Out of reach? Mitigation of CO\(_2\) emissions from road transport sector in Bahrain

M. AlSabbagh, Y. L. Siu, A. Guehnemann, J. Barrett

February, 2015

No. 78

SRI PAPERS

SRI Papers (Online) ISSN1753-1330
About the Sustainability Research Institute

The Sustainability Research Institute conducts internationally recognised, academically excellent and problem-oriented interdisciplinary research and teaching on environmental, social and economic aspects of sustainability. Our specialisms include: Business and organisations for sustainable societies; Economics and policy for sustainability; Environmental change and sustainable development; Social and political dimensions of sustainability.

Disclaimer

The opinions presented are those of the author(s) and should not be regarded as the views of SRI or The University of Leeds.
Out of reach? Mitigation of CO₂ emissions from road transport sector in Bahrain

© AlSabbagha, Y. L. Siua, A. Guehnemann, J. Barrett 2015

Email: eemal@leeds.ac.uk

Contents

Contents.............................................................................................................. 3
Abstract .......................................................................................................... 4
About the Author ............................................................................................ 4
Introduction .................................................................................................... 5
Methodology................................................................................................... 9
Results and Discussion.................................................................................... 14
Conclusions.................................................................................................... 20
References...................................................................................................... 21
Abstract

The major outline of a universal agreement on climate change is greatly anticipated to be adopted in the Conference of the Parties (COP21) in France in 2015 with entry into force in 2020. Yet, there is no research on reduction potentials from the rapidly growing transport sector in Bahrain where per capita carbon emission is among the highest in the world. This paper aims to examine the reduction potentials and costs for implementing a number of mitigation options in addition to exploring policymakers’ views in Bahrain. Additionally, the combined effects of mitigation scenarios, barriers, opportunities and co-benefits of implementation are investigated. A modified participatory methodology for the development process of mitigation scenarios is adopted using Long-Range Energy Alternative Planning System (LEAP) and the Greenhouse Gas Costing Model (GACMO). Analysis showed that the greatest environmental effectiveness is associated with setting high fuel economy standards. Reaching 22% reductions in emissions is possible at a relatively low cost (US$ 112 per tonne CO₂e). In terms of economic effectiveness, setting low fuel economy standards has the lowest cost of US$ 90 per tonne of Carbon Dioxide Equivalent (CO₂e) emissions reduction. Substantial reductions in emissions can be achieved (28%) when different mitigation scenarios are combined, with cost of US$ 399 per tonne of avoided CO₂e emissions. These findings are significant to decision making regarding climate change mitigation in Bahrain. Bahrain can commence with national target preparation and setting fuel economy standards. This research can also alert other Gulf Cooperation Council countries to act before their resources deplete, along with preparing to face forthcoming international environmental commitments.

Key words: Bahrain, CO₂ mitigation, GACMO, LEAP, passenger vehicles, scenarios

Submission date 13-11-2014; Publication date 02-02-2015

About the Author

Maha Alsabbagh, PhD student, Sustainability Research Institute, School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK, E-mail: eemal@leeds.ac.uk

Yim Ling Siu, Senior Teaching Fellow, Sustainability Research Institute, School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK, Telephone: +44(0) 113 34 36717, E-mail: Y.L.Siu@leeds.ac.uk

Astrid Gühnemann, Senior Lecturer in Transport Policy, Institute for Transport Studies, University of Leeds, Leeds, LS2 9JT, UK, Telephone: +44 (0)113 34 35342, E-mail: a.guehnemann@its.leeds.ac.uk

John Barrett, Professor of Sustainability Research; Deputy Director of Research (Excellence), Sustainability Research Institute, School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK, Telephone: +44(0) 113 34 32394, E-mail: j.r.barrett@leeds.ac.uk
1. Introduction

The major outline of a universal agreement on climate change will almost certainly be adopted in the forthcoming Conference of the Parties (COP21) in France in 2015. All parties will be committed to emission reduction targets starting from 2020. This includes developing countries as was agreed in Durban in 2011. Yet, there is no previous research on reduction potentials from the rapidly growing transport sector in the Gulf Cooperation Council (GCC) and where per capita carbon emissions are among the highest in the world.

Bahrain, being surrounded by petroleum countries, is extremely in need of reducing its energy demand and CO₂ emissions. Mitigation of CO₂ emissions is not a luxury any more as Bahrain must be ready for the carbon reduction commitments. Furthermore, as a small island nation, Bahrainis vulnerable to sea level rise (SLR). This could be between 11% and 56% of the total land area which would be lost from a 0.3 meter to a 5 meter increase in the SLR (PMEW 2012).

It should be noted that adopting energy efficiency measures and reducing rapid growth in energy demand in Bahrain will achieve two main goals. Firstly, it will contribute to the life of the resource which has been identified as a target for the government of Bahrain. According to available statistics, Bahrain’s reserve will approach its life’s end within approximately six years. In contrast, the proven crude oil reserves in other GCC countries are expected to last longer, ranging from 17 years in Oman and up to 120 years in Kuwait, assuming constant production as was in the year 2010. Secondly, it will contribute to the country’s gross domestic product (GDP). Bahrain imports around 78% of its refined oil, consumes 9% of the processed petroleum products locally, and exports the remaining. This makes up 20% of Bahrain’s GDP. Consuming less petroleum products locally would be highly beneficial as fuel prices are heavily subsidized in Bahrain. It should be noted that subsidies to oil and gas prices in Bahrain amounted to US$ 2.2 billion in 2012 (Ministry of Finance – Bahrain 2013).

The problem of the research at hand is exclusive to Bahrain, but is also shared by other GCC countries. In Bahrain –as in other GCC countries, high levels of energy consumption, energy intensity, and energy consumption per capita can clearly be discerned. Subsequently, carbon emissions are high as well, considering the complete reliance on fossil fuels. Figures for CO₂ emissions per capita in Bahrain exceed that of the USA and additionally exceed the Organization for Economic Co-operation and Development (OECD) countries, by 10% and 90%, respectively (The World Bank 2014a). This reliance on fossil fuels indicates high carbon intensive economy in Bahrain as it makes 107 folds of that of the USA and 150 folds of carbon intensity in the OECD (IEA 2013) which emphasizes the need to reduce carbon emissions.

Trends in carbon emissions in GCC countries are accelerating with an average annual growth rate of 6.6% between 1994 and 2005. Transportation makes up 13% of the average total emissions, with the highest of percentage occurring in Saudi Arabia (21%) and the lowest in Qatar (7.3%). Emissions from this sector are expected to increase
further as a result of growing energy consumption if no new policies are introduced (Lahn and Prestonne 2013).

The transport sector in the GCC countries consumes a considerable amount (25% on average) of the total energy consumption with an average of 60 gigajoule (GJ) per capita compared to 52 GJ per capita in North America (IPCC 2014). There are a number of factors that specifically contribute to the rapid growth of passenger vehicles such as economic growth and population increase. Vehicle ownership in the GCC countries ranges between 192 per 1000 population in Saudi Arabia, and 537 per 1000 population in Bahrain (IRF 2011). Bahrain’s figure is close to that of UK (523 per 1000) and Ireland (513 per 1000). Yet, the energy efficiency in Bahrain is significantly lower (Figure 1).

Figure 1 shows the gross national income, motor vehicles and road sector energy consumption in selected countries. The X axis shows Gross National Income (GNI) per capita, and the Y axis shows motor vehicles per 1000 population. The size of the circumference of the circles reflects energy efficiency and road sector energy consumption per veh-km in a number of selected countries (IRF, 2011). Although vehicle ownership in Bahrain and Saudi Arabia is close to that of developed countries, energy consumption is relatively higher which likely indicates energy efficiency opportunities.

The number of passenger vehicles in Bahrain grew by 7.3% on average per year over the last decade. When it comes to mitigating CO₂ emissions from passenger vehicles, it is not the number of vehicles that is the only concern, but also the technical specifications of the vehicles. Furthermore, the growth in the size and weight of new passenger vehicles in Bahrain has resulted in slower growth in the fuel economy of new vehicles (Alsabbagh et al. 2013).
In order to control the rapid increase in the number of passenger vehicles, some transport demand management strategies have been put into place. Bahrain is studying the expansion of the public transport infrastructure starting with introducing new service provider and adding new routes for bus rapid system (BRT). Dubai was the first in the region that established a wide public transport network that includes BRT, trams and metro systems. Both of Kuwait and Saudi Arabia have expressed interest in expanding their public transport systems. Kuwait has gone further when it set restrictions over obtaining driving licences for non-nationals. However, when it comes to adopting CO₂ mitigation options, hardly any initiatives can be found in the transport sector. Alternative fuels can rarely be seen in the region with the exception of Dubai that is changing its taxis to include hybrid-gasoline vehicles. Furthermore, current unified requirements for new cars in GCC countries lack any fuel economy or CO₂ emissions standards, not to mention emission reduction targets (Lahn and Prestonne 2013).

Despite the numerous mitigation options available and those possibly applicable to the case of GCC countries, in general, and to Bahrain in particular, no clear energy and economic assessment has been carried out so far. Communications to the United Nations Framework Convention on Climate Change (UNFCCC) mention a number of options including fuel efficiency improvements, compressed natural gas (CNG) cars, and public transport. Yet, none of the national reports from the GCC countries explored the emissions reduction potentials or its economic feasibility. In fact, only two countries, Bahrain and Kuwait, have prepared projections of their total energy consumption and CO₂ emissions. Such scenarios are crucial to aid decision making on climate change mitigation in addition to setting reduction targets.

The existing literature shows a considerable number of mitigation options available for passenger vehicles, although there is no internationally agreed classification system for these options. The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) (2014) highlights four main groups of mitigation options: avoiding journeys, modal shift, lowering energy intensity, and reducing carbon intensity of fuels. The literature review in this study also cites various assessment approaches to explore different trajectories to low carbon mobility. Backcasting is one of these approaches where an emission target is set and possible paths are identified either by the researchers themselves (e.g. Ashina et al. 2012) or developed in a participatory process (e.g. Tuominen et al. 2014). Another approach is scenario building in which economic analysis and environmental assessment are mainly used. Projections of abatement cost, emissions reduction potentials and energy use are the commonly used parameters in building mitigation scenarios (e.g. Dedinec et al. 2013; Sharma et al. 2013; He and Chen 2013). A recent trend towards involving stakeholders in the mitigation building process can clearly be observed. The research of Schmid and Knopf (2012) is an example of this where mitigation scenarios were discussed first with stakeholders and then, economic analysis and environmental assessment was carried out. Finally, the plausibility of scenarios was discussed with stakeholders to raise any concerns about social acceptance.
The current research at hand aims to provide answers to three main questions:
1. What is the CO$_2$ reduction potential that can be achieved from road passenger transport sector in Bahrain? What is the abatement cost of this reduction?
2. How do policymakers and experts perceive different alternatives to achieve low-carbon transportation in Bahrain?
3. What are the combined effects of the previously explored alternatives for scenario writing? What are barriers, opportunities and co-benefits of the implementation of each scenario?

This study provides novel insights into a region that has never been explored before. Results from scenarios are obtained for the first time for Bahrain using bottom-up calculated indicators. In addition, the possibility of adopting such mitigation measures has never been examined before in similar socio-economic and political context. Moreover, the results of this study can bridge the gap between the work carried out worldwide and the reality of replication within the GCC countries. Furthermore, the results and recommendations drawn from this current work can provide guidance for other GCC countries especially because they have similar contexts. In terms of the methods, this study delivers a modified participatory methodology for the development process of mitigation scenarios in transport sector as it provides better understanding and incorporation of stakeholders’ views.

This research paper consists of four main sections. Section 2 explains methods and tools used to carry out this research. The results of modelling and the survey are presented in section 3, while section 4 delivers the main conclusions along with recommendations.
2. Methodology

In this paper, a methodology was adopted similar to that suggested by Justen et al. (2014) for policy packaging. In their suggested model, policy measures are selected and assessed first and then presented to stakeholders for revision. After doing necessary modifications, policy packages are implemented, monitored and evaluated. In this current study, their suggested model was modified and used for scenario building (Figure 2). The methodology steps are detailed in the next sub-sections.

![Figure 2: The methodology steps](image)

2.1. Select mitigation options: Among numerous mitigation options available for the transport sector, only those recommended for GCC countries are explored as they are more likely to suit its special socio-economic context. Five main mitigation measures have been selected for this study: annual vehicle registration fees based on CO₂ emissions, fuel economy standards, hybrid cars, natural gas cars (CNG), and public transport. These five options were selected as examples that show emission reduction potentials. Other fiscal and management measures are left for a future study for two reasons. The first being to provide infrastructure and alternatives required as no clear implementation of any mitigation options is in place currently and the second is not to put financial burden on society before providing the alternatives.

2.2. Build future scenarios: Basic transport indicators obtained from a bottom-up calculation approach are used to construct baseline scenario (Table 1) (Table 2) (Alsabbagh et al. 2013). The Long-Range Energy Alternative Planning System (LEAP) is used to obtain future energy demand and CO₂ emissions from passenger vehicles in Bahrain. LEAP is an accounting model that was selected for this study because it can
work with minimum data and does not require a high level of expertise. Moreover, it is used in preparing the national communication reports on climate change for more than 85 countries (including Bahrain) and used widely in researches in more than 150 countries around the world (Heaps 2008). Within LEAP, we use the stock turn over calculations that apply the following equations (Stockholm Environment Institute 2014):

Stock Turnover: \( \text{Stock}_{t,y,v} = \text{Sales}_{t,v} \times \text{Survival}_{t,y-v} \) \hspace{1cm} (Equation 1)

\( \text{Stock}_{t,y} = \sum \text{Stock}_{y,v} \) \hspace{1cm} (Equation 2)

Where:
- \( t \) is the type of technology (i.e. the technology branch)
- \( v \) is the vintage (i.e. the year when the technology was added)
- \( y \) is the calendar year
- \( \text{Sales} \) is the number of vehicles added in a particular year
- \( \text{Stock} \) is the number of devices existing in a particular year
- \( \text{Survival} \) is the fraction of devices surviving after a number of years
- \( V \) is the maximum number of vintage years

Energy Intensity: \( \text{Energyintensity}_{t,y,v} = \text{Energyintensity}_{t,y,v} \times \text{Degradation}_{t,y-v} \) \hspace{1cm} (Equation 3)

Where:
- \( \text{Energy intensity} \) is energy use per device for new devices purchased in year \( y \)
- \( \text{Degradation} \) is a factor representing the change in energy intensity as a technology ages. It equals 1 when \( y=v \)

Energy Consumption: \( \text{Energyconsumption}_{t,y,v} = \text{Stock}_{t,y,v} \times \text{Energyintensity}_{t,y,v} \) \hspace{1cm} (Equation 4)

Energy-Based Emissions (e.g. CO\(_2\) and other Greenhouse Gases): \( \text{Emission}_{t,y,v,p} = \text{EnergyConsumption}_{t,y,v} \times \text{EnergyFactor}_{t,y,p} \times \text{EmDegradation}_{t,y-vp} \) \hspace{1cm} (Equation 5)

Where:
- \( P \) is any criteria air pollutant.
- \( \text{Energy Factor} \) is the emissions rate for pollutant \( p \) (e.g. grammes/veh-mile) from new vehicles of vintage \( v \).
- \( \text{Em Degradation} \) is a factor representing the change in the emission factor for pollutant \( p \) as a vehicle ages. It equals 1 when \( y=v \)

Several scenarios were explored for each mitigation option using different assumptions for the period 2015-2030 with 2010 being the base year. Before running the model, the baseline scenario results were verified using historical data for the period 2003-2012. Results of the estimated number of passenger vehicles were compared with the actual published statistics. Mean bias error (MBE), root mean squared error (RMSE), and coefficient of determination (\( R^2 \)) were calculated. From the \( R^2 \) result, it can be said that the number of passenger vehicles is well estimated as the \( R^2 \) is more than 0.99. With regard to the MBE and RMSE results, the errors are less than 1% and 3% respectively, which is acceptable for forecasting (Pongthananaisawan and Sorapipatana 2013).

Furthermore, the Greenhouse Gas Costing Model (GACMO) was utilized to get the abatement cost of CO\(_2\) emissions. GACMO is a Microsoft Excel spreadsheet that
calculates the cost for each mitigation option by dividing incremental cost by the reduced emissions (Equation 6) (Borba et al. 2012). Results obtained from GACMO are used as inputs in LEAP to combine mitigation scenarios in the next step.

\[
AAC_{\text{option}} = \sum_{t} \frac{NAC_{t}^\text{low carbon} - NAC_{t}^\text{reference}}{AE_{t}^\text{reference} - AE_{t}^\text{low carbon}}
\]  
(Equation 6)

Where:
AAC is the average abatement cost of avoiding one tonne of CO\textsubscript{2} emission in year t
NAC is the net annual cost for implementing each mitigation option
AE is the annual emissions

| Table 1: Assumptions used to build business-as-usual scenario |
|---------------------------------|---------------------------------|
| **Items**                       | **Assumptions (growth rate % p.a.)** |
| 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) |

| Table 2: Assumptions used to build mitigation scenarios |
|---------------------------------|---------------------------------|
| **Mitigation option**           | **Scenario**                    |
| Hybrid cars                     | **Assumptions**                 |
| Low penetration, low fuel economy | 1%, 17.7 km/l                 |
| 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            |
| CNG cars                        | **Assumptions**                 |
| Low penetration, low fuel economy | 1%, 13.2 km/l                 |
| High penetration, low fuel economy | 25%, 13.2 km/l             |
| Fuel economy standards (by 2030) | **Assumptions**                 |
| Low (the USA target for 2015)    | 15.4 km/L, US$ 716             |
| Medium (the USA target for 2020) | 18.8 km/L, US$ 858             |
| High (the USA target for 2020)   | 23.5 km/L, US$ 2,067           |
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.

Elasticity assumptions were based on the IPCC’s fourth report (2007), Small and Dender (2007) and Jorgensen and Dargay (2006).

### Registration fees (using 3 types of price elasticity of demand for each scenario: -0.04, -0.4, -1.1)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>The CO₂ limits are not tightened over time (starting from &lt;141 till &gt;300, with 20 g CO₂ intervals) - Fees start from 0 up to US$ 600</td>
</tr>
<tr>
<td>Medium</td>
<td>Decreasing CO₂ limits after 10 years (starting from &lt;141 till &gt;300, with 20 g CO₂ intervals, then starts from &lt;121)</td>
</tr>
<tr>
<td>High</td>
<td>Set up as the ‘medium’ scenario - Double duty rates - Fees start from 0 up to US$ 1,200 in phase 1 and US$ 2,400 in phase 2.</td>
</tr>
</tbody>
</table>

### Public transport

- Introducing light rail transit (LRT) system and improving the current bus rapid transit (BRT) system. - 2.8 billion veh-km is saved

Capital cost: US$ 5.3 billion

Maintenance cost: US$ 513 million

Costs were obtained from a consultancy work carried out by SYSTRA-MVA (2008) based on a request from the Bahraini government.

Note: Discount rate of 3.3% was used to calculate the costs. This rate is the average for the period 2000-2010 for Bahrain.

Within the same mitigation option, scenarios are only considered that achieve an emission reductions difference of more than 10% compared to the low scenario. This decision is made to limit the number of scenarios that undergo further analysis.

2.3. Plausibility of scenarios: In this step, structured interviews were conducted with policymakers and experts in Bahrain. The interviews consisted of 2 parts. In the first part, a brief description of seven CO₂ mitigation options was delivered to the participants while the second part aimed to know more about the participants’ views and acceptance of the described mitigation options. This survey also aimed to identify barriers and
concerns related to each option to inform decision making on mitigation options for passenger vehicles in Bahrain. The list of questions is presented in Table 3.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Responsibility</td>
<td>• In your view, who should be responsible for reducing the impacts of car-use on climate change? (name all responsible parties)</td>
</tr>
</tbody>
</table>
| Registration fees         | • Do you support imposing a new registration fees system based on the car’s CO₂ 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 CO₂ emissions and fuel consumption? (please specify your reasons) |

Cochran’s sample size formula for categorical data (Bartlett et al. 2001) was used to determine the minimum sample size required for policymakers and experts group as follows:

\[ n = \left(\frac{t^2 \cdot pq}{d^2}\right) \]  

(Equation 7)

Where:
\( t \) is the value for the selected alpha level, in this case, 1.96 for 95% confidence  
\( pq \) is the estimate of variance, assuming a heterogeneous population that is more or less 50% - 50%  
\( d \) is the acceptable margin for error, which is 0.05 in this case

A total number of 40 participants (out of 44) were interviewed to obtain feedback and acceptance of the selected mitigation options. The total number of questions was fifteen and each interview lasted around 40 minutes.

2.4. Design of combined scenarios: the modified mitigation options were combined to deliver fifty combined scenarios. Using LEAP, total emission reductions and cost were obtained for these scenarios.
3. Results and Discussion

The results of the economic analysis, environmental assessment and surveys are delivered in this section according to the research questions presented in section 1.

3.1. What is the CO\textsubscript{2} reduction potential that can be achieved from road passenger transport sector in Bahrain? What is the abatement cost?

Projections of energy demand and CO\textsubscript{2} emissions were constructed for the first time for Bahrain using a bottom-up modelling approach. Energy demand under the business-as-usual scenario (BAU) of passenger vehicles will be doubled by 2030 compared to the base year 2010 reaching 1.13 million tonnes of oil equivalent (toe) with an average annual growth rate of 3.7%. A similar figure is obtained for CO\textsubscript{2} emission where it will experience an increase from 1.6 million tonne in 2010 to 3.2 million tonne of CO\textsubscript{2} in 2030. This growth rate of 3.7% is relatively lower than that projected by PMEW (2012) of 5.6%. However; the former reflects emissions from passenger vehicles whilst the latter extends to include all other transport modes. Furthermore, projections made by PMEW (2012) were based on historical energy consumption by the transport sector in Bahrain, whereas the results of the study are obtained mainly using fuel economy of new vehicles. It should be noted that the findings in this research represent 66% of the former projections which is consistent with the results from the CO\textsubscript{2} inventory that was conducted in the year 2000 when emissions from passenger vehicles were accounted for 60% of transport emissions.

Results from mitigation scenarios highlight an opportunity for up to 22% reduction under the high fuel economy standards scenario compared to the BAU scenario. Energy efficiency and improvements in vehicle fuel economy can achieve between 30 and 50% reductions in global CO\textsubscript{2} emissions in 2030 compared to 2010, according to the AR5.

Potential reductions under the remaining scenarios range between 0.04 to 9.7%. Some mitigation options seem to provide promising reduction opportunities including fuel economy standards (9.4-21.9%) followed by hybrid vehicles (up to 9.7%), CNG cars (up to 5.1%) and registration fees (up to 1%). With regard to the public transport option, construction of the required infrastructure and operation of the system is expected to take more time, and therefore, saved kilometres and consequently CO\textsubscript{2} emissions are expected to appear after five years of the start the project (i.e. in 2020).

Out of the nineteen different scenarios, only seven were selected for further analysis based on the CO\textsubscript{2} emission reduction potentials. The selected scenarios represent the five main mitigation options. Results from cost-effectiveness analysis show that most cost-effective option is setting low fuel economy standards (US$ 90 per tonne of CO\textsubscript{2}e reduced) followed by high fuel economy standards (US$ 112 per tonne of CO\textsubscript{2}e reduced). Results of cost-effectiveness for other options range between US$ 173 per tonne of CO\textsubscript{2}e reduced for low penetration of CNG cars and US$ 9,288 per tonne of CO\textsubscript{2}e reduced for public transport (Figure 3).
(a) Cost (Thousand U.S. Dollar/Tonne CO$_2$e) (b) CO$_2$ reduction potential (Million ton CO$_2$)

Notes:
L0.4: registration fees system under 0.4 price elasticity of demand
PM 70: modified registration fees system after the policymakers and experts survey
High FE: high fuel economy standards
Low FE: low fuel economy standards
PT: public transport
Low HB: low penetration of hybrid cars with low fuel economy
High HB no.: high penetration of hybrid cars with low fuel economy
Low CNG: low penetration of natural gas cars

When the above results are compared to findings of other researches, results from literature review conducted by Kok et al. (2011) differ from our findings with regard to fuel economy standards. For instance, the cost of achieving 135 gCO$_2$/km ranges between US$ 160 and 240 whereas the cost of achieving 150 gCO$_2$/km equals to US$ 67 per tonne CO$_2$e. With regard to vehicle technologies, the AR5 provides negative costs for hybrid-gasoline cars and CNG cars (<US$ -220 and US$ -400 per ton CO$_2$e respectively) whereas the range of our findings is between US$ 172 and 413 per ton CO$_2$e.

Nevertheless, a comparison between the finding of our research and results from other literature cannot be conducted due to various assumptions used for building mitigation scenarios (e.g. fuel price, analysis period, discount rate, penetration rate). Additionally, the socio-economic, geographic and political contexts are different as well which affect the modelling results. A literature review that cover GCC countries was conducted, however no assessments were found. The AR5 acknowledges the existence of this gap and states that:

“The data presented on the cost-effectiveness of different carbon reduction measures is less detailed than data on the potential CO$_2$eq savings due to literature gaps. The number of studies assessing potential future GHG 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.” (page 623, Climate Change 2014: Mitigation of Climate Change)

3.2. How do policymakers and experts perceive different alternatives to achieve low-carbon transportation in Bahrain?

The results of the survey reveal that 60% of policymakers and experts believe that the responsibility of CO₂ mitigation from road transport sector in Bahrain is shared by the government, the public and the car manufacturing companies. However, a considerable number (35%) believes that this is the government’s responsibility alone as it has the power and the tools to address the issue and then make the required changes.

Pricing strategies can contribute to the reduction of carbon emissions through increasing the demand for more efficient vehicles (IPCC 2014). However, only 60% of the participants supported the proposed annual vehicle registration fees system (Figure 4). Of the proponents, one participant said:

“Although the registration fees system may not achieve significant emissions reductions but it can provide finance to other options such as public transport.”

However, most of the participants supported another fee system which was actually suggested by one of the participants, in which the maximum fee is US$ 190 instead of proposed US$ 600 in order not to add to the financial burden of the public. Opponents of the suggested policy (40%) thought that such proposal would not contribute to the CO₂ reduction as people would pay the extra fees to have the cars they prefer. They believed that this was especially true for family cars and sports utility vehicles (SUVs) which are widely used throughout the region for daily use and for travelling to neighbouring countries.

In Chakravarty et al. (2009), a proposal to apply the principle of ‘common but differentiated responsibilities’ on individuals instead of countries was introduced. If such proposal is considered, it will be less accepted in Bahrain. A considerable percentage of policymakers (35% of participants) believe that mitigating the CO₂ emissions from passenger vehicles is the government’s responsibility which contradicts with the ‘common’ part of the principle. Furthermore, the opponents of the proposed registration fees system believe that it would interfere with the public’s freedom of vehicle choice omitting the differentiated part of the proposed modification on principle number 7 of Rio declaration.

It should be noted that policymakers and experts in Bahrain seem to prefer the one-off payments over the annual fees. Although the fuel economy standards can have an extra cost of a maximum of US$ 2,067 per vehicle, around 90% of the participants highly supported imposing such standards and believed that it will contribute to reducing energy consumption and CO₂ emissions. Indeed, one of the participants said:

“I do not know why we still do not have fuel economy standards in Bahrain!”
Although vehicle technologies and alternative fuels are widely spread, policymakers and experts seem to have their doubts and concerns about their suitability to Bahrain. The majority of the participants (85%) had heard about hybrid cars and knew how they work, but only half of these participants (55%) would consider purchasing of hybrid car. Moreover, 48% of the participants thought that it would not fit within the Bahraini context and had their concerns with regard to a hybrid’s suitability to the hot weather in Bahrain. They were also concerned about the required infrastructure, cost and public awareness. The participants believed that hybrid cars should be tested first on a small-scale before encouraging the public in general through wide-spread incentives. A policymaker added:

"Introducing hybrids on a small scale would be beneficial due to two of reasons; firstly we would be able to identify problems and requirements and secondly, it will encourage people to buy such cars when they see them in the streets."

It is worth noting in this context that in Dubai, where similar weather conditions to that of Bahrain exist, hybrids were tested and gradually introduced into the taxi fleet. This provides strong evidence that such technology can work well for Bahrain also. More cooperation between Bahrain and Dubai with this regard can enhance the move to low-carbon transportation in Bahrain.

With regard to CNG cars, things seem to be less favourable. About 80% of participants knew about the CNG car system, but only 18% would consider the purchase of such a car, and only 25% believe that it would fit within the Bahraini context, especially with taxis. Opponents' main concerns were related to its safety, suitability to the harsh weather in Bahrain, sources of natural gas and the cost of building the required infrastructure. It is worth noting in this context that this option was considered in Dubai as well. However, many obstacles rose when it was considered in Dubai which included the need for new fuel stations and the fuel source itself. Thus, this option was eventually cancelled.

Regarding the public transport option, almost all of the participants have never used public transport. However, more than 70% of them do support improving the current system and said that they would use it if reliable service is offered.

From the point of view of policymakers and experts, barriers to vehicle technologies and alternative fuels in Bahrain are mainly related to economic feasibility and weather. Nevertheless, policy measures are more accepted and preferred with some concerns related to adding to financial burden for the public. This is why around 58% of the participants refused to remove fuel subsidies in Bahrain.

Fuel prices in Bahrain are highly subsidised (current fuel price = US$ 0.21 per litre) which has resulted in relatively low price compared to many countries worldwide (e.g. China US$ 1.11, UK US$ 1.92, USA US$ 0.76 per litre) and even some GCC countries (e.g. Kuwait US$ 0.23, Oman US$ 0.31, UAE US$ 0.41 per litre) (The World Bank 2014b). Although this encourages irrational use of the non-renewable resource and hinders the use of more efficient vehicles, the literature review demonstrates low price elasticity of demand for gasoline in the region. The literature indicates low price
elasticity’s in Saudi Arabia and Kuwait which suggests similar case in Bahrain due to the lack of alternatives to private cars, which already was mentioned by the participants in the survey. Furthermore, the participants refused to add more financial burden on the residents. Nonetheless, approximately 45% of participants said that such move would contribute to reducing the fuel consumption and CO$_2$ emissions as people would use their cars less often and seek out more efficient vehicles. In fact, one expert suggested that removing the fuel subsidies would promote the use of hybrid cars in Bahrain.

![Figure 4: The policymakers and experts acceptance of different mitigation options (%)](image)

Notes:
CNG: Natural gas cars
HB: Hybrid cars
PT: Public transport
FE: Fuel economy standards
RF: Annual vehicle registration fees

3.3. What are the combined effects of the previously explored options for scenario writing? Additionally, what are barriers, opportunities, and co-benefits of implementation of these?

Based on the policymakers’ recommendation, a new registration fee scenario is added to the list of scenarios. The suggested system can achieve only a 0.09% emissions reduction when compared to the BAU scenario. This is the lowest potential of all tested options. Furthermore, this option has a cost of more than US$ 4,168 per tonne of avoided CO$_2$ emissions.

When mitigation options are compared as stand-alone options, differences can be clearly noticed in the reduction potential and cost. Alternative fuels options owned by the government (i.e. CNG cars and hybrid cars) creates low emission reductions (16 and 42 million tonne CO$_2$ respectively) at a relatively high cost (US$ 173 and 413 per tonne CO$_2$ respectively). Nevertheless, such options are highly encouraged by policymakers so that they can demonstrate their suitability to the Bahraini context. On the other hand,
the wide spread use of hybrids (40% of new passenger vehicles by 2030) can achieve more emission reductions (3,777 million tonne CO₂) at a lower cost (US$ 232 per tonne CO₂e), yet it is suggested as the next step after the pilot testing.

Policy options are more economically favourable compared to alternative fuels. Fuel economy standards can reduce carbon emissions at relatively low cost (US$ 90 per tonne CO₂e). Therefore, different mitigation scenarios were combined (Figure 3) to merge their advantages. In this research fifty different combined scenarios were produced using the LEAP. Figure 5 shows the results of the CO₂ emissions reduction (Y axis) and cost-effectiveness of each combined scenario (bubble size). Since the suggested registration fees scenario is more ‘politically accepted’, the designed packages can be distinguished based on this (X axis). From the figure, one can clearly observe that a considerable amount of reductions can be achieved at a relatively low cost. Approximately 28% reduction can be obtained at around US$ 399 per tonne of avoided CO₂e emissions while a lower reduction (22%) can be achieved at a relatively low cost (US$ 17 per tonne of avoided CO₂e emissions). Such various combined scenarios provide evidence to policymakers that the cost of a mitigation option can significantly be reduced when combined with other options. An example of this can be seen in the public transport which costs as an individual option more than US$ 9,288 per tonne of avoided CO₂e emissions. Nevertheless, it should be noted that it costs around US$ 290 per tonne of avoided CO₂e emissions only when combined with other mitigation options.

![Figure 5: The results of the combined scenarios](image)

**Notes:**
- X axis represents political acceptance of combined scenarios
- Y axis represents CO₂ emissions reduction potentials of combined scenarios
- Bubble size represents cost-effectiveness of combined scenarios
- Blue bubbles represent different combined scenarios

Adopting one of the suggested combined scenarios can achieve some co-benefits at four different areas: opportunity cost, lifetime of the crude oil reserve, air pollutants and
creating jobs. The saved amount of gasoline when implementing mitigation measures can be sold to international markets instead of being consumed locally as projected under the BAU scenario. This amount ranges between US$ 0.7 million and 2,400 million over the period 2015 – 2030.

In addition, reducing the energy demand can add an additional two years to the crude oil proven reserve lifetime. The proven reserve lifetime figures imply that Bahrain will import 100% of its refined oil after six years and accordingly the energy bill will increase. This means that Bahrain will have to pay for the oil it used to produce, as well as subsidizing fuel prices if the Bahraini government decides to keep the fuel price unchanged.

Mitigation of CO₂ emissions can also contribute to improving air quality as other pollutants (e.g. carbon monoxide, nitrogen oxides and sulphur dioxide) emitted from gasoline consumption may be reduced by between 0.01 – 28% when compared to the BAU scenario. Furthermore, infrastructure projects will provide many job opportunities especially in the public transport scenario. These vocations will not be at construction phase only, but at the running phase as well.

4. Conclusions

Gasoline consumption and CO₂ emissions follow an upward trend in transport sector in Bahrain. Controlling and reducing both of these is crucial to the country considering its limited resources, future international commitments, and its vulnerability to a rise in sea level. Mitigation of CO₂ emissions in the road transport sector at such a special socio-economic and political context has never been researched or explored before. In this paper, a baseline scenario was constructed or the first time for the passenger vehicles using bottom-up calculated indicators. Different trajectories to a relatively lower carbon transport in Bahrain were examined along with the cost of mitigation scenarios. Views of policymakers and experts and their acceptance of the developed scenarios were also explored. In this paper a first-of-its-kind study in Bahrain is presented along with proposal for a modified participatory methodology for the development process of mitigation scenarios.

Analysis shows that CO₂ emissions will grow by 100% over the course of analysis period (2015-2030, with 2010 as base year). The highest environmental effectiveness is associated with setting high fuel economy standards in Bahrain. This option has CO₂emission reduction potentials of 22% compared to the BAU scenario at relatively low cost (US$ 112 tonne CO₂e). In terms of economic effectiveness, setting low fuel economy standards has the lowest cost of US$ 90 per tonne of avoided CO₂e emissions. In order to combine the advantages of different mitigation scenarios, we produced 50 different combined scenarios using LEAP. Some of these combined scenarios are more politically accepted, but with less emissions reduction potentials and higher cost per tonne of avoided emissions. Overall, emission reductions can reach 28% compared to the business-as-usual scenario with cost of US$ 399 per tonne of avoided CO₂e emissions.
Delaying mitigation is estimated to accelerate approaching the end-of-life of the oil reserve in Bahrain. It will also affect the air quality especially in congested areas, not to mention the rapid increase in CO₂ emissions. Reducing carbon emissions from the transport sector is not uncomplicated or unproblematic, but rather is quite challenging as described in the AR5. Mitigation requires changes throughout the economy. Investments in cleaner technologies and the public transport infrastructure would contribute to reducing emissions if they were subsidised rather than of oil prices. Awareness needs to be raised among policymakers. These are the individuals who need to be convinced that mitigation of CO₂ emissions is a shared responsibility. That is to say that each individual has a role in building low-carbon transportation and to extend this even further, in a low-carbon economy. Exploring the general public’s acceptance of different mitigation options would be a necessity and is recommended for future research.

The findings presented in this paper are of significant importance to aid decision making on climate change mitigation in Bahrain. Bahrain can start preparing national targets with strategies on how this can be achieved. Furthermore, closing the regulations gap can be done through introducing fuel economy standards and a labelling scheme. Fiscal measures can be used in a limited way at this stage until the infrastructure is prepared and alternatives are provided. Bahrain can benefit from the experience of other GCC countries especially with regard to vehicle technologies and alternative fuels which allows for focusing on other alternatives.

Results of this work can give a glance of potential pathways and policymakers’ views of other GCC countries as well. GCC countries share many things in common including the same GCC standards required for new vehicles. It can also alarm Bahrain’s neighbouring countries to act before their resources deplete and to act on the international commitments that all countries will face.

References


