Methods and data set

The following steps describe the methodology and dataset we used to carry out the study. These are arranged based on the paper's three main objectives:

4.1. Passenger vehicle population profile

In order to prepare a passenger vehicle profile, we conducted an extensive literature review. The purpose was to gather information related to passenger vehicles in addition to some influencing factors (e.g. population and economy). Furthermore, we compiled on-road vehicle data from the General Directorate of Traffic – Ministry of Interior for the period from 2000 to 2010. The dataset was received in a set-up from Microsoft Access and included some of the vehicle characteristics including the plate type, vehicle make, model, year manufactured, colour, engine size (measured in cubic centimetres – cc), and weight (measured in kilograms – kg).

A number of tasks involved with data processing and management were undertaken. First, the scale of the obtained data set of more than 400,000 vehicles appeared as a challenge that required considerable processing power. This led us to use the SPSS[12] for better data handling and management. We had another challenge which was related to the vehicle classification system. The vehicle registration system in Bahrain distinguishes between 18 different groups of vehicles based on their use. Therefore, the passenger vehicle number was not readily available and we had to calculate that. The

[10] The Car-Fuel-Data portal http://carfueldata.direct.gov.uk/ , and The Next Green Car http://www.nextgreencar.com/
[11] In addition to two diesel vehicles
[12] SPSS stands for Predictive Analytics Software, formerly known as the Statistical Package for Social Sciences. SPSS can perform both descriptive and inferential statistics.

definition of passenger vehicles used for the classification purpose in this study includes cars and sport utility vehicles (SUVs) that are designed to carry passengers. Trucks, buses and motorcycles are not included in this category.

The passenger vehicle profile section pays more attention to the technical improvements throughout the observation period, i.e. the engine size and vehicle weight. This analysis is mainly descriptive and focuses on the new vehicles to show how they evolved over time.

4.2. Calculation of missing transport-related indicators

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

We followed the steps below to carry out the calculations:

- The data set was split into 22 subsets representing 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 in order to select representative samples. Technical parameters of the vehicle determined its carbon emissions and fuel economy. Since the engine size is the only common factor between the data set and the websites, from which missing data can be collected, and we used this as a grouping factor. Since there is no classification system to the passenger vehicles based on their size, we consider those with engine capacity more than 3000cc large vehicles[13].
- Random stratified samples were drawn from each subset using the SPSS. We took the first set of samples based on the engine size groups from the newly registered vehicles between 2000 and 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 (Bartlett et al., 2001) was used to determine the minimum sample size as follows:

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

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

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

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

It is noteworthy to mention that we addressed and eliminated major outliers based on the engine size. This method was used because the data was mixed with data regarding engine power.

[13] Due to different categorization systems available worldwide, we considered the Australian system as it uses the engine capacity among the classification factors.

Four main elements of the data set were utilised to obtain CO_2 emissions and fuel economy per passenger vehicle, namely the vehicle make, model, manufacturing year, and the engine size. We used the US fuel economy website[14] to get the CO_2 emissions and fuel economy per passenger vehicle data. A further challenge in this study was to look for sources that provided both reliable data on the missing indicators, and vehicle models similar to those sold in the GCC countries. The suggested sources as indicated in AFED's report, covers models available in the European Union's (EU) market for vehicles that substantially differed from the ones we were looking for. Therefore, we had to explore other government and non-government websites until we settled on the US fuel economy website.

- We then indicated the dominant vehicle manufacturers for the 2010 model year. The CO_2 emission was then calculated from representative samples drawn from each of the major car companies' sales in Bahrain. This step was taken to determine any differences in carbon emissions of new models sold in Bahrain and some selected countries
- Calculate the average annual distance travelled per passenger vehicle through solving the following equation backwards (Wright and Fulton, 2005). Total emissions published in the 2nd communication report to the UNFCCC, number of vehicles, and the calculated CO_2 emission per vehicle are all used to calculate the distance travelled.

*Total emissions = number of vehicles * distance travelled * emissions per vehicle-distance travelled* (4)

- Since there were no previous surveys on vehicles mileage, we conducted a limited survey of 555 vehicles in different ministries, universities, and markets, using 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.
- Findings were then compared to the published numbers and to that of selected countries worldwide.

4.3. Development of future scenarios

We used our 'novel' findings to develop future scenarios that would provide transport CO_2 emissions and energy demand projections. The time span for these developed scenarios is from 2010 to 2030 with 2010 as the base year and 2015 as the first implementation year. The year 2030 was selected as the end year to match with Bahrain Economic Vision 2030.

The designed scenarios examine the effect of different fuel economy improvements regarding CO_2 emissions and energy demand of passenger vehicles in Bahrain. Given the limited data availability, we used the passenger vehicles number, the fuel economy, and the distance travelled data to develop future models. This method was also adopted

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

in a number of research studies (e.g. Zachariadis and Samaras, 2001; Kennedy et al, 2010; and Solis and Sheinbaum, 2013). We assumed that fuel economy remains constant throughout the lifespan of the vehicle and that the vehicle's average lifespan is 25 years. Additionally, we used the last decades' growth rates averages for the passenger vehicle number. We also assumed that the modal split of passenger transport is constant due to data limitations. Furthermore, we assumed that the distance travelled is decreasing by an average of 1.5% annually following the same trend as that of the last decade.

Based on these assumptions (Table 1), three different future scenarios were developed: do nothing (Business-As-Usual, BAU), do the minimum (low fuel economy improvements), and do the maximum (high fuel economy improvements). In the fuel economy improvements scenarios, we assumed that Bahrain will achieve the current fuel economy level for the EU by the year 2030, while EU's target for the year 2020 is set as Bahrain's target for the year 2030 under the 'do the maximum' scenario.

Table 1: Assumptions used to develop future scenarios for passenger vehicles in Bahrain

Factor / Scenario	BAU	LOW improvements	HIGH improvements
Passenger vehicles	7.3 % p.a.	7.3 % p.a.	7.3 % p.a.
Fuel economy of new vehicles	0.7% p.a. (11.2 km/l by 2030)	3.3% p.a. (16.5 km/l by 2030)	6.1% p.a. (24.4 km/l by 2030)

We utilised the Long-range Energy Alternatives Planning System (LEAP) to build the three future scenarios. LEAP is among the available bottom-up models that can work with minimal data and does not require a high level of expertise. Moreover, LEAP is increasingly being used in the preparation of national communication reports on climate change for more than 85 countries, including Bahrain. It is also used in research in more than 150 countries around the world (Heaps, 2008).

Specifically, LEAP offers different methods for transport data modelling (e.g. based on fuel economy, distance travelled data, and on transport intensity), depending on the level of the available data in addition to the desired outcome. Moreover, it saves the time and effort required to perform sensitivity analysis and test different future targets impacts. For instance, LEAP allows for data interpolation, functions use, or end year target settings. It also allows for combining scenarios and exploring the economic impacts in addition to the environmental effects of different options. Therefore, LEAP was selected in order to build future models in this study instead of just using a simple Excel worksheet so that it can be used for further CO_2 emission mitigation option appraisals.

5. Results and discussion

The study results are presented in this section based on the paper's main objectives:

5.1. Passenger vehicle population profile

Using the limited data available, we tried to portray the picture of the passenger vehicle fleet in Bahrain for the first time. Descriptive analysis of the on-road vehicle data set indicates a steady proportion of passenger vehicles throughout the analysis period between 2000 and 2010 (Figure 3). Passenger vehicles made about 83.5% (370,564 vehicles) in 2010 of the total vehicle fleet in Bahrain. When compared to the EU (87.1%) (ACEA, 2010), passenger vehicle's proportion of the on-road vehicles in Bahrain is relatively lower. However, it is still higher than that of some countries, such as New Zealand (77.6%) (Ministry of Environment - New Zealand, 2009). This could be due to the diversity of transportation modes used for passenger and freight, public, and the proportion of non-motorized transportation used in other countries. The situation has not changed much over the analysis period with regard to other modes of transportation in Bahrain, and therefore the passenger vehicle's proportional share was insignificantly changed.

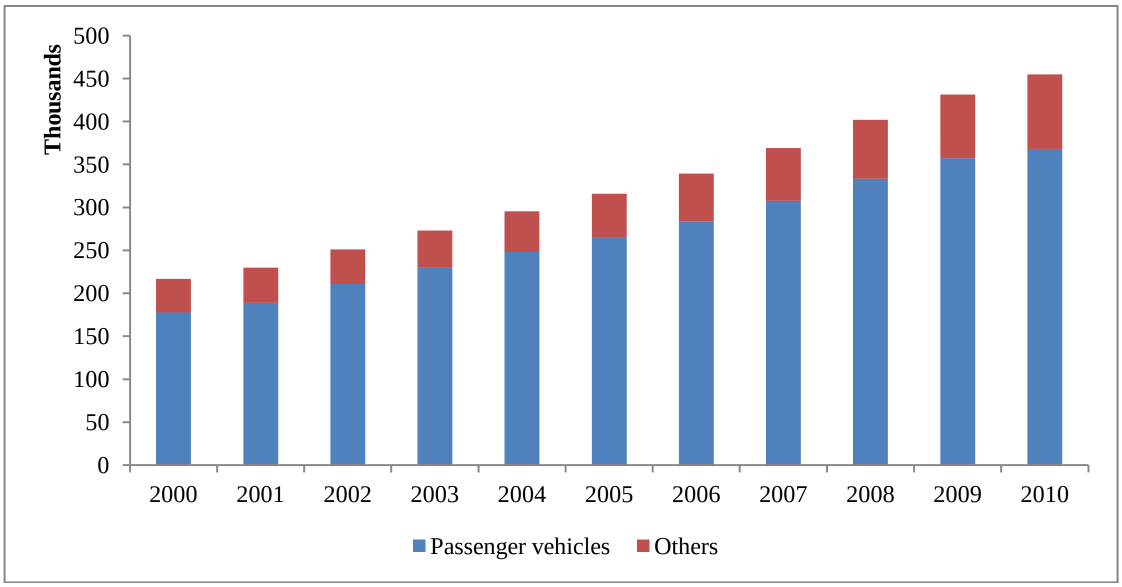

Figure 3: Passenger vehicles' proportional share of the total vehicles in Bahrain between 2000 and 2010

Further investigations showed that the average age of passenger vehicles in Bahrain is approximately 10.5 years. Again, we compared this number to selected countries in order for it to be meaningful. We found that the average age of vehicles in Bahrain is slightly higher than that of the EU (8.2 years) (ACEA, 2011). More specifically, it is higher than the UK (7.1 years) and Germany (8.1 years), but closer to Greece (10.7 years) and slightly less than Slovakia (11 years) and Finland (11.6 years). The age factor of a vehicle contributes to the entire fleet of passenger vehicle emissions as new vehicles should benefit from technological advances and therefore have less CO_2 emissions.

Looking at the passenger vehicle fleet in terms of technical performance, we concentrated on the engine size and weight only. Figure 4 depicts the distribution of passenger vehicles based on their engine size. A remarkable increase can be observed in the number of vehicles with an engine size of less than 3000cc. These vehicles make up around 70% of the total on-road passenger vehicles registered in 2010. Although vehicles with this engine size might be perceived as small to medium-sized vehicles in Bahrain, they are considered as luxury vehicles in other countries such as Singapore (engine capacity >2001 cc) (Seik, 1998).

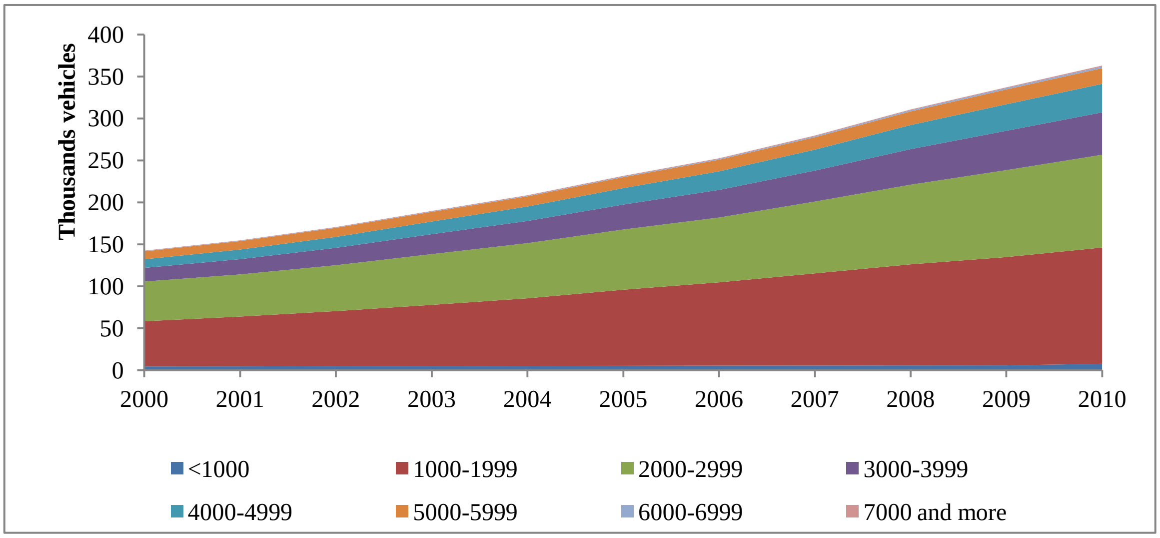

Figure 4: Development of engine size (cc) of the passenger vehicle population in Bahrain between 2000 and 2010

We observed a similar trend with respect to the weight of passenger vehicles (Figure 5). The number of vehicles that weigh more 1000 kg is growing at a rate of 10% per year on average, whilst the number of less weight vehicles is growing at a slower rate of around 5% on average.

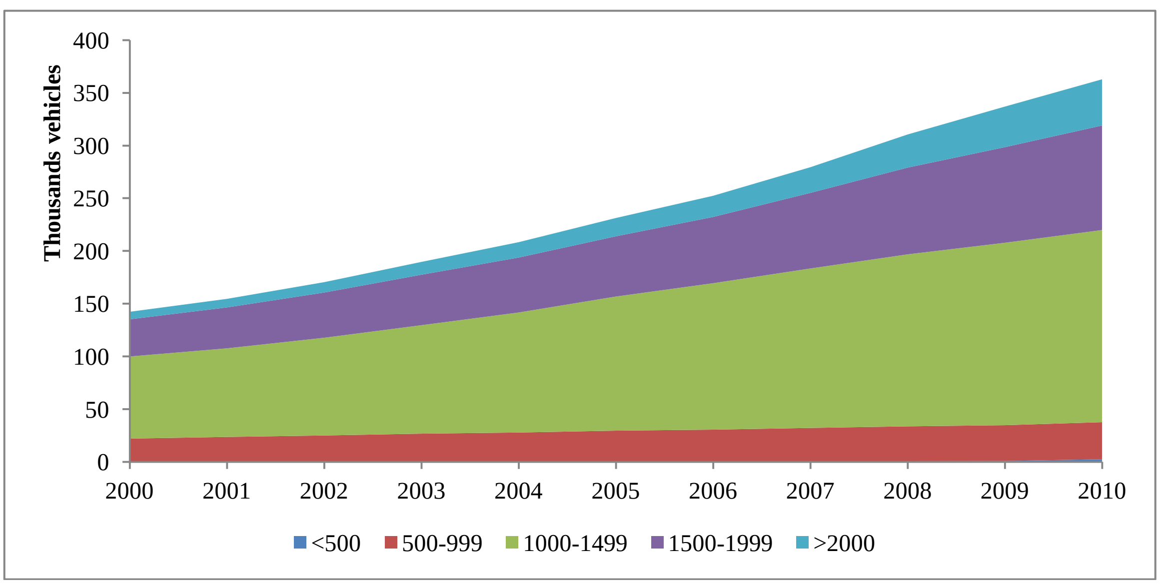

Figure 5: Development of the passenger vehicle population weight (kg) in Bahrain between 2000 and 2010

The notable increases in the engine size and vehicle weight of new models reflect an increasing interest in the buying large vehicles. This trend was predicted by Alnaser (1995) and Eltony (1996)[15]. Both studies concluded that shifting towards more and larger vehicles will start soon in Bahrain, which is evidenced in this paper. A similar trend is expected to be found in other GCC countries as suggested by Eltony (1996), but the issue is yet to be investigated.

There are many reasons that may contribute to these trends in Bahrain, however, none is evidenced yet. Social factors and how people perceive their vehicles are among those reasons, in addition to economic development. Subsidized fuel prices are another factor that may encourage the increase of large vehicle number. Furthermore, the absence of any regulatory framework on a sold vehicles' efficiency and emissions can influence the buyers' preferences and choices.

5.2. Calculation of transport-related indicators

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 2). This number has been fluctuating during the observation period ending with a decrease in 2010 of 5.1% compared to the year 2000.

Table 2: 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

Further investigations were carried out 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 2010 models which indicates a decrease compared to the year 2000 (254 g CO_2/km) as shown in Table 3.

Table 3: 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
EU	172.2	169.7	167.2	165.5	163.4	162.4	161.3	158.7	153.6	145.7	140.3
Bahrain	254	260	250	244	243	237	237	236	247	242	238

Source: EEA, 2013; our calculations

Once again, as shown in Table 3, 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 of the year 2000 (172.2 g CO_2/km).

[15] These are the only relevant studies that we found

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 being 7 km/litre in 2007. It also demonstrates improved energy economy for passenger vehicles when compared to that of the USA's (8.7 km/litre) (RITA, 2013). The average fuel economy of new vehicles has fluctuated over the period 2000-2010 with an average annual increase of 0.7%. When compared to the fuel economy trend of new vehicles in the USA, the gap widens over time in favour of the USA as shown in Table 4.

Table 4: A comparison between the average fuel economy of new passenger vehicles registered in the USA and Bahrain between 2000 and 2010 (km/litre)

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

Source: RITA, 2013; our calculations

The Global Fuel Economy Initiative figures show that the average fuel economy for new vehicles in non-OECD[16] has decreased from 13.3 km/l in 2005 to 13 km/l in 2008 (GFEI, 2013b). Although a different trend is found in Bahrain, the fuel economy figures are obviously lower than the non-OECD countries' average.

In order to locate the exact differences between the passenger vehicles specifications in Bahrain and that in the EU and Australia, some additional analysis was conducted using the 2010 model year vehicles. We performed a comparison between the dominate manufacturers' sales in Bahrain, EU and Australia for that purpose. 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 5), whilst the numbers from Bahrain are closer to that from Australia. This could be a result of number of factors including dissimilar weather, consumption patterns, alternative modes of transportation, vehicle age, and fuel economy standards.

Table 5: Average CO_2 emissions for a number of vehicle makes in Bahrain, EU and Australia in 2010 (g CO_2/km)

Make	EU	Australia	Bahrain
Toyota	129	222	234
Honda	144	194	226
Nissan	147	231	216

Source: EEA, 2010; our calculations

We calculated another important transport-related indicator for the passenger vehicle fleet in Bahrain. Unlike the previous ones, the vehicle-use intensity can be found in official reports published before 2008. This indicator was calculated based on the fuel

[16]Organisation for Economic Co-operation and Development (OECD)

consumption data, assuming 7 km/litre for fuel efficiency. Modifications on the calculation method were suggested[17], 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 Eq. 4 (Wright and Fulton, 2005), we got about an 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 the 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 to 9.6 km/litre. Table 6 demonstrates the average annual distance 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 (Table 7). There are many factors that explain this trend. The fuel economy of passenger vehicles may have significantly improved, (yet this is not the case here), the distance travelled has decreased, or the issue of fuel tourism especially that the Saudi Arabia sell gasoline at a relatively lower price. However, further research is recommended to explore this trend.

Table 6: 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: General Directorate of Traffic, 2010; our calculations

Table 7: Gasoline consumption and gasoline vehicles in Bahrain between 2000 and 2010

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Gasoline consumption (K TOE)	386	407	434	462	489	518	543	570	605	629	671
Gasoline vehicles	201078	213236	232908	253557	274209	293149	315097	342547	372943	400313	422109
The ratio	0.0019	0.0019	0.0019	0.0018	0.0018	0.0018	0.0017	0.0017	0.0016	0.0016	0.0016

Source: General Directorate of Traffic, 2010; CIO, 2012; our calculations

Nevertheless, the limited survey result validates that of our calculations. The survey reveals that the average annual distance travelled by a passenger vehicle that has never travelled abroad equals to 17,276 km. This number is 2.7% only less than the calculated number. It is worth 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 (Table 8). This may be due to the different passenger transport modes available in those countries, whilst private passenger vehicles

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

represent the main transport mode in Bahrain. Other factors affecting the average distance travelled include geography, patterns of urban planning, and consumer behaviour.

Table 8: Distance travelled in selected countries

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

Source: IRF, 2011; RITA, 2013; our calculations

a Calculated from IRF data

b Obtained from RITA 2013

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 considerably lower in Bahrain. Consumption patterns and lifestyle definitely contribute to vehicle model selection; however, another factor controls the situation in the USA that is fuel economy standards. Fuel economy standards are set at 11.7 km/litre for 2010 models in the USA. This 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 may 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.

5.3. Development of future scenarios

We used the previously mentioned findings to develop three different future scenarios with regard to the fuel economy of passenger vehicles in Bahrain. The CO_2 emissions and the gasoline demand projections are illustrated in

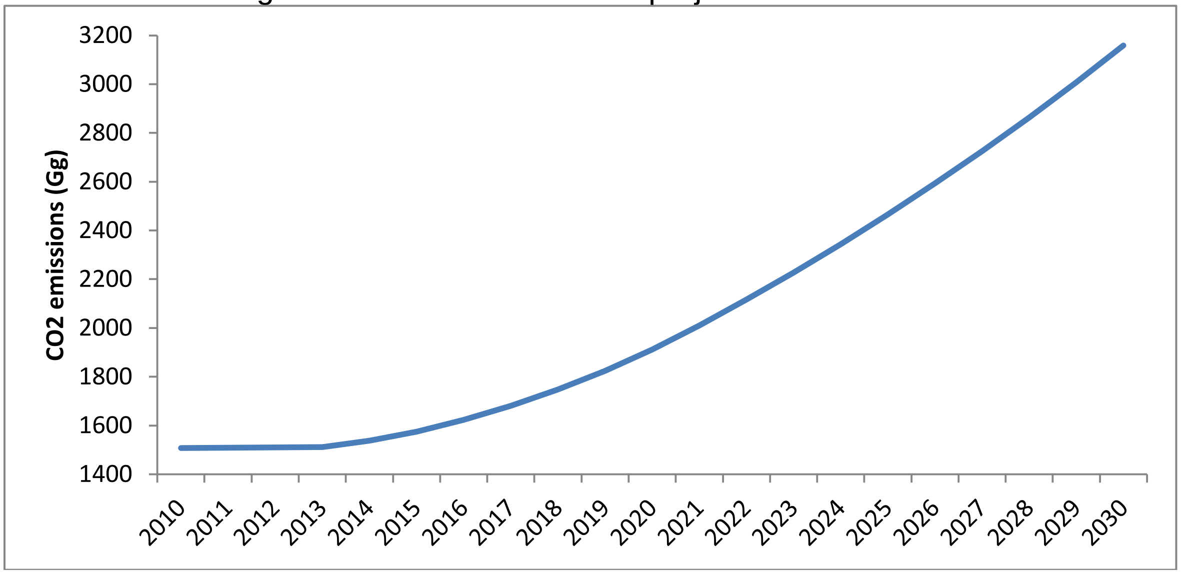

Figure **6** and Figure 7.

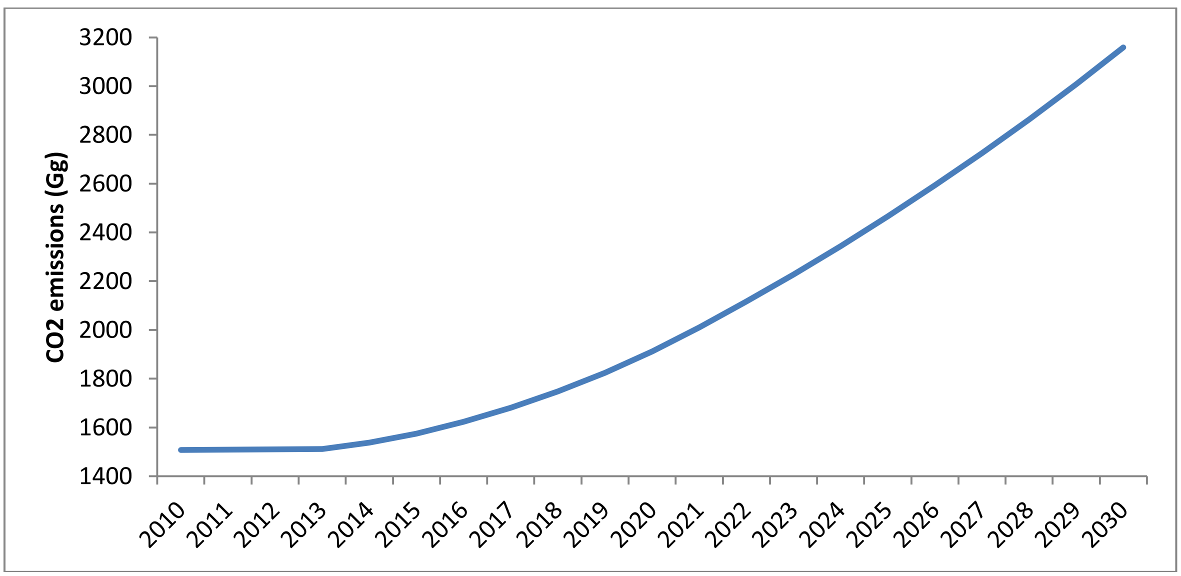

Figure 6: Projected CO_2 emissions for passenger vehicles in Bahrain under the business-as-usual scenario for the period 2010 – 2030 (Gg CO_2)

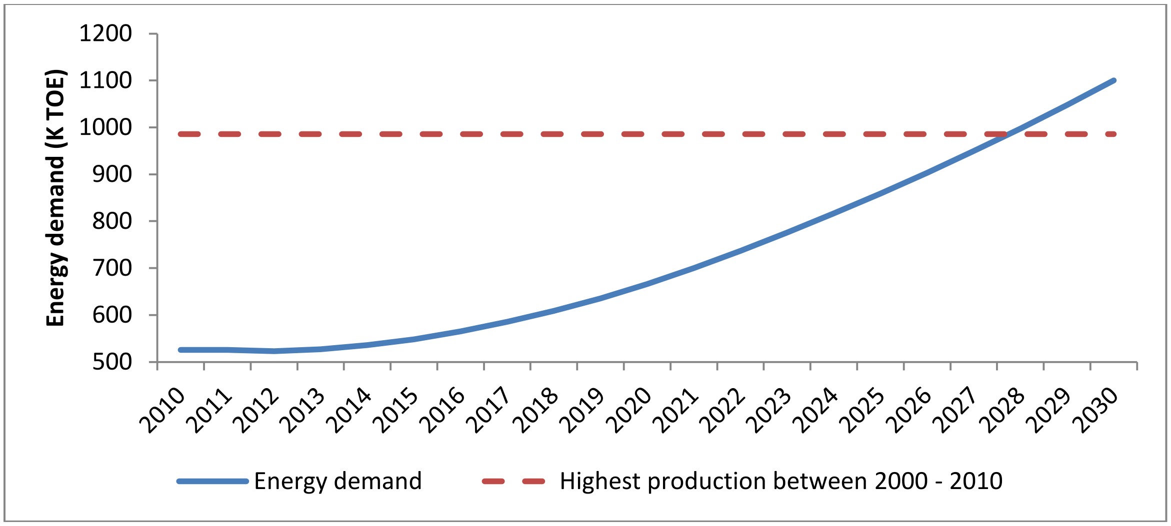

Figure 7: Projected energy demand for passenger vehicles in Bahrain under the business-as-usual scenario for the period 2010 – 2030 (K TOE)

Under the business-as-usual scenario (BAU), the passenger vehicles' energy demand and CO_2 emissions are expected to stabilize during the first few of years due to the stock turnover being that approximately 15% of the stock is above 20 years of age. A rapid increase in the CO_2 emissions was then projected with an average of 4.6% annually. This number will be almost double in 2030 compared to the base year 2010. Furthermore, local demand on gasoline will jump with the same rate reaching 100% of the country's production in the year 2028. By then, Bahrain will have to produce the highest amount of gasoline it did during the last decade. Most importantly, Bahrain's exports of gasoline will diminish until they stop by 2028 if no policy interventions are made.

We also developed two mitigation scenarios to show potential savings of low and high improvements in vehicle fuel economy (Figure 8 and Figure 9). All other factors are disregarded and assumed to be constant following the same pattern of the last decade. The low improvements mitigation scenario indicates a possibility of about14% reductions in energy demands and CO_2 emissions. Setting more stringent standards is expected to achieve 27% compared to the BAU scenario. It should be noted that when applying the low fuel economy improvement assumptions, fuel shortages will be delayed until after 2030 compared to the BAU scenario.

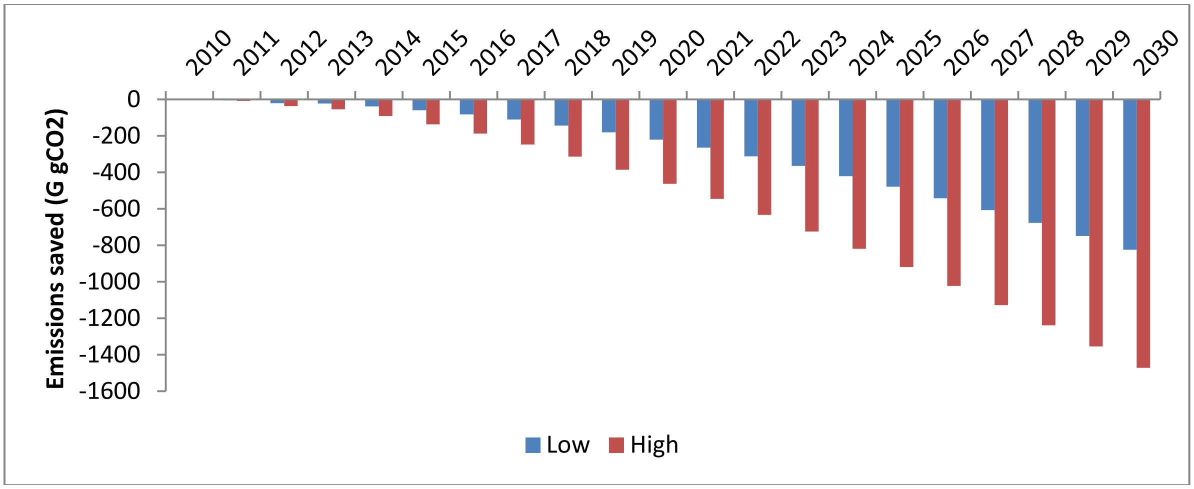

Figure 8: Potential savings of CO_2 emissions from passenger vehicles in Bahrain under two mitigation scenarios for the period 2010 – 2030 (Gg CO_2)

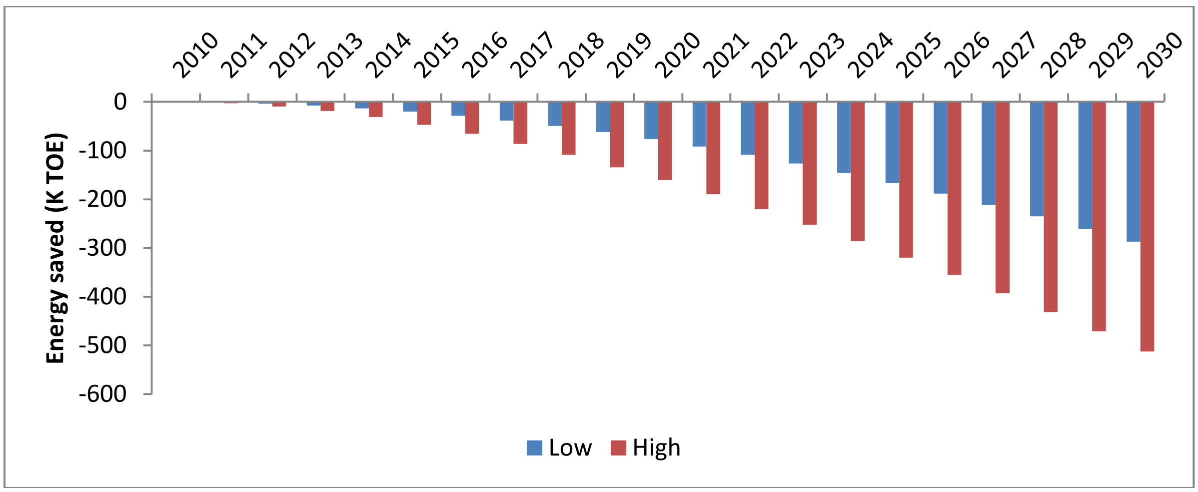

Figure 9: Potential savings of energy consumed by passenger vehicles in Bahrain under two mitigation scenarios for the period 2010 – 2030 (Gg CO_2)

The developed scenarios show that even with high growth rates in both population size and passenger vehicle number, CO_2 emission and energy savings can still be achieved. The potential of a further considerable amount of reductions is possible especially with the absence of almost any other mitigation strategies or instruments.

6. Conclusions and policy implications

This paper aims to provide a clear picture of the current status and future trends of the passenger vehicles in Bahrain in which the majority of the findings are presented for the first time. Profiling of passenger vehicles shows an increasing trend towards buying large vehicles. This trend was predicted by both Alnaser (1995) and Eltony (1996) and has been evidenced in this study. The passenger vehicles problem in Bahrain is not just about the increasing number of vehicles, but also about vehicle specifications, size, and fuel economy, as demonstrated in this study. One implication that can be drawn is that the increase in vehicle engine size and weight has offset the potential of significant savings gained from the wide distribution of small and more efficient vehicles. Although this could be a common problem that may 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 are yet to be developed for the country. Hence, this denotes abundant objectives for focusing policy framing and research to encourage the use of more efficient vehicles and the introduction fuel economy standards.

This research's findings show where Bahrain stands compared to some selected countries. Results reveal that although Bahrain might be performing better than some countries, it is still far away from the EU's model. In the BAU future scenario, concerns over the fuel security issue may arise, in addition to concerns over carbon emissions. By 2028, Bahrain will have to produce a larger volume of gasoline than at any other point between 2000 and 2010. This will place considerable pressure on the country's depleting resources. Bahrain may even lose its gasoline exports and may have to bear higher expenditure if current practices continue.

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.

Bahrain faces a challenging task in balancing its growing demand for fuel with the need to achieve sustainable transport and comply with any future international agreements or protocols. Before introducing any relevant policies, Bahrain needs to close the remaining information gaps (e.g. modal split of passenger transport, and load factors). Additionally, making the most of the annual car inspection will be beneficial through documenting the distance travelled and the engine power of each vehicle. Conducting large-scale surveys will be useful as well in order to explore the issues of the fuel tourism, distance travelled and fuel consumption. Data refinements can be carried out at a later stage to validate the results of this present study.

Although this research paper comes as an attempt to close some of the information gaps with regard to the transport sector in Bahrain, it has some limitations. First of all, CO_2 calculations and fuel economy depend mainly on only one official website, and therefore the accuracy of the results solely depends on these published numbers. Secondly, the same calculations depend on the specifications of passenger vehicles obtained from the General Directorate of Traffic. We tried to ensure accuracy of these through data processing and management, but we still may find some disorganised data especially with regard to engine capacity and power. Therefore, we highly recommend measuring the actual CO_2 emissions and fuel economy of a large representative sample in future research. This could then determine realistic thresholds during the fuel economy standards setting process.

Nevertheless, this research is the first-ever attempt at modelling the fuel use and carbon emissions of passenger vehicles in Bahrain, despite the poor availability and quality of transport data. The proposed 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 need to be paid closer attention to. Furthermore, the developed and tested bottom-up methodology used could be transferred to other GCC countries where similar situations may exist.

Bahrain will need to take the initiative towards achieving sustainability in the transport sector. Following the footsteps of other countries in the international community, learning from their experiences, and considering different options, and getting benefit from the global initiatives will all help put Bahrain on the right track. If further climate and energy-oriented policies with specific targets and action plans are addressed, considerable savings can be achieved. We intend to pursue additional research in this area in the near future to explore the effects of different policy packages.

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