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ORIGINAL ARTICLE

Mitigation of CO_2 emissions from the road passenger transport sector in Bahrain

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Abstract There is much optimism that the 2015 Conference of the Parties of the United Nations Framework Convention will yield an agreement on mitigation of climate change, to become effective in 2020. In this context, Bahrain represents a developing country with insufficient data to assess mitigation opportunities: its per capita carbon emissions rank among the world's highest, yet there has been no research on the reduction potential of its rapidly growing transport sector. We examine this reduction potential and the costs of various mitigation measures and, further, explore barriers and the view of policymakers and experts. Potential benefits of combined mitigation scenarios are also identified based on their acceptability. We adopt a modified participatory method to develop the scenarios, using the long-range energy alternative planning (LEAP) modelling system, and find that an integrated policy approach can deliver a 23 % reduction in carbon dioxide emissions, costing 108 United States dollars per avoided metric tonne, with politically acceptable scenarios. Better performance, however, would require less acceptable approaches. These findings are significant for decision-making in Bahrain and other Gulf Cooperation Council countries; national target preparation and the setting of fuel economy standards should be begun promptly. We offer lessons to other developing countries on the timely regulation of technical specifications and numbers of passenger vehicles. Participatory approaches to the assessment of mitigation measures can advance environmentally effective, economically feasible and politically acceptable scenarios. The global community can use these results to provide necessary technical and financial assistance to developing countries.

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1 Introduction

It is widely anticipated that agreement on a broad framework for mitigating climate change will be reached at the forthcoming United Nations Framework Convention on Climate Change Conference of the Parties, to be convened in Paris, France in 2015, with all parties committing to emission reduction targets starting in 2020. This includes developing countries, as agreed in Durban in 2011. However, because of the limited data available, there has been no research into the reduction potential of the rapidly growing transport sector in Gulf Cooperation Council (GCC) countries. Although not all countries have amassed the necessary data, this should not be an excuse for inaction regarding mitigation policy, especially given that the per capita carbon emissions in these countries are among the highest in the world.

In Bahrain, as in other GCC countries, high energy intensities[1] and energy consumption per capita are readily discerned. Carbon emissions are therefore also great, given the complete reliance on fossil fuels. The figure for carbon dioxide (CO_2) emissions per capita in Bahrain exceeds those for the United States of America (USA) and the Organisation for Economic Co-operation and Development (OECD) countries by 10 and 90 %, respectively (World World 2014a). This reliance on fossil fuels means that Bahrain has a highly carbon-intensive[2] economy, 107 times that of the USA and 150 times that of the OECD (IEA 2013). These figures highlight the need to reduce carbon emissions.

Trends in the carbon emissions of GCC countries are increasing, with an average annual growth rate of 6.6 % between 1994 and 2005. Transportation contributes an average of 13 % of the total emissions in these countries, with 6.8 % in Bahrain (PMEW 2012). The per capita carbon emissions of transport is high in most of GCC countries ranging between 4.7 metric tonne of CO_2 emissions (Mt CO_2) in the United Arab Emirates (UAE) and 2.3 Mt CO_2 in Bahrain (World Energy World Energy 2015). These figures exceed that of the European Union countries (1.8 Mt CO_2/capita) and Japan (2.2 Mt CO_2/capita) and are expected to increase further as a result of growing energy consumption if no new policies are introduced (Lahn and Preston 2013).

Published statistics indicate that the transport sector in the GCC countries contributes a considerable proportion (25 % on average) of total energy consumption, with an average 60 gigajoules (GJ) per capita compared with 52 GJ per capita in North America (IPCC 2014). Economic growth and population increase have contributed to a rapid growth of passenger vehicles in these countries. Vehicle ownership in Bahrain is 537 per 1000 people, a figure similar to that of the United Kingdom (UK) (523 per 1000) and Ireland (513 per 1000) (Fig. 1) (IRF 2011). However, energy efficiency in Bahrain is significantly lower due to rapid growth in the size and weight of new passenger vehicles in Bahrain, which result in slower growth of new vehicle fuel economy (Alsabbagh et al. 2013).

[1] Energy intensity is defined as a measure of the total primary energy use per unit gross domestic product (IEA 2014).

[2] Carbon intensity is calculated by dividing total carbon emissions by gross domestic product. An example is available at http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=91&pid=46&aid=31.

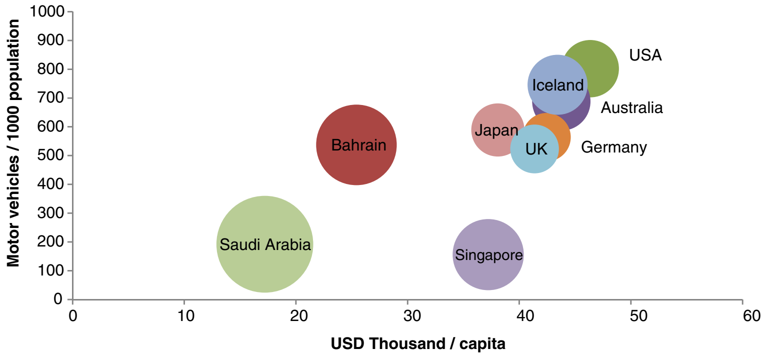

Fig. 1 Road sector energy consumption (in thousand metric tonnes oil equivalent/million vehicle-kilometre) is indicated by the size of the *circles*. Although vehicle ownership in Bahrain and Saudi Arabia is similar to that of developed countries, energy consumption is greater. This may indicate opportunities for improving energy efficiency

Adopting energy-efficient measures and reducing the rapid growth of energy demand in Bahrain will achieve two main goals. First, they will help to extend the life of the nation's crude oil resources, in line with a target identified by the government. According to the Energy Minister, Bahrain's proven crude oil reserve will run out within approximately 36 years (Gulf Daily 2015). By contrast, the proven crude oil reserves in other GCC countries are expected to last as much as 120 years in Kuwait, assuming that production remains constant at the 2010 level. Second, energy efficiencies and reduction of energy demand will contribute to the country's gross domestic product (GDP). Bahrain imports around 78 % of its crude oil, consuming 9 % of processed petroleum products locally and exporting the balance. This comprises 20 % of Bahrain's GDP. Consuming less petroleum products locally would be very beneficial because fuel prices are heavily subsidised in the country. Bahraini subsidies for oil and gas production and distribution were estimated to amount to 2.2 billion United States dollars (USD) in 2012 (Ministry of Finance 2013).

Despite the numerous mitigation measures available to reduce CO_2 emissions and energy consumption, there has been no clear energy and economic assessment in Bahrain. National communications relating to the United Nations Framework Convention on Climate Change suggest a number of measures, including improvements in fuel efficiency, the introduction of compressed natural gas (CNG) cars and the use of public transport. However, none of the national reports produced by the GCC countries have explored the issue of emissions reduction potential or its economic feasibility. In fact, only two countries, Bahrain and Kuwait, have prepared projections of their total energy consumption and CO_2 emissions. Such projections are crucial to decision-making in climate change mitigation and to setting CO_2 emission reduction targets.

The literature reveals numerous mitigation measures for passenger vehicles, although there is no internationally agreed upon classification system for these measures. The Fifth Assessment Report (AR5) of the United Nations Intergovernmental Panel on Climate Change (IPCC) (2014) highlights four main groups. These are journey avoidance, modal shifts, lowering energy intensity and reducing carbon intensity of fuels. The literature also cites various assessment approaches for exploring different trajectories toward low-carbon mobility. Backcasting is one of these, in which an emission target is set and potential paths are identified, either by researchers themselves (e.g. Ashina et al.

2012) or as developed within a participatory process (e.g. Tuominen et al. 2014). Another approach entails building forecast scenarios, mainly using economic analyses and environmental assessments. Projections of abatement cost, emissions reduction potential and energy use are parameters commonly used to build mitigation scenarios (e.g. Dedinec et al. 2013; Sharma et al. 2013; He and Chen 2013). A trend toward involving stakeholders in the assessment of mitigation measures is also evident. The research of Schmid and Knopf (2012) provides an example in which mitigation scenarios are first discussed with stakeholders, followed by economic analysis and environmental assessment. Finally, the plausibility of scenarios is discussed with stakeholders to identify any concerns related to social acceptance.

The present study provides insights into an unexplored area. Scenarios for Bahrain were obtained for the first time using bottom-up, calculated indicators. The possibility of adopting related mitigation measures within a similar socioeconomic and political context has not been explored previously. Further, we believe that the results can bridge the gap between work within a global context and the reality of its application within the GCC countries. The results and recommendations from this study can provide guidance to other GCC countries, especially given their similar contexts. The methods of the study represent a modified participatory model for assessing mitigation scenarios in the transport sector, which improves understanding and incorporation of policymakers and experts views.

The study has the following objectives:

1. Examine the CO_2 reduction potential that can be achieved for the road passenger transport sector in Bahrain, along with the abatement cost of this reduction.
2. Explore the views and preferences of policymakers and experts toward various alternatives for achieving low-carbon transportation in Bahrain.
3. Identify the combined effects of mitigation measures for scenario development, with a focus on the barriers, opportunities and co-benefits of the implementation of these scenarios.

2 Methodology

We employ a modified participatory model based on that developed by Justen et al. (2014) for policy packaging. In their model, policy measures were first selected and assessed and then presented to stakeholders for revision. After making necessary modifications, policy packages were implemented, monitored and evaluated. For the current study, this model was modified and applied to scenario building (Fig. 2).

2.1 Building future scenarios

2.1.1 Modelling method

We used the long-range energy alternatives planning (LEAP) modelling system to prepare the scenarios. LEAP is an accounting model that uses a bottom-up approach. It is a scenario-based tool for evaluating physical, economic and environmental impacts of mitigation measures or policies. Model inputs include demographic, economic and energy data (Heaps 2008; Suganthi and Aamuel 2012).

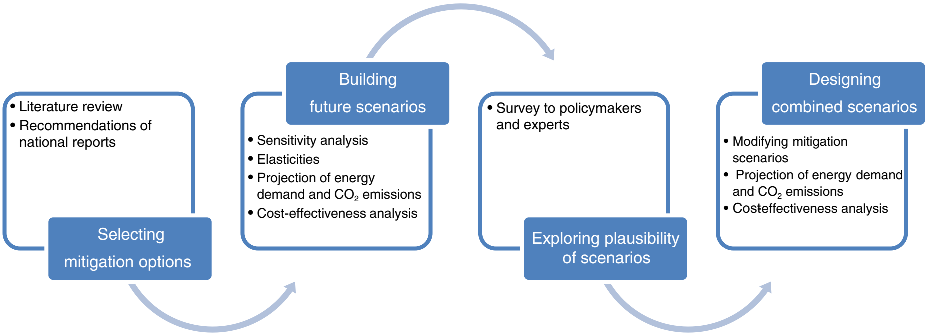

Fig. 2 In the first step, a literature review was performed to select a number of mitigation measures as subjects of analysis. The next step was to build future mitigation scenarios using different assumptions and price elasticity of demand. Future scenarios show energy demand, CO_2 emissions and cost of abatement for the period 2015–2030. The plausibility of future mitigation scenarios was explored in the next step, through semi-structured interviews conducted with policymakers and experts. Finally, the scenarios were modified, and combined scenarios were constructed to examine the combined effects of various mitigation measures

LEAP has been used in several studies across the world. For example, it has been used at the local scale in Seattle, USA, to assess measures for achieving a zero-carbon transport system (Lazarus et al. 2011). It has also been used in California to explore different energy alternatives through 2035 (Ghanadan and Koomey 2005). Other applications are discussed by Shabbir and Ahmad (2010) and Dhakal (2003) regarding the use of LEAP to calculate energy demand and emissions from the transport sectors in Pakistan (Rawalpindi and Islamabad) and Nepal (Kathmandu Valley), respectively. There have been recent applications of LEAP in developing countries, including China (e.g. Wang et al. 2011; Pan et al. 2013), Colombia (Palencia et al. 2014) and the Philippines (Ahanchian and Biona 2014).

The list of LEAP applications extends to national communication reports on climate change from more than 85 countries (Heaps 2008). This is mainly because LEAP can be implemented with minimal data and does not require substantial expertise to usefully employ. Furthermore, LEAP includes several approaches to calculating specific indicators. This flexibility is very important, especially in contexts characterised by limited data.

For calculating the energy demands and emissions of passenger vehicles, LEAP offers two calculation methods. These are activity analysis and stock-turnover analysis, to be chosen based on the available inputs. We selected the stock-turnover method, as described by the following equations:

$$\mathrm{Stock}_{t,y,v} = \mathrm{sales}_{t,v} \times \mathrm{survival}_{t,\, y-v}\,, \tag{1}$$

$$\mathrm{Stock}_{t,y} = \sum_{i=0,\ldots,v} \mathrm{stock}_{y,v,t} \tag{2}$$

(Stockholm Environment 2014), where

t	denotes the type of technology (i.e. the technology branch)
v	is the vintage (the year the technology was added)
y	is the calendar year
Sales	is the number of vehicles added in a particular year

Stock is the number of existing vehicles in a particular year
Survival is the fraction of vehicles surviving after a number of years and
V is the maximum number of vintage years.

We also compute

$$\text{Energy intensity}_{t,y,v} = \text{energy intensity}_{t,y,v} \times \text{degradation}_{t,\ y-v}, \tag{3}$$

Where *energy intensity* is the energy use per vehicle for new vehicles purchased in year y and *degradation* is a factor representing the change in energy intensity as a technology ages, which is 1 when $y=v$.

Energy consumption was calculated as

$$\text{Energy consumption}_{t,y,v} = \text{stock}_{t,y,v} \times \text{energy intensity}_{t,\ y,v}. \tag{4}$$

Energy-based emissions (e.g. CO_2 and other greenhouse gases) were calculated as

$$\begin{aligned}\text{Emission}_{t,y,v,p} = \text{energy consumption}_{t,y,v} \times \text{emission factor}_{t,\ y,p} \\ \times \text{EM degradation}_{t,\ y-vp},\end{aligned} \tag{5}$$

where p is any air pollutant criterion (CO_2 emissions in this case), *emission factor* is the emission rate for pollutant p (e.g. grammes/vehicle-mile) from new vehicles of vintage v and *EM degradation* is a factor representing the change in emission factor for pollutant p as a vehicle ages, which equals 1 when $y=v$.

A cost-effectiveness analysis was also conducted using LEAP to determine the abatement cost of CO_2 emissions. The cost for each mitigation scenario was calculated by dividing the incremental cost by the reduction in emissions (Borba et al. 2012):

$$\text{AAC}_{\text{scenario}} = \sum_t \frac{\text{NAC}_t^{\text{low carbon}} - \text{NAC}_t^{\text{reference}}}{\text{AE}_t^{\text{referebce}} - \text{AE}_t^{\text{low carbon}}} \tag{6}$$

where

AAC is the average cost of avoiding 1 Mt CO_2 in year t
NAC is the net annual cost for implementing each mitigation scenario and
AE is annual emissions.

2.1.2 Data sources

Basic transport indicators obtained from a bottom-up calculation were used to construct a baseline scenario (Table 1) (Alsabbagh et al. 2013). The dataset of registered vehicles was compiled from information available from the Bahrain General Directorate of Traffic, Ministry of Interior, for the period 2000–2014. Other data required to build mitigation scenarios were collected from peer-reviewed journals and published reports.

Table 1 Assumptions used to build business-as-usual scenario

Items	Assumptions (growth rate % per annum)
Base year	2010
Analysis period	2015–2030
Passenger vehicles stock	347,131
New passenger vehicles	28,035 (6.8)
Average fuel economy of new passenger vehicles	9.7 km/L (0.7)
Distance travelled per passenger vehicle per annum	17,751 (−1.5)

2.1.3 Building the baseline scenario

The baseline scenario was constructed for the period 2015–2030 with 2010 the base year. The year 2030 was selected as the end year in accord with *Economic Vision 2030* for Bahrain. Results of the baseline scenario were then used as a reference for the mitigation scenarios.

The scenario results were calibrated using historical data on the number of passenger vehicles for 2000–2009. The estimated number of passenger vehicles was then validated through comparison with the published statistics for the period 2011–2014. Mean bias error (MBE), root mean squared error (RMSE) and coefficient of determination (R^2) were calculated as follows:

$$\mathrm{MBE} = \frac{1}{\overline{y}}\sum_{i=1}^{n}\frac{\widehat{y}-y_i}{n}\times 100, \tag{7}$$

where

MBE is the percentage of mean bias error of estimation
$\hat{y}$ is the estimated value
y is the observed value
$\overline{y}$ is the mean of observed values and
n is the number of items.

RMSE is the percentage of root mean squared error of estimation:

$$\mathrm{RMSE} = \frac{1}{\overline{y}}\sqrt{\sum_{i=1}^{n}\frac{\left(\widehat{y}_1-y_i\right)^2}{n}}\times 100. \tag{8}$$

Finally,

$$R^2 = \frac{\left[\sum_{i=1}^{n}\left(y_i-\overline{y}\right)\left(\widehat{y}_i-\overline{y}\right)\right]^2}{\sum_{i=1}^{n}\left(y_i-\overline{y}\right)^2\sum_{i=1}^{n}\left(\widehat{y}_i-\overline{y}\right)^2}. \tag{9}$$

The number of passenger vehicles appears to have been well estimated in the model, with R^2>0.99. The errors for the MBE and RMSE results were less than 3 and 4 %, respectively, which is acceptable for forecasting (Pongthanaisawan and Sorapipatana 2013).

2.1.4 Building mitigation scenarios

Among the numerous mitigation measures available for the transport sector, only those recommended for GCC countries were explored because they are most likely to suit the specific socioeconomic context under consideration. We selected five main mitigation measures: (1) changing the current annual vehicle registration fee system to be based on a vehicle's CO_2 emission instead of its weight; (2) setting fuel economy standards; (3) market penetration of hybrid gasoline-based cars; (4) market penetration of CNG cars; and (5) improving the public transport system. These five measures were selected as examples of emission reduction potential. Other fiscal and management measures have been left to future study for two reasons. The first is to enable provision of required infrastructure and alternatives because there is no clear implementation of any mitigation measures at present. The second is to avoid placing financial burdens on society before providing alternatives.

Several scenarios were explored for each mitigation measure, using different assumptions, which are presented in Table 2. Some adjustments were made to the data to ensure compatibility with the Bahraini context. These include the following:

- Converting all monetary data to 2010 USD values (the base year of this study)
- Converting all units to match those used in the present study (e.g. converting miles per gallon (mpg) or litres per 100 km (L/100 km) to kilometres per litre (km/L) in relation to fuel economy)
- Assuming a lifetime of 25 years for transport infrastructure (e.g. gas fuelling stations and public transport); the cost of residual value was deducted because the analysis period was 15 years
- Calculating the average cost of CNG fuelling stations using data from the literature

In terms of achieving fuel economy targets, the costs of a selected sample of passenger vehicles in Bahrain were first compared with those sold in the USA (available from www.fueleconomy.gov), considering the same technical specifications. Given an almost complete match of these data, the average cost of the desired fuel economy based on engine size group was then calculated using data obtained from the aforementioned website. Costs of hybrid gasoline-based and CNG vehicles were also obtained from that website. All other cost assumptions were derived from the Bahraini context. These include data related to the registration fee system and public transport.

Within the same mitigation measure, only scenarios achieving a difference in emission reductions greater than 10 % relative to the low scenario were considered. This decision was made to limit the number of scenarios subject to further analysis.

2.1.5 Combining future mitigation scenarios

The mitigation scenarios were combined to create 50 combined scenarios. There was no restriction on the number of mitigation measures, because the main impetus for combination was avoiding contradiction among the selected measures. For instance, high and low fuel economy standards were not combined. Market penetration of CNG and hybrid cars is another example. Using LEAP, total emission reductions and costs were obtained for these scenarios. This method was borrowed from policy packaging, in which policy measures are first assessed and then combined within policy packages (Justen et al. 2014).

Table 2 Assumptions used to build mitigation scenarios

Mitigation measure	Scenario	Assumptions	Economic inputs	Sources of assumptions
Hybrid gasoline cars	Low penetration, low fuel economy	1 %, 17.7 km/L	Average cost difference per car=USD 6250	Fuel economy assumptions and costs are based on a calculated sample of cars. Data on vehicles are retrieved from: http://www.fueleconomy.gov/
	Low penetration, high fuel economy	1 %, 21.3 km/L		
	High penetration, low fuel economy	40 %, 17.7 km/L		
	High penetration, high fuel economy	40 %, 21.3 km/L		
Compressed natural gas cars	Low penetration	1 %, 13.2 km/L	Cost of fuel station USD 1.5 million (a station per 1000 cars), difference in maintenance cost=USD 1033 every 5 years, difference in car price: USD 7000 for new car and USD 2,000 for retrofitting.	Fuel economy assumption and vehicle cost are based on a calculated sample of cars. Data on vehicles are retrieved from: http://www.fueleconomy.gov/ Other costs were based on Windecker and Ruder (2013), Thamsiriroj et al. (2011), Whyatt (2010) and Colorado Energy Colorado Energy (2012).
	High penetration	25 %, 13.2 km/L		
Fuel economy standards (by 2030)	Low	15.4 km/L (the USA target for 2015)	USD 716	Vehicle costs are based on a calculated sample of cars. Data on vehicles were retrieved from: http://www.fueleconomy.gov/ Fuels economy for vehicles from each engine size class was calculated and average vehicle cost was obtained. Costs of vehicles from the same class with higher fuel economy were then calculated. The first cost was then subtracted from the second one to get additional cost.
	Medium	18.8 km/L (the USA target for 2020)	USD 858	
	High	23.5 km/L (the USA target for 2025)	USD 2067	
Registration fees (using 3 types of price elasticity of demand for each scenario: −0.04, −0.4, −1.1)	Low	- The CO_2 limits are not tightened over time (starting from <141 g CO_2/km till >300 g CO_2/km, with 20 g CO_2/km intervals) - Fees start from 0 up to USD 600		Running costs of cars in Bahrain are collected from car agents and insurance companies. Elasticity assumptions are based on the IPCC's fourth report (2007), Small and

Table 2 (continued)

Mitigation measure	Scenario	Assumptions	Economic inputs	Sources of assumptions
	Medium	Decreasing CO_2 limits after 10 years (starting from <141 g CO_2/km till >300 g CO_2/km, with 20 g CO_2/km intervals, then starts from <121 g CO_2/km)		Dender (2007) and Jorgensen and Dargay (2006).
	High	- Set up as the 'medium' scenario - Double duty rates - Fees start from USD 0 up to 1200 in phase 1 and USD 2400 in phase 2.		
Public transport		- Introducing light rail transit (LRT) system and improving the current bus rapid transit (BRT) system. - 2.8 billion veh-km is saved	Total capital cost: USD 5.3 billion Total maintenance cost: USD 513 million	Costs were obtained from a consultancy work carried out by SYSTRA-MVA (2008) based on a request from the Bahraini government.

A discount rate of 3.3 % was used to calculate the costs. This rate is the average for the period 2000–2010 for Bahrain. Registration fees are set here based on grammes of CO_2 emissions per kilometre (gCO_2/km). Savings from improving the public transport system are measured in vehicle-kilometres (veh-km)

2.2 Survey

2.2.1 Tools

Various techniques are available for fostering the involvement of stakeholders. These can be divided into two groups, *interactive tools*, including interviews, focus groups, public hearings and workshops, and *non-interactive tools*, including questionnaires and surveys (DETR 2000). We used a mix of these two approaches. Semi-structured interviews were conducted using a prepared questionnaire. This technique allowed exploration of the views and preferences of participants in an interactive way, as well as attainment of the desired response rate and collection of required information in a timely and efficient manner.

2.2.2 Target group

The policymakers and expert population targeted by this study included those with strong involvement in Bahrain's policymaking process who work in senior administrative positions (undersecretaries, directors, consultants and senior experts) (SYSTRA-MVA 2008). The list of policymakers also included members of two respective committees of the Chamber of Deputies and Consultative Council (the public utilities committee and the environment committee) because they are influential in proposing and approving related legislation in Bahrain.

Cochran's formula for calculating sample size for categorical data (Bartlett et al. 2001) was used to determine the minimum sample size required for groups of policymakers and experts:

$$n = t^2 pq/d^2, \tag{10}$$

where

t is the selected confidence level (α), in this case, 1.96 for 95 % confidence
pq is the variance, estimated by assuming a heterogeneous population that is more or less equally divided and
d is the acceptable margin of error, 0.05 in this case.

A total of 40 participants were interviewed for around 20 min each, to obtain feedback and assess the level of acceptance of the different mitigation measures.

2.2.3 Questionnaire design

Our survey was aimed at exploring the plausibility of achieving different scenario outcomes. The questionnaire consisted of two parts. In the first part, a brief description of seven CO_2 mitigation scenarios was presented to the participants. The second part aimed to elicit participant views and their acceptance of the described mitigation scenarios. The survey was also aimed at identifying barriers and concerns related to each scenario, to inform decision-making on mitigation policies for passenger vehicles in Bahrain. The list of survey questions is presented in Table 3.

2.2.4 Statistical analysis

Information collected from the surveys was analysed using IBM predictive analytics software, formerly known as the Statistical Package for the Social Sciences (SPSS).

Table 3 Survey questions

Topic	Questions
• Responsibility	• In your view, who should be responsible for reducing the impacts of car use on climate change? (Name all responsible parties)
• Registration fees	• Do you support imposing a new registration fees system based on the car's CO_2 emissions? (Please specify your reasons). If yes, how much extra do suggest? • In your view, will such a change make a difference with regard to saving environment and non-renewable resources? (Please specify your reasons)
• Fuel economy standards	• Would you support the setting of controls over the efficiency of cars, in terms of fuel use, entering the country? (Please specify your reasons) • In your view, will such a control make a difference with regard to saving environment and non-renewable resources? (Please specify your reasons)
• Public transport	• How often do you use public transport? • Do you support improving the public transport system? Are you willing to use public transport if reliable and affordable services are offered?
• Hybrid cars	• Have you ever heard about hybrid cars? • Do you support hybrid cars? How do you feel about buying a hybrid car in the future? (Please specify your reasons) • Do you think that such hybrid car technology fits within the Bahraini context? (Please specify your reasons)
• Natural gas cars	• Have you ever heard about natural gas cars? • Do you support CNG cars? How do you feel about buying a natural gas car in the future? (Please specify your reasons) • Do you think that such technology fits within the Bahraini context? (Please specify your reasons)
• Fuel price	• Do you support raising the fuel price? (Please specify your reasons) • Do you think that raising fuel price will help reducing CO_2 emissions and fuel consumption? (Please specify your reasons)

SPSS can handle various types of data. For instance, it has the ability to handle coded options and qualitative and quantitative data. For this reason, this statistical package was chosen for descriptive statistics analysis.

3 Results

Energy demand and CO_2 emissions were projected for Bahrain for the first time using a bottom-up modelling approach. The results show that according to the baseline of passenger vehicles number and specifications, energy demand will double by 2030 relative to the base year (2010), reaching 1.13 million metric tonnes of oil equivalent (TOE) with an average annual growth rate of 3.7 %. A similar figure was obtained for CO_2 emissions, which increased from 1.6 million Mt CO_2 in 2010 to 3.2 million in 2030.

Results from the mitigation scenarios highlight the opportunity for as much as a 22 % reduction with the high fuel economy standard scenario compared with the baseline scenario. Potential reductions for the remaining scenarios were between 0.04 and 9.7 %. Some mitigation measures appeared to provide promising reduction opportunities, led by fuel economy standards (9.4–22 %), followed by the use of hybrid vehicles (up to 9.7 %), CNG cars (up to 5.1 %) and registration fees (up to 4 %).

Of the 19 scenarios, only seven were selected for further analysis based on their CO_2 emission reduction potential. The selected scenarios represented the five main mitigation measures. The results of cost-effectiveness analysis showed that setting low fuel economy standards (USD 90 per Mt CO_2 reduction) was the most cost-effective scenario, followed by changing the vehicle registration fee system (USD 105 per Mt CO_2 reduction) (Fig. 3). Cost-effectiveness results for other scenarios were between USD 112 per Mt CO_2 reduction for setting high fuel economy standards and USD 9288 per Mt CO_2 for public transport (Fig. 3).

The survey results revealed that 60 % of policymakers and experts believed that responsibility for CO_2 mitigation relating to Bahrain's road transport sector is shared by the government, the public and car manufacturing companies. However, a considerable number (35 %) believed that this was the government's responsibility alone because it has the power and tools to address the issue and, consequently, to make the required changes.

With regard to changing the current vehicle registration fee system, around 60 % of participants supported the idea (Fig. 4) but preferred another fee system (suggested by one of the participants) in which the maximum fee would be USD 190 instead of the proposed USD 600 per car, to avoid imposing a financial burden on the public. Opponents (40 %) of changing the current vehicle registration fee system thought that such a proposal would not contribute to CO_2 reduction as suggested because people would pay the extra fee to have their preferred cars. They believed that this would be especially true for family cars and sport-utility vehicles, which are widespread in Bahrain for daily use and travel to neighbouring countries. However, proponents viewed this mitigation measure from a different angle. One participant stated that 'although the registration fee system may not achieve significant emission reductions, it can provide financing required for other mitigation measures, such as public transport'.

Policymakers and experts in Bahrain appear to prefer setting fuel economy standards; 90 % of survey participants strongly supported imposing such standards and believed that this would contribute to reducing energy consumption and CO_2 emissions. Indeed, one participant forcefully stated, 'I do not know why we still do not have fuel economy standards in Bahrain!'

Although advanced vehicle technologies and alternative fuels are widely available, policymakers and experts appear to have doubts and concerns about their suitability for

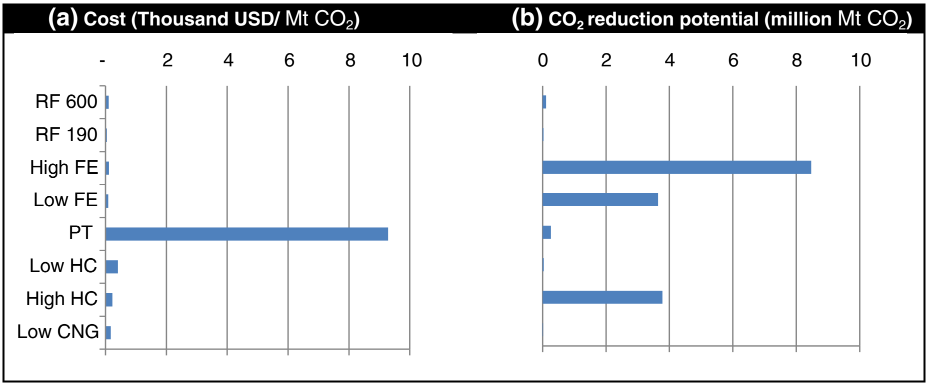

Fig. 3 The scenarios include changing the current vehicle registration fee system so that it is based on vehicle CO_2 emissions, with a maximum fee of USD 600 (*RF 600*), another scenario with maximum fee USD 190 (*RF 190*), setting low fuel economy standards (*Low FE*) and high fuel economy standards (*High FE*), improving the public transport system (*PT*), low penetration of hybrid gasoline cars (*Low HC*) and high penetration of hybrid gasoline cars (*High HC*), plus low penetration of natural gas cars (*Low CNG*)

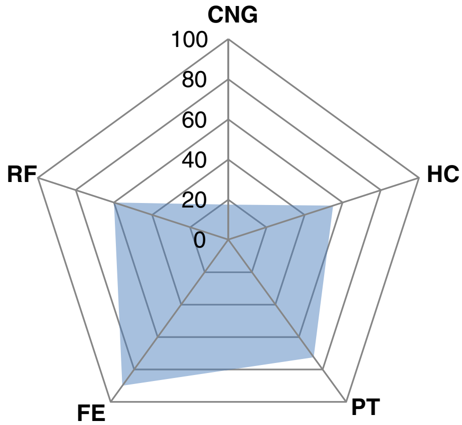

Fig. 4 The mitigation measures include changing the current vehicle registration fee system so that it is based on vehicle CO_2 emissions (*RF*), setting fuel economy standards (*FE*), improving the public transport system (*PT*), penetration of hybrid gasoline cars (*HC*) and penetration of natural gas cars (*CNG*). Views and preferences of policymakers and experts in Bahrain were determined from a survey of 40 participants. The results show that the participants preferred setting fuel economy standards (90 %), with less than 20 % in favour of natural gas cars

Bahrain. The majority of participants (85 %) had heard about hybrid vehicles and knew how they worked, but only about half (55 %) would consider purchasing a hybrid car. Moreover, 48 % thought that hybrid vehicles would not work as hoped in the country and had concerns related to cost and public awareness. These participants believed that hybrid cars should first be tested on a small scale before encouraging the general public to purchase them through widespread incentives. One policymaker added:

> Introducing hybrids on a small scale would be beneficial for two reasons. First, we would be able to identify problems and requirements, and second, it will encourage people to buy such cars when they see them on the streets.

The situation appears less favourable regarding CNG cars. About 80 % of participants knew about the CNG system, but only 18 % would consider purchasing such a car. Moreover, only 25 % believed that this type of car would fit the Bahraini context, especially regarding taxis. Opponents' main concerns were related to its safety, suitability to Bahrain's harsh climate, natural gas sources and cost of building the required infrastructure.

Regarding the public transport scenario, almost none of the participants had ever used public transport. However, more than 70 % supported improving the current system and said that they would use it if the service was reliable.

When asked how they felt about removing fuel subsidies in Bahrain, around 58 % of participants opposed the idea because they were concerned about adding to the public's financial burden. Nonetheless, around 45 % of participants said that such a move would contribute to reducing fuel consumption and CO_2 emissions because people would use their cars less often and seek out vehicles that are more efficient. In fact, one expert suggested that removing fuel subsidies would promote the use of hybrid cars in the country.

Based on the recommendation of the policymakers, a new registration fee scenario was added to the existing list. The suggested system could achieve around a 1.3 % reduction in emissions compared with the baseline scenario. This is less than the potential savings of the system initially proposed (4 % compared to the baseline scenario); however, it has a relatively low cost of USD 48 per Mt CO_2 reduction (Fig. 3).

After exploring the emission reduction potential, abatement cost and plausibility of mitigation scenarios, the latter were combined to produce 50 combined scenarios. An approximate 37 % reduction could be obtained at a cost of around USD 316 per Mt CO_2 reduction using less politically acceptable mitigation measures. However, a smaller reduction (23 %) could be attained at lower cost (USD 108 per Mt CO_2 reduction) using politically acceptable measures. Less politically acceptable measures include high market penetration of hybrid cars and implementation of the initially proposed registration fee system, whereas more politically acceptable measures begin with low market penetration of hybrid cars and the registration fee system suggested by participants.

Adopting one of the suggested combined scenarios could achieve some co-benefits in four different areas, namely, opportunity cost, lifespan of the crude oil reserve, air pollutants and job creation. Gasoline saved by implementing mitigation measures could be sold to international markets instead of being consumed locally, as projected by the baseline scenario. The opportunity cost of this projected accumulated amount ranges between USD 0.7 and 2400 million over 2015–2030 depending on the selected mitigation measure.

In addition, reducing energy demand could add 2 additional years to the known lifespan of Bahrain's proven crude oil reserve. The available information suggests that the country will import 100 % of its refined oil after 36 years (if the proven crude oil reserves remain unchanged), and energy bills will increase accordingly (Gulf Daily 2015). This means that the country will have to pay for oil it used to produce, in addition to subsidising fuel prices if the Bahraini government decides to retain the current fuel price.

Mitigation of CO_2 emissions can also contribute to improving air quality because other pollutants (e.g. carbon monoxide, nitrogen oxides and sulphur dioxide) emitted from consumed gasoline may be reduced by 0.01–28 % relative to the baseline scenario depending on the selected mitigation scenario. Furthermore, infrastructure projects will provide many job opportunities, especially in the public transport scenario. These jobs will be available not only during the construction phase but also in the operational phase.

4 Discussion

4.1 CO_2 emission reduction potential and cost of abatement

The present results provide evidence that Bahrain has the potential to achieve considerable emission and energy savings from passenger vehicles. To our knowledge, no previous study has calculated the potential savings within the transport sector in Bahrain or any other GCC country.

The rapid growth in fuel economy of new vehicles through the establishment of fuel economy standards could achieve as much as a 22 % reduction in CO_2 emissions specifically in Bahrain. However, an even greater reduction (30–50 %) in CO_2 emissions relative to 2010 could be achieved by 2030 through implementation of improvements in vehicle fuel economy, according to the AR5 (IPCC 2014).

Providing alternatives to private passenger vehicles can also contribute to CO_2 emission reduction. The Bahraini government is studying the possibility of expanding its public transport infrastructure, starting with the introduction of a new service provider and adding new routes to the bus rapid system. However, this scenario has a very low reduction potential for the 2015–2030 period because construction of the required infrastructure and system operability are expected to take more time. Therefore, saved kilometres and consequent changes in CO_2 emissions are expected to begin to manifest only 5 years after the start of the proposed project (i.e. in 2020). Nonetheless, the provision of reliable and affordable public transport system in Bahrain can contribute to solving the congestion problem and reducing the rapidly growing number of passenger vehicles (an annual average of 6.8 % over the last decade). Other GCC states are considering similar approaches. Dubai was the first to establish a comprehensive public transport network, which includes a rapid bus system, trams and metro systems. Kuwait and Saudi Arabia have also expressed interest in expanding their public transport systems.

The abatement costs provided in this study seem to be different from those of other studies. The costs for imposing fuel economy standards as reviewed by Kok et al. (2011) are higher than our findings. For instance, their cost of achieving 135 grammes of carbon dioxide per kilometre driven (gCO_2/km) was between USD 160 and 240 per Mt CO_2, whereas our calculated cost of achieving 99 gCO_2/km was USD 112 per tonne. Regarding vehicle technologies, the AR5 gives negative costs for hybrid gasoline-based and CNG cars (less than −220 USD and approximately −400 USD per Mt CO_2, respectively), whereas the range of our findings is USD 228 and 408 per Mt CO_2.

These differences can be explained by the various assumptions entailed in building mitigation scenarios (e.g. fuel price, analysis period, discount rate and penetration rate). In addition, socioeconomic, geographic and political contexts of the studies differ, affecting the modelling results. Although we did a literature review covering GCC countries, no such assessments were found. The AR5 acknowledges the existence of this gap, stating

> The data presented on the cost-effectiveness of different carbon reduction measures is less detailed than data on the potential CO_2 savings due to literature gaps. The number of studies assessing potential future [greenhouse gas] reductions from energy intensity gains and use of low-carbon fuels is larger than those assessing mitigation potentials and cost from transport activity, structural change and modal shift, since they are highly variable by location and background conditions (IPCC 2014, p. 623).

Accordingly, the present study attempted to close the knowledge gap related to abatement cost in a developing and oil-exporting country. The methods and assumptions used herein can also be adopted by other GCC countries.

4.2 Views of policymakers and experts in Bahrain

Policymakers and experts in Bahrain appear to prefer one-time payments over annual fees. Although fuel economy standards can incur an extra maximum cost of USD 2067 per vehicle, around 90 % of our participants supported such standards. Some of them suggested incorporating these standards into the current guideline on unified requirements for new cars in GCC countries, which lacks any fuel economy or CO_2 emission standards (Lahn and Preston 2013).

On the other hand, a smaller acceptance percentage was obtained for the proposed registration fee system. Pricing policies can contribute to the reduction of carbon emissions by increasing demand for more efficient vehicles (IPCC 2014). However, these strategies are not well accepted in Bahrain. A reduced-fee system was proposed by one participant and accepted by most of the policymakers. Although the proposed scenario would achieve a smaller reduction at lower abatement cost compared with the initially proposed registration fee mitigation measure, it is more politically acceptable and could therefore be introduced as a first step to communicate a message of energy efficiency to the public.

Chakravarty et al. (2009) proposed applying the principle of 'common but differentiated responsibilities' in relation to individuals instead of countries. The original principle, which originates with the Rio Declaration, places emission reduction obligations on developed countries based on their historical responsibility, whereas the proposed modification of this principle includes all high CO_2 emitting individuals, regardless of their location. Such a proposal would receive low acceptance in Bahrain. The belief held by a considerable number of policymakers (35 % of participants) that mitigating CO_2 emissions from passenger vehicles is the government's responsibility contradicts the 'common' part of the modified principle. Furthermore, opponents of the proposed registration fee system believe that it would interfere with the public's freedom of vehicle choice, thereby disregarding the differentiated aspect of the proposed modification.

Participants appeared willing to consider alternative vehicle technologies and fuels in Bahrain, but with caution. Their main concerns were related to required infrastructure, climate compatibility and securing of necessary funds. Bahrain can learn from the experience of Dubai, where hybrid gasoline-based cars were tested and gradually incorporated into the taxi fleet, whereas the CNG car mitigation measure was withdrawn. This was basically because the latter requires construction of new fuel stations and providing the fuel source. Dubai's experience provides strong evidence that hybrid cars could also work well in Bahrain. More cooperation between Bahrain and Dubai in this regard could enhance a move toward low-carbon transportation in the former country.

The provision of alternative fuel scenarios by the government (i.e. low market penetration of hybrid cars through government-owned car fleets) appears more acceptable. Although the prospective emission reductions are low (42 million Mt CO_2) and the costs relatively high (413 per Mt CO_2), its suitability to the Bahraini context can be demonstrated. On the other hand, the widespread use of hybrids (40 % of all new passenger vehicles by 2030) could achieve greater emission reductions (3.7 million Mt CO_2) at lower cost (USD 232 per Mt CO_2). However, this is recommended as a next phase after pilot testing.

Reforming fuel prices remains a controversial path in the map toward low-carbon mobility in Bahrain and other GCC countries. The fuel price in Bahrain is heavily subsidised by the government (current fuel price is USD 0.21 per litre of gasoline). This has resulted in a low price relative to many countries worldwide, such as the USA (USD 0.76 per litre), China (USD 1.11 per litre) and the UK (USD 1.92 per litre), and even some GCC countries such as Kuwait (USD 0.23 per litre), Oman (USD 0.31 per litre) and the UAE (USD 0.41 per litre) (World World 2014b). Recently, Kuwait announced that its fuel price would increase by 66–88 %. However, the government plans to provide indirect subsidies to its nationals, through monthly vouchers of around USD 100 each.

Although highly subsidised fuel prices encourage irrational use of a non-renewable resource and hinder the adoption of more efficient vehicles, the literature review for this paper demonstrates low price elasticity of demand for gasoline in the region, notably in Saudi Arabia and Kuwait (Lahn and Preston 2013). This suggests that the situation in Bahrain is similar, given the lack of alternatives to private cars, as mentioned by survey participants.

A remaining major barrier, indicated by participants relates to how the public would perceive the aforementioned changes and whether they would support a transition toward low-carbon mobility. The implementation and success of any policy requires acceptance and support from the people concerned and therefore needs to be investigated prior to decision-making.

4.3 An integrated approach to mitigation policies

The combining of scenarios can synthesise the advantages of various mitigation measures. For Bahrain, the differences in reduction potential and cost are clear when compared with mitigation scenarios as stand-alone measures.

Such combined scenarios provide policymakers with evidence that the cost of a mitigation measure can be significantly reduced when combined with other measures. This is illustrated by the case of public transport, which as an individual measure would cost more than USD 9288 per Mt CO_2 reduction. However, when combined with other mitigation measures, it constitutes only around USD 316 per Mt CO_2 overall.

Considering the preferences of policymakers and experts, we have developed three groups of combined scenarios with varying levels of acceptance. Such variety provides policymakers with an opportunity to select mitigation measures that achieve the desired emission reduction, using available funds in an acceptable manner. For instance, a combined scenario that achieves a 37 % reduction of emissions at a cost around USD 316 per Mt CO_2 may be environmentally favourable. However, a scenario with 23 % emissions reduction at a cost of USD 108 per Mt CO_2 may be more promising from an economic and political standpoint.

4.4 Research limitations

Uncertainties may arise within related studies as a result of instrumental, modelling and sampling errors (Rogan et al. 2011). The present study identified two main sources of uncertainty, the fuel economy correction factor and the passenger-vehicle dataset.

Similar to Rogan et al. (2011), our study used fuel economy figures obtained from standardised tests. Such figures may not, however, reflect 'real life' emissions for a number of reasons, including the environment and driving style. Because of this, we used an on-the-road factor of 1, suggesting the need for further studies in the Bahraini context.

The other source of uncertainty is associated with the dataset of vehicles registered in Bahrain. There are a number of deficiencies in these data, owing to issues with data entry and the use of different units. The dataset was scanned for outliers and errors prior to its use, to buttress the credibility of the results. Furthermore, accurate figures related to vehicle technical specifications could only be calculated from the year 2000 onward.

Another limitation of this study relates to the cost-effectiveness analysis. Although we acknowledge that different types of benefits are acquired through CO_2 emission reduction, only monetary benefits were included in the assessment. Incorporating non-monetary co-benefits is therefore recommended for future studies. A further recommendation is to explore the effects of integrating the preferences and views of the general public when assessing mitigation policies. In addition, it would be worthwhile to examine a wider range of regulatory and economic mitigation policies, including road pricing, congestion charges and subsidies for cleaner fuel.

It is noteworthy in this context that although LEAP can be used in the assessment of mitigation policies effectively, it must be used carefully when combining scenarios. According to the principle of scenario inheritance used for combining scenarios, specific inputs from the first scenario are sought before moving to the second scenario if no data are found. This implies that mitigation policies that affect the same input cannot be combined, because LEAP would only use the first input. To resolve this issue, we manually combined the inputs in one combined scenario.

5 Conclusions

Not all countries have access to the data necessary to analyse CO_2 emissions and abatement opportunities. However, this should not be an excuse for inaction in relation to a mitigation policy. This paper fills a knowledge gap for a developing and oil-exporting country with limited existing data, by adopting a modified approach to assessing and accounting for the effects and costs of a number of possible mitigation policies. This approach can also provide a framework for countries with similar data limitations, socioeconomic contexts or both.

The present study gives various scenarios for mitigating CO_2 emissions from passenger vehicles in Bahrain. It is the first study, to our knowledge, to quantify CO_2 emission reduction potential and abatement costs in the country and incorporates the views and preferences of policymakers and experts in the assessment. The outcomes suggest that setting fuel economy standards alone can achieve a 22 % reduction in CO_2 emissions. An integrated approach to assessment could result in a 37 % reduction with less politically acceptable measures whereas a 23 % reduction can be achieved at relatively low cost and with politically acceptable measures.

Delay of mitigation is likely to accelerate the pace of the exhaustion of Bahrain's oil reserve. This would also affect air quality, especially in congested areas. As described in the AR5, reducing carbon emissions is challenging because it requires changes throughout the economy. Investments in cleaner technologies and public transport infrastructure would reduce emissions if these, rather than oil prices, were subsidised. However, awareness must be raised among policymakers and experts in Bahrain. Exploring the public's acceptance of various mitigation scenarios is a necessity and is recommended for future research.

The results of the present study provide a glimpse of potential pathways with respect to the views of policymakers in other GCC countries. These nations have much in common, including standards required for new vehicles. The study results could sufficiently alarm Bahrain's neighbours to act in a timely fashion before their resources are depleted and to invest in low-carbon technologies and fuel efficiency. The results can also be used in international negotiations on CO_2 reduction targets because they show amounts and costs of emission reductions.

Our findings can inform global mitigation strategies in different ways. They provide evidence of the need for a consulting body that can assist developing countries in the preparation of national targets, strategies and closing of the regulation gap related to fuel economy standards and labelling, at least for Bahrain and the other GCC countries. Such a consulting body could also facilitate economic reforms to reduce market distortions, improve efficiency and secure required funds. A funding mechanism may also be required for the implementation of mitigation measures, given that securing the required financing has been identified as a barrier in the case of Bahrain. Extending the Clean Development Mechanism programme, or developing a similar one, is recommended for the new regime.

For developing countries, it is evident that adopting an integrated approach to mitigation policies can deliver greater emission reductions at lower costs. Furthermore, following a participatory approach can advance various mitigation scenarios that can be environmentally effective, economically feasible and politically acceptable. Our research provides evidence that LEAP can be an effective tool, even where data are limited, by using different approaches to calculation. However, LEAP demands careful treatment in the combination of scenarios. The case of Bahrain can also deliver another message to developing countries, to begin controlling vehicle technical specifications at an early stage. A delay in this task will result in facing the issue of increasing numbers of vehicles and slow improvement of vehicle fuel economy and policymakers' willingness to change.

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