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Integrated approach to the assessment of CO_2e-mitigation measures for the road passenger transport sector in Bahrain

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Abstract

The transport sector is one of the fastest-growing energy-consuming sectors in the world and it contributes greatly to emissions of carbon dioxide equivalent (CO_2e). In Bahrain, CO_2e emissions from the transport sector grew by an average of 8% annually between 1994 and 2006. The aim of this research was to develop an integrated approach to assess the measures adopted to reduce CO_2e emissions by the transport sector within the context of climate change mitigation. This approach used the multi-criteria analysis methodology of the Analytic Hierarchy Process (AHP) to embed conventional assessment methods and a participatory approach. Three extensions to the original AHP methodology were developed: multi-AHP models, scenario packaging, and the examination of the plausibility of the results. The AHP results showed that certain fuel economy standards achieved the highest scores against five qualitative and quantitative criteria. Using socially and politically acceptable options, an integrated approach to CO_2e mitigation could achieve a reduction in emissions of around 22% by 2030 (compared with 2010), at a cost of USD 112 per metric tonne of avoided CO_2e emissions. Results from surveys of policymakers, experts, and the general public indicated that the outcomes of scenario packaging were plausible. The contributions of this research are two-fold. First, for the first time in Bahrain, the preferences of the general public have been considered and integrated with both the preferences of policymakers and experts and the results obtained from conventional assessment methods. Second, a structured approach for the integration of different assessment methods, transferable to other contexts, was developed and examined. Furthermore, multi-AHP models were introduced that can reflect the preferences of different concerned groups. Applications of this approach include

assessment of the implementation of mitigation measures that could affect a number of concerned groups, decision making in energy-consuming sectors, and development of mitigation policy packages.

Keywords: Bahrain, public participation, CO_2e mitigation, road passenger transport sector, AHP, scenario packaging

Contents

Abbreviations: AHP, Analytic Hierarchy Process; AR5, The Fifth Assessment Report; CNG, Compressed Natural Gas; CO_2e, carbon dioxide equivalent; $GtCO_2$e, Giga tonne carbon dioxide equivalent; IPCC, The United Nations Intergovernmental Panel on Climate Change; MCA, Multi-criteria analysis; Mt, Metric tonne; USD, United States Dollars.

1. Introduction

According to the Fourth Assessment Report from the United Nations Intergovernmental Panel on Climate Change (IPCC), during the last decade, emissions of carbon dioxide equivalent (CO_2e) from the transport sector have grown faster than those from other energy sectors [1]. The IPCC's Fifth Assessment Report (AR5) [2] revealed that CO_2e emissions in 2010 had increased by around 81%, compared with 1970, to reach 49 giga tonnes of carbon dioxide equivalent ($GtCO_2e$), 10.2% of which was released from the road transport sector. The expectation is that emissions from the transport sector will grow by between 125% and 150% by 2030, compared with 2010, unless “aggressive and sustained mitigation policies” are implemented [2]. Adopting mitigation policies with regard to transportation could reduce the potential increase in emissions by 8%–25% compared with a no-policies scenario. The AR5 classifies mitigation policies into four categories: journey avoidance, modal shifts, lowering of energy intensity, and reduction of carbon intensity of fuels.

Assessment of transport-related mitigation policies usually fits within the transport planning cycle. Although transport planning focuses mainly on transport infrastructure projects and investments, several applications can be observed within the context of climate change mitigation [3, 4]. In the available literature, there are two classifications for existing national practices and methods related to transport planning for the assessment of existing alternatives: conventional assessment methods and participatory approaches. Conventional assessment methods include cost-benefit analysis and cost-effectiveness analysis, in addition to some other methods used for assessing factors other than the economic aspects of the alternatives, such as scenario analysis and environmental assessment. The inclusion of social aspects into the process of assessing transport alternatives within the context of climate change mitigation is possible when utilising conventional methods (e.g., the social cost-benefit analysis method). Participatory assessment methods include multi-criteria analysis (MCA), which is a participatory approach widely used in transport assessment and decision making that considers a number of alternatives and their various aspects. The transport literature emphasises development of participatory assessment methods, particularly with reference to calls to involve “society as a whole” and to include social acceptability among the criteria considered in the assessment process [5].

It is acknowledged that the adoption of economic measures and the preparation of mitigation policies might constitute challenging tasks for some countries. For example, countries with heavily subsidised fuel prices and highly energy-intensive economies might be required to implement radical changes and substantial reforms of their energy sectors. These countries could face challenges including the provision of required data, assessment of different measures, appropriate selection from among the wide range of available mitigation measures, and most importantly, canvassing public approval for the selected measures. The importance of the latter is acknowledged because mitigation measures would be highly likely to include some requirement for lifestyle changes, in addition to energy price reform and new taxation systems.

Bahrain, which is a developing oil-exporting country with approximately 28% of its gross domestic product derived from oil exports, is an example of a country that needs to reduce its transport-related CO_2e emissions. Despite the relatively small amount of its CO_2e emissions, Bahrain is a country that has one of the highest carbon-per-capita rates in the world and it ranks among the top 10 for the lowest gasoline prices. Furthermore, reducing CO_2e emissions would be associated with a decrease in energy consumption, which is a target set by the Government of Bahrain. However, the move toward a low-carbon future requires consideration of the preferences of the affected groups, i.e., the general public. The involvement of the general public in the process of assessment of any mitigation measures would be vital to ensure their acceptance and successful implementation. Many countries throughout the world already apply such practices; however, the balance between what people prefer, what is economically feasible, and what is environmentally effective could be a challenge in Bahrain, especially considering the lack of literature related to similar socioeconomic, political, and geographical contexts.

The objectives of this study were two-fold. First, it aimed to review the assessment approaches related to the mitigation of transport CO_2e emissions. Second, it sought to develop an integrated assessment model that considers economic, environmental, social, and political dimensions in the assessment. Accordingly, conventional assessment methods were integrated with a participatory approach in a holistic manner under the umbrella of MCA. Quantitative data were obtained from relevant literature and qualitative inputs elicited from semi-structured interviews conducted with policymakers, experts, and the general public. Ultimately, ranking orders for mitigation scenarios were obtained, scenario packages were produced, and the plausibility of those packages was explored to inform decision making on climate change mitigation in Bahrain.

In the following section, a review of both the sources of CO_2e emissions in Bahrain and the projected emissions from the transport sector is delivered. Section 3 provides a review of the available mitigation measures, assessment methods, and main participants in the assessment process. Discussions of the MCA method and scenario packaging are presented in sections 4 and 5, respectively, followed by the main conclusions and recommendations in section 6.

2. CO_2e emissions and the transport sector

The transport sector accounts for 27% of the world's energy consumption [6], a proportion that has increased from 23% in 1973 [7]. In 2012, the transport sector accounted for around 63% of total oil consumption, 6% of total gas consumption, and <1% of total coal consumption [8]. According to AR5, the contribution of CO_2e emissions from fossil fuel combustion and industrial processes has increased from 55% in 1970 to 65% of total CO_2e emissions in 2010 [2]. The International Transport Forum, within the Organization for Economic Cooperation and Development, has predicted a 120% growth of global transport emissions by 2050 compared with the levels in 2000 [9]. However, the IPCC Integrated Assessment Modelling scenarios show wide variance of between 40% and 190% in the predicted growth rates of passenger and freight emissions by 2030 [2]. Evidence from sectorial studies conducted as part of AR5 [2] suggests a rate of growth of between 100% and 140% for transport emissions by 2030, if mitigation policies were adopted. Such evidence suggests that transport emissions would peak by 2040 and then decline [2].

Two inventories have been conducted with regard to CO_2e emissions in Bahrain: one in 1994 and the other in 2000 [10, 11]. The results from these inventories illustrate that total CO_2e emissions in Bahrain have increased on average by 1% annually between 1996 and 2000, reaching a figure of 22 million metric tonnes (Mt) of CO_2e in 2000, of which around 6% was from the transport sector. However, average annual emissions from the transport sector have increased at the higher rate of 2.7% during the same period. Although the amount of CO_2e emissions from passenger transport is relatively small in comparison with other sectors, unpublished inventory results show that such emissions have increased rapidly between 2000 and 2006 by an average of 11.3% annually. This means that CO_2e emissions from Bahrain have increased on average by around 8% annually from 1994 to 2006.

Projections of future CO_2e emissions from passenger vehicles in Bahrain indicate an increase from 1.6 Mt of CO_2e in 2010 to 3.2 Mt of CO_2e by 2030 [12]. This is especially likely for the case with complete reliance on fossil fuels and no clear intention to shift toward low-carbon fuels. Furthermore, the high proportion of private passenger vehicles in the modal split of overall passenger transport (private and public) contributes to the projected increase in future emissions. Available figures indicate that journeys in private vehicles constitute 89%–93% of all trips in Bahrain, making this the principal mode of road transport in the country. Passenger vehicle numbers have grown dramatically in Bahrain since 2000, totalling >367,000 vehicles in 2010, which corresponds to an average annual growth rate of 7.3% [13]. However, during the same period, the fuel economy of newer vehicles has improved at the slower annual rate of about 0.7% on average [12], which is because of the increasing trend toward buying larger vehicles. This implies that the increase in vehicle weight has offset the potential for significant savings from the wider distribution of small and more efficient vehicles, resulting in slower improvement in the average fuel economy for new passenger vehicles.

Of the wide variety of mitigation measures, Bahrain has considered only the improvement of the public transport system to facilitate a shift from private to public transport in the country. A new service provider commenced operations in February 2015 with the intention of adding new routes to the bus rapid-transit system, which were designed to cover 77% of the country. Furthermore, the size of the bus fleet and number of bus stations will increase from 35 and 400 to around 140 and 900, respectively, by 2016.

There are no published guidelines regarding the assessment of transport projects in Bahrain; however, there are examples of the application of MCA to the assessment of transport infrastructure projects. The law in Bahrain does not mandate the involvement of the general public in the assessment process, but approval from the Chamber of Deputies and the Consultative Council is a requirement for the approval of ministry budgets concerning large transport infrastructure projects. Furthermore, consideration of feedback received from the general public does occur during or after the implementation stage. Additionally, in cases where an Environmental Impact Assessment is required, because a certain transport infrastructure project entails reclamation, public participation occurs at an early stage through the relevant elected municipal council. Other than this, there is no involvement of the general public in the assessment process of transportation projects.

3. Mitigation measures and assessment methods

There has been extensive research on the measures available for the mitigation of CO_2e emissions from the road transport sector [14-18]. Many of these measures are well developed and in operation in various countries throughout the world. The potential for the reduction in CO_2e emissions varies between the different measures. Alternative fuels such as compressed natural gas (CNG) can reduce emissions by 15%–25% (from well to wheel) [1, 19], whereas biofuels can realise higher reductions of around 30% [20]. However, regulatory measures tend to achieve lower reductions of emissions. For example, the adoption of fuel economy standards has improved vehicle efficiency by 15% since 1990 in those countries that are part of the International Energy Agency. Unfortunately, growth in the numbers of both vehicles and trips has offset the CO_2e savings [21]. In terms of planning and information, eco-driving is an example of a measure that can increase the fuel efficiency of vehicles and reduce carbon emissions by 5%–20% on average over the long term [22]. Furthermore, lowering the speed limit can reduce both carbon emissions and traffic incidents. For example, in Rotterdam in The Netherlands, the reduction of the speed limit from 120 to 80 km/h resulted in emission reductions of 15% on roads with lengths ≥3.5 km [22].

The process of assessment and selection of mitigation measures varies. A literature review undertaken for this study revealed the different approaches and methods used for the assessment process. The dominant assessment methods focus on economic feasibility and the achievability of environmental benefits. Social factors receive special attention in accordance with sustainability through the adoption of an organised analysis framework, i.e., the MCA.

Among the available assessment methods, MCA appears the most suitable methodology for use in environmental assessments and policymaking [23-25]. By its nature, MCA is a participatory approach. It is a methodology and set of procedures used for assessment when many criteria are under consideration and when a number of stakeholders are involved in the assessment process. It enables the assessment of the alternatives for mitigation based on a quantitative analysis of multiple criteria without assigning them all monetary values. It also acts as a facilitator in the decision-making process that involves different groups of stakeholders [26-30].

MCA also promotes bottom-up democracy because the implementation and success of any policy requires its acceptance and support from the people concerned [31]. Even if other factors such as bias or hidden agendas play roles in the final decision that causes the rejection of the MCA recommendation, the process itself adds considerably to the discussion of the issue; it raises concerns, identifies problems, reflects opinions, and illustrates the beliefs and preferences of the concerned groups [30].

There are various MCA methods but those used most commonly in transport planning are the multi-attribute theory variants (e.g., Analytic Hierarchy Process [AHP], Multi-Attribute Utility Theory, Multi-Attribute Value Theory, Simple Multi-Attribute Rating Technique, and Multi-Attribute Rating Technique Extended to Ranking), outranking methods (e.g., Preference

Ranking Organization Method for Enrichment Evaluation, Elimination and Choice Expressing Reality), and regime analysis [4]. Of these, the AHP is the method used most widely.

A review of the relevant literature revealed the wide adoption of an integrated approach for assessing transport-CO_2e-mitigation measures (Fig. 1). This is because the use of such an approach is often required [32]. Fig. 1 shows that 67 out of 83 (81%) reviewed studies applied an integrated approach to the assessment. Of those studies, 92% applied economic and environmental assessments and scenario analysis as methods for the assessment of transport-CO_2e-mitigation measures. Furthermore, a review of the literature that reported the use of an integrated approach to the assessment emphasised the use of MCA as a participatory method. However, and despite the wide application of MCA in the transport sector, only a few studies have used MCA to develop future scenarios [3] or have involved wide groups of stakeholders in the assessment process.

Multiple stakeholders can play various roles during different stages of an MCA. The principal players in the assessment process can be policymakers, experts, and various organised/unorganised groups of stakeholders. These different groups have various roles at different stages of the assessment process. In a recent literature review, Macharis and Bernardini [112] identified the participation of stakeholders in three areas during the MCA assessment process. First, they can participate in the complete analysis through a structured framework. This is referred to as stakeholder MCA (as in [113]), social MCA (as in [114]), or deliberative MCA (as in [115]). Second, their participation might be limited during the first stages of the MCA, such as identifying alternatives, formulating evaluation criteria, and setting the criteria weights. Third, when the analysis is finished, the role of the different stakeholders concerns the provision of feedback on its results. Macharis and Bernardini [112] cite combinations of the second and third participatory areas in some literature, whereas the participation of stakeholders is rare during the latter stages of the MCA, including the evaluation of the alternatives and the attainment of consensus among the participants.

A review of the relevant literature has revealed three main stages of the assessment process in which stakeholders are involved: identifying mitigation measures that undergo assessment, assessing the identified measures, and investigating the plausibility of the assessment results. Table 1 presents some of the main peer-reviewed studies and stages of the assessment process, along with different participating stakeholder groups and their roles during the assessment stages.

Identification of the mitigation measures list is the first stage in which stakeholders can be involved and various groups of stakeholders can participate during this early stage of the assessment process. The second stage for the involvement of stakeholders is the assessment of mitigation measures. The usual participants in this stage are the experts, because they assess the suggested measures and provide quantitative or qualitative data. The purpose of this stage is purely to assess the initially selected mitigation measures or scenarios, and modification of these measures is rare (Table 1). The third stage of participation by stakeholders includes the investigation of the plausibility of the assessment results. This stage is relatively new when assessing mitigation measures related to the transport sector within the context of climate change mitigation. It aims to identify any pending concerns and to ensure stakeholders' acceptance.

This review also identified gaps in the literature that the present paper aims to fill. Table 1 indicates the absence of a qualitative–quantitative conventional–participatory approach for the assessment of transport-CO_2e-mitigation measures. Moreover, it is rare for the preferences of the general public to be incorporated within the assessment models and for the mitigation scenarios to be modified during the assessment stage .Furthermore, only a limited number of studies have investigated the plausibility of the assessment results.

4. AHP method

4.1. About AHP

The AHP methodology is used widely for assessment and decision making related to transport projects [112]. Various applications for assessment within the context of climate change mitigation can be observed either as a stand-alone methodology (e.g., [45, 46]) or integrated with other MCA methods (e.g., [4, 29, 34]). This implies the suitability of the AHP method to the assessment of mitigation measures for the transport sector and it allows for its integration with other assessment methods to inform the decision-making process.

Thomas Saaty developed the AHP in 1980 [116]. The AHP is based on a linear additive model and it uses pairwise comparisons, which makes it suitable for both single- and multi-dimensional cases [23, 117]. Moreover, AHP has a built-in test to verify the consistency of the participants' judgments [23, 117]. The AHP method can function with both quantitative and qualitative data and it provides a final ranking for all the alternatives under assessment. A literature review for this study has suggested that the AHP method requires less time, less effort, and fewer data than other methods. Moreover, it is a systematic methodology with clear steps that can be applied, calculated, and understood easily by stakeholders.

The AHP has a clear structure and systematic method of application. The hierarchy itself clearly shows the objective, those criteria that affect the decision making, and the list of alternatives. This method is suitable for combining both numbers and opinions and it is useful in cases where policymakers lack adequate knowledge or experience of certain criteria. Pairwise comparison has been proven a useful tool when priorities have not been set, ranking is confusing, or weights cannot be defined accurately [23, 28, 118]. Moreover, pairwise comparisons allow participants to express their real opinions and show their true interests. In mathematics, if A>B and B>C, then A>C; however, this is not the case in the real world. Biases, hidden agendas, and previous experience can all affect an individual's decisions [28].

There are various software packages available on the market for AHP calculations and Expert Choice® is one of those suitable for application in different fields. For instance, applications for Expert Choice® can be found in transport-related assessment (e.g., [4, 119]), marine and coastal resources (e.g., [120, 121]), and project management (e.g., [122]). Microsoft Excel® is also suitable for undertaking AHP calculations; however, the use of software that automates all such calculations can save time and effort, especially when considering a wide group of participants, conducting sensitivity analyses, and constructing multi-AHP models, as proposed in this paper.

4.2. Building the hierarchy

The construction of the AHP hierarchy in this study included the three main levels: objective, evaluation criteria and sub-criteria, and alternatives that achieve the main objective (Fig. 2). Expert Choice® was used to build the hierarchy and to calculate the priorities.

The main objective of the AHP analysis is to mitigate CO_2e emissions from the road passenger transport sector in Bahrain. Seven mitigation scenarios were analysed in this study based on recommendations from consultancy reports for the countries of the Gulf Cooperation Council (Table 2). Five main evaluation criteria were used to assess the selected mitigation scenarios. Policymakers and experts performed the selection of both the evaluation criteria and their weighting (Table 3). The scores of performance related to the economic and environmental quantitative criteria were derived from our calculations in a previous work [123], whereas policymakers, experts, and groups of the general public assigned the scores of performance related to the social, political, and other qualitative criteria.

When comparing the structure of the applied hierarchy in this study with that reported in the literature, the design was almost the same in terms of the number of alternatives, evaluation criteria, and collected data. Regarding the number of alternatives, the relevant literature showed that the various numbers of alternatives that undergo assessment range from 3 [34] to 12 [29]. However, the seven alternatives assessed in this study match those recommended by Saaty [124] when applying the AHP methodology, and it accords with the "magic number" of alternatives suggested by Miller [125] (i.e., 7 ± 2).

A review of the literature showed that the number of main evaluation criteria ranges between 3 [4] and 11 [29], with 5 as the mode. This number matches the five main evaluation criteria employed in this study (Fig. 2). However, the lists of criteria differ because they depend mainly on the measures being assessed [126]. Nonetheless, two main criteria are evident in most of the reviewed literature (i.e., emission savings and costs), and the same criteria were also used in this research. However, the criteria weights are relative and, therefore, they differ depending on the number of evaluation criteria used in the assessment. The literature on British assessment practices suggests that significant weight is assigned to economic criteria [127]. The situation is the same in Germany, where an inferior role is assigned to non-monetary criteria [128]. The results presented in this paper are consistent with this because high scores were assigned to economic criteria.

With regard to the type of data employed as inputs to the AHP assessment models, relevant literature demonstrated the use of quantitative, qualitative, or combinations of both data types. Qualitative data were usually derived from pairwise comparisons conducted by experts [29] or by the scholars themselves [45], whereas quantitative data were usually obtained from modelling tools [3]. The use of quantitative and qualitative data together has been applied widely applied, as discussed in [34, 90, 129], and a similar approach was applied in this study. However, this research is unique in terms of incorporating the preferences of the general public within the AHP framework for the assessment of transport-CO_2e-mitigation measures.

A new methodological extension, proposed in this paper, relates to how different feedback received from stakeholders is dealt with within the AHP methodology. A review of the relevant literature reveals several approaches. One approach suggests splitting the MCA model and creating a specific single-assessment model for each scenario. In this approach, different weights are subsequently assigned to the evaluation criteria under each scenario [130, 131]. Schroeder and Lambert [132] used a similar approach in which weights of the evaluation criteria were altered. This approach, which is referred to as a sensitivity analysis in the relevant literature, investigated the impact of changing the criteria weights [133]; however, the performance of the different alternatives based on each criterion was not explored.

A second approach for dealing with the various preferences of stakeholders is to obtain the participants' consensus regarding the selected alternatives, which can be obtained using the Delphi method [108]. Another example entails experts conducting the assessment and then presenting the results to the public, following which modifications could be performed as necessary. Finally, the assessment is repeated based on the comments received from the public [37].

In a third approach, a list of various possible alternatives is developed by policymakers and experts themselves or is identified through a literature review. The alternatives are then screened by the concerned stakeholders or experts to explore their feasibilities [3]. An example of this approach entails the preparation by stakeholders of a wish list of preferred alternatives. Then, experts subsequently explore the feasibilities of selected alternatives [38].

In this study, a new approach was proposed. Considering the feedback received from the participants, two additional AHP models were constructed that differed only in terms of one of the mitigation scenarios (i.e., the maximum proposed registration fees). The maximum fees originally proposed were USD 600 per car annually, depending on the vehicle's CO_2e emissions/km (RF original scenario) and the associated AHP model was called the Original RF AHP. However, the participants proposed two additional lower amounts: USD 100 (RF 100 scenario), for which the AHP model was called the RF 100 AHP, and USD 190 (RF 190 scenario), for which the AHP model was called the RF 190 AHP. This approach is new and here, it is called the multi-AHP models approach.

4.3. Embedding conventional assessment methods

4.3.1. About conventional assessment methods

The use of a wide variety of well-developed conventional assessment methods in different socioeconomic contexts is common in various fields. The methods incorporated in this study included cost-effectiveness analysis, scenario analysis, and environmental assessment. These methods can provide a picture of expected costs and potential environmental savings, whereas scenario building can portray various pictures of the future under different assumptions.

The widespread use of conventional methods has maintained their dominance in the assessment process of transport-related mitigation measures. However, the implementation of these methods on a stand-alone basis excludes the aspect of the acceptance of the general public, which could jeopardise the success of the assessment, as has been suggested in the literature (e.g., [134-136]). Additionally, the different applications of these methods have largely used quantitative data and they have rarely embedded qualitative data in the assessment. Social cost-benefit analysis is one method that includes qualitative criteria (e.g., ecological, spatial, or social criteria) in the assessment process; however, this technique invokes the problem of monetisation [112].

4.3.2. Data collection

The results from previous work related to cost-effectiveness analysis and environmental assessment [123] were used in this study as quantitative inputs to the economic and environmental criteria in the AHP model. A linear scoring function was used for the environmental and economic criteria with scores ranging from 1–9 (worst–best performance) for compatibility with Saaty's original scale. Then, and for the purpose of normalisation, the principal eigenvector was calculated, as explained by Saaty [137].

4.3.3. Results

The results of the economic criteria show that all the mitigation scenarios have the same score (i.e., 16%), except the scenario for improving the public transport system (PT), which scores very low (1%) (Table 4). This is mainly because of its high capital costs and the delayed benefits. However, the final ranking of the mitigation scenarios reflects the scores of performance against the five evaluation criteria, including the economic criteria, taking into account their different weights.

Results for the environmental criteria show that setting high fuel economy standards (H FE) receives around 40% of the environmental criteria weight, because it is the highest scenario with incremental savings over the period 2015–2030. Setting low fuel economy standards (L FE) and the high penetration of hybrid cars (H HC) are second, totalling around 37% of the total environmental savings. Conversely, the low penetration of both hybrid cars (L HC) and natural gas cars (L CNG) only contributes 4% of the total environmental savings.

4.4. Embedding the participatory approach

4.4.1. About the participatory approach

The use of participatory approaches to investigate the preferences of stakeholders is evident in literature. A review of the literature revealed that preferences of policymakers have been embedded within MCA models for the assessment of transport-related CO_2e-mitigation measures. Specifically, the preferences of policymakers and experts have been incorporated with the results obtained using conventional assessment methods [3, 4, 34]. However, although the concerned public has long felt abandoned and as unwanted intruders in the entire process, the literature suggests that "public participation has made a comeback" and that now the term "governance" has replaced the term "government" [138], which implies greater involvement by the general public in the decision-making process.

Acceptance by the general public is crucial to ensure the legitimacy and sustainability of the adopted policy [134-136]. Public participation increases democracy, enhances the competence of the final decision, and adds to the understanding of the public's behavioural patterns and perceptions in relation to the studied issue. Moreover, public participation enhances the transparency of the policy-making process [139], helps to avoid potential future conflicts, and raises awareness [136]. In contrast, some argue that the participatory approach only provides qualitative information and that it does not provide a systematic analysis of the inputs. However, although the combination of a qualitative participatory approach with a quantitative systematic analysis approach (as in the AHP) could overcome this problem [135], a literature review revealed a lack of the integration of these methods.

There is a growing body of literature that pays special attention to the views and preferences of the general public. However, many of these studies have aimed to enhance the understanding of the views and perceptions of the general public without incorporating their preferences into the assessment models. For instance, the objectives of the reviewed studies focused on understanding the preferences of the general public [140, 141], identifying those factors that influenced their preferences [142, 143], or comparing the general public's preferences with those of experts [144].

The literature identifies two groups of techniques for involving stakeholders in the policy-making process: interactive tools that include interviews, focus groups, public hearings, and workshops and non-interactive tools that include questionnaires and surveys. Interactive tools are best suited for use with a limited number of participants and without time boundaries. Although these tools can help with information gathering, the person–person contact could introduce some bias. Conversely, non-interactive tools are suitable for reaching many people within a limited time. Furthermore, these tools are impersonal and can reflect the participants' real opinions. However, there is a risk of a low response rate, especially if the participants are busy or unconvinced of the importance of the topic. In addition, poorly set questions could lead to their misinterpretation and affect the validity of the responses.

Literature that specifically explores stakeholders' preferences related to transport-CO_2e-mitigation measures indicates the use of various participatory techniques ranging from interviews with the general public [140] to focus groups [144]. However, questionnaires have proved suitable as pre-designed surveys prepared for interviews and focus groups or for self-administration.

4.4.2. Eliciting preferences

Two surveys in the form of semi-structured interviews were used to elicit the preferences of policymakers, experts, and the general public in Bahrain with regard to social, political, and other criteria. Cochran's sample-size formula was used for categorical data [145] to determine the minimum sample size as follows:

$$n = (t^2 \times pq)/d^2, \quad (1)$$

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%, and d is the acceptable margin for error (in this case, 0.05).

The total number of participants from the policymakers and experts group was 40, whereas the total number of participants from the general public was 400. For the general public group, a stratified sample based on four main criteria, namely, nationality, age, sex, and geographical location, and ensured equivalent representation of the different groups within society. Participants responded to questions about these four criteria prior to their participation, which ensured the required percentages, after which the convenience sampling was applied. Potential participants were approached in a number of public places spread throughout the country, including shopping centres, markets, companies, universities, ministries, and at bus stops, and the interviews were conducted directly, face to face.

Pairwise comparisons determined the preferences of the participants, as suggested by Saaty [146]; however, instead of using Saaty's original scale (1–9), the use of a modified scale (1–3) made the ranking task easier, clearer, and faster.

4.4.3. Results

Results from the two surveys illustrate the participants' preferences towards setting fuel economy standards and improving the public transport system (Tables 5 and 6). However, the setting of annual vehicle registration fees based on CO_2e emissions is preferred less by both groups of participants, scoring the lowest priority in the multi-AHP model. With regard to the job creation criterion, the penetration of hybrid cars and improvements in the public transport system achieve the highest scores, whereas public transport is the most politically feasible option in terms of the legislative framework. With regard to the performances against the other criteria, the alternatives of setting fuel economy standards and registration fees receive the highest scores against the land availability criterion because they are policy options that do not have any specific land requirements (Table 7). Regarding the weather criterion, public transport is the least suitable alternative because it requires a maximum of 20 minutes walking to a bus stop in the harsh weather of Bahrain. Accordingly, the performances of the different mitigation scenarios vary under the different criteria, as seen by policymakers, experts, and the general public.

4.5. Aggregated results

The application of the AHP methodology and use of Expert Choice® provided the final weights and rankings of the mitigation scenarios for the AHP model (Table 8). Setting high fuel economy standards ranks first against the five evaluation criteria, while the low penetration of CNG cars is last in the list of mitigation scenarios. The public transport scenario receives a high score in both the original RF and the RF 100 AHP models, implying that it is preferred by all participants, other than those who preferred the RF 190 scenario. Although the public transport scenario does not provide substantial CO_2e savings over the analysis period, and its costs per reduced Mt of CO_2e emissions are high, public transport can be an investment for the future, especially when supported by policymakers, experts, and the general public.

The scenarios regarding the penetration of hybrid cars receive medium scores, with the high-penetration scenario scoring very slightly higher than the low-penetration scenario. Although the high-penetration scenario achieves higher emission savings for lower costs, it is preferred less by the participants because they prefer initial small-scale testing prior to the incentivisation and encouragement of wider penetration.

Regarding the registration fees system, this mitigation scenario has low scores under the different multi-AHP models. However, the scores of the two additional scenarios (i.e., the RF 100 and RF 190 scenarios) are slightly higher in comparison with the scenario proposed initially (i.e., the RF original scenario). The relative score of 10.5% for the registration fees scenario in the Original RF AHP model increases to 12.6% and 13.6% in the RF 100 AHP and RF 190 AHP models, respectively. This implies that consideration of the participants' feedback could result in better levels of acceptance of the suggested mitigation scenarios. Notably, the difference between the highest and lowest scores in the AHP model is only 8.3%. The differences between the ranks (e.g., between first and second, and between second and third) is even lower, i.e., only 1.4% on average. This means that a stand-alone technique cannot recommend a leading mitigation scenario; on the contrary, an integrated approach through scenario packaging might perform better in reducing CO_2e emissions for the case of Bahrain. Adopting scenario packaging could be useful in shedding light on the relative weaknesses and strengths of each scenario prior to its implementation.

A non-parametric test was also applied to identify whether there are statistically significant differences between the rankings of the mitigation scenarios under the three AHP models. Results from the Friedman non-parametric test show that there are no statistically significant differences between the rankings of the scenarios under the multi-AHP models (significance = 0.565). This means that the introduction of the two modified registration fees scenarios through the multi-AHP models has no statistically significant influence over the final rankings of the mitigation scenarios. The Wilcoxon non-parametric test was also used to explore any statistically significant differences between the rankings of the mitigation scenarios under the Original RF AHP and RF 100 AHP, Original RF AHP and RF 190 AHP, and RF 100 AHP and RF 190 AHP models. The results also suggest no statistically significant differences exist between the different pairs of multi-AHP models (significance = 0.612, 0.735, and 0.310, respectively).

Further analysis determined the differences in the rankings of the mitigation scenarios based on qualitative criteria, quantitative criteria, and integrated quantitative and qualitative criteria. Results demonstrate that the mitigation scenario of setting high fuel economy standards ranks first based on the quantitative criteria under the multi-AHP models; however, this does not match its ranking based on the qualitative criteria. Nonetheless, setting high fuel economy standards also ranks the highest based on the integrated quantitative and qualitative criteria. This could be because of the relatively higher weighting of the quantitative criteria (55.8%) compared with the qualitative criteria (44.2%).

The Wilcoxon non-parametric test was also used to analyse the differences in priorities between policymakers, experts, and the general public. The results indicate no significant differences between the preferences of policymakers, experts, and the general public, or between Bahrainis and non-Bahrainis in all of the multi-AHP models. This provides evidence that the implementation of any of the multi-AHP models should be an easy task because the preferences of the general public (Bahrainis and non-Bahrainis), policymakers, and experts are not significantly different. However, some level of communication will be required because the preferences do not constitute an exact match between the different groups in the multi-AHP models.

5. Scenario packaging and plausibility of AHP results

5.1. Description

Policy packaging is a well-established approach (e.g., [89, 147]); however, to our knowledge, this is the first implementation of this approach using the scores of the MCA. The usual way to implement policy packaging is to prepare scenario packages prior to the implementation of the MCA (e.g., [3]), which means that the scenario packages are the alternatives that undergo the MCA analysis. In this study, an extension to the usual MCA model through performing scenario packaging was used after obtaining the priorities to combine and maximise the benefits. This method of scenario packaging achieves several benefits. First, the cost per reduced Mt of CO_2e emissions can decrease significantly, as evidenced in Alsabbagh et al. [123]. Second, the maximum potential of emissions reductions is identifiable. Third, and most importantly, the packaging of acceptable mitigation scenarios can ensure the success of their implementation. This approach suggests packaging the most socially and politically preferred scenarios without the need to undergo further analysis. In the more common method of application, once the scenario packages are developed and assessed under the MCA model, de-packaging cannot be performed at the final stage, which limits the usefulness of the results when a specific single scenario is deemed undesirable and needs to be removed from the package.

A further step that is mainly seen in connection with participatory approaches (e.g.,[37, 49]), but not in the MCA literature, is related to the exploration of the plausibility of the results. This step was borrowed from the pure participatory approaches to ensure the plausibility of the scenario-packaging results. The participation of policymakers, experts, and the general public at this stage also highlights concerns related to the implementation or identifies potential barriers and it offers suggestions on how to resolve them.

5.2. Calculation

Mitigation scenarios were combined from the multi-AHP models, creating 132 scenario packages. There was no restriction over the number of mitigation scenarios packaged in this study because the main factor used for the combination has no contradiction between the selected scenarios. For instance, high fuel economy standards and low fuel economy standards were not combined and neither were the penetrations of CNG and hybrid cars.

Expert Choice® was used to calculate the un-normalised scores for each scenario. When combining two scenarios to determine their ranking, it is necessary to remove the other five scenarios to eliminate their effects on the pairwise comparison. The addition of the final scores of the selected scenarios, obtained from the results of the multi-AHP models, permitted their comparison with the other scenario packages. Based on the number of scenarios included, the scenario packages were grouped into three categories. Group 1 included scenario packages that consisted of only two mitigation scenarios. Group 2 included scenario packages comprising three mitigation scenarios, and Group 3 included scenario packages that consisted of four mitigation scenarios.

With regard to exploring the plausibility of the multi-AHP models results, a questionnaire for policymakers, experts, and the general public was prepared. To make it easier for the participants to accomplish the ranking process, only the top scenario packages from each group (five in total) were selected for inclusion in the final questionnaire. For policymakers and experts, a two-round ranking Delphi method explored the plausibility of the resulting scenario packages through the prepared questionnaire. The questionnaire consisted of two parts. In part one, the participants were asked to rank the five combined scenarios based on their preferences. Then, the scores of the scenario packages were presented and the participants were asked to repeat the ranking task. A third round, included for the general public, comprised the ranking results from the policymakers and experts.

5.3. Results

The results of the scenario packaging show that Group 3 received the highest scores, which is because it includes more mitigation scenarios. These scores reflect the performances of the selected mitigation scenarios against the five evaluation criteria. Scenario packages from the RF100 AHP model have the highest scores for almost all the groups, whereas those for the Original RF AHP have the lowest. This means that social preferences are considered highly when the mitigation scenarios are combined, resulting in higher scores when preferred by the general public.

The development of the scenario packages shows that a reduction of around 22% in CO_2e emissions (compared with 2010) is achievable by 2030 at the cost of USD 112 per Mt of avoided CO_2e emissions using socially and politically acceptable options. Achieving a higher reduction of emissions (36%) is possible, but it would entail a higher abatement cost of around USD 316 per Mt of avoided CO_2e emissions and the use of less socially and politically acceptable options, such as the original registration fees system (i.e., the RF original scenario) and higher penetration of hybrid cars.

The results of Kendall's W coefficient show that there is a high level of agreement between the policymakers and experts (0.566) during the final ranking. The consensus of agreement among the group participants improves slightly from 0.551 in round 1 to 0.566 in round 2, after the presentation of the scenario-packaging results to the participants. However, the overall rankings of the combined scenarios remain unchanged in round 2 compared with round 1 (Table 9).

Similar improvement in the agreement occurs within the general public's group. The Kendall's W coefficient improves from 0.587 in round 1 to 0.674 in round 3, after the presentation of the scenario-packaging results to the participants (Table 9).

A comparison of the rankings of the scenario packages based on the multi-AHP results and the rankings by the policymakers and experts reveals some differences. The differences occur mainly in the ranking order of scenario packages 2, 3, and 5 (Table 9). Reflecting on the list of preferences by the policymakers and experts, the scenario of low penetration of hybrids is more politically preferable than the registration fees scenario, which results in scenario package 3 receiving the highest ranking by the participants. This implies that the preferences expressed by the policymakers and experts have remained almost constant since their preferences were elicited during the semi-structured interviews. Nevertheless, the results of the Wilcoxon non-parametric test show that these differences are not statistically significant (significance = 1), which means that the scenario-packaging results are largely plausible.

The ranking of the scenario packaging performed by the general public shows differences in the ranking order for all the rankings except scenario package 4 (Table 9). However, these differences are also not statistically significant (significance = 0.713). Furthermore, the ranking performed by the participants of the general public group match their initial preferences produced through the pairwise comparisons. A comparison of the ranking order of the scenario packaging performed by the general public with that of the policymakers and experts, reveals an almost complete match, except for scenario package 5. The general public ranked this last because it entails increasing the maximum of the proposed registration fees system to USD 190.

The results from Friedman's non-parametric test show that there are no statistically significant differences between the ranking orders of our results and those of policymakers, experts, and the general public for the five scenario packages (significance = 0.584) (Table 9). It indicates that our results are plausible to the different participating groups and it reflects the reality of their likely acceptance and implementation. Furthermore, these results provide evidence that the preferences of policymakers, experts, and the general public remain constant throughout the assessment process.

6. Conclusions and recommendations

The AR5 states that CO_2e emissions from the entire transport sector increased in 2010 compared with 1970 and that the road transport sector accounted for 10.2% of these emissions. Numerous mitigation measures are available for reducing CO_2e emissions from the transport sector and some are in operation in many countries throughout the world. The method for the assessment of these measures varies, with some countries using conventional assessment methods and others using participatory approaches or a combination of both.

This study reviewed the assessment methods related to transport-CO_2e-mitigation measures. The review of relevant peer-reviewed articles showed that an integrated approach that combines conventional and participatory methods prevails in recent literature. Furthermore, MCA proved adequate for analysing environmental issues. However, although incorporation of various stakeholders' preferences within the MCA is evidenced, the incorporation of the general public's preferences is lacking. This specific omission led to the second objective of this study, which was the development of an integrated assessment model that combines quantitative and qualitative data obtained from conventional and participatory methods in a holistic manner, to reflect the preferences of different stakeholder groups including the general public. This objective was achieved through the design of an AHP model (which is an MCA method) that combined the results both from economic and environmental assessments and from surveys of policymakers, experts, and the general public in Bahrain.

The results of the integrated conventional and participatory assessment methods showed that setting high fuel economy standards ranked first of the five quantitative and qualitative evaluation criteria, whereas the low penetration of CNG cars ranked bottom of the priority list. Combining different numbers of mitigation scenarios means that greater reductions of emissions are achievable for lower abatement costs. The results of surveys of policymakers, experts, and the general public, exploring the plausibility of the scenario packages, suggested that there are no statistically significant differences between the rankings of the selected scenario packages and those of the participants. Further in-depth analysis of the AHP results showed agreement between the preferences of the policymakers and experts on the one hand and with the general public on the other.

The integrated quantitative–qualitative method of assessment using the AHP method provided evidence-based environmentally effective, economically feasible, and socially and politically acceptable alternatives to achieve low-carbon mobility in Bahrain. However, the results from the present study cannot be compared with results from the literature, within the context of climate change mitigation, because of the uniqueness of the integrated assessment approach. Furthermore, the present study is the first of its kind ever conducted for Bahrain, or for any of the other countries of the Gulf Cooperation Council, for the assessment of the effectiveness of measures for the mitigation of CO_2e emissions from the road transport sector. Nonetheless, a methodological comparison with studies that have applied MCA for assessing transport-CO_2e-mitigation measures shows consistency in terms of the number of alternatives, evaluation criteria, and collected data.

This study also developed three extensions to the original AHP methodology. The first extension was the development of what is called here, the "multi-AHP models", in which consideration of the feedback from the participants through modifying mitigation scenarios occurred concurrently with the initially designed AHP model. This extension permitted consideration of different perspectives and preferences of other groups when implementing alternatives from a specific AHP model. The second extension was the construction of scenario packaging, which provided the flexibility to examine the effects of different mitigation scenarios when merged together. The third extension was the exploration of the plausibility of the results of multi-AHP models, which validates the qualitative data inputs and ensures the acceptability of various policy packages prior to policymaking.

The outcomes of this research shed light on the possibility of setting acceptable, affordable, and effective mitigation policies through the development of these methodological extensions. Such an assessment approach could inform decision making on desired mitigation policies, guide the handling of issues and concerns raised by various interested groups, and acknowledge the preferences of the general public.

Future work should explore how the adoption of different participatory approaches could affect the preferences of the general public, as well as to examine the applicability of this integrated assessment approach to other energy-consuming sectors and to other socioeconomic, political, and geographical contexts.

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Table 1: Key stakeholders and their roles in the assessment process relating to transport CO_2 mitigation measures (from selected peer-reviewed studies)

Study	Scope of study	Methods used	Identification of alternatives	Assessment of alternatives				Modification of alternatives	Plausibility
				Selection of criteria	Setting criteria weights	Data type	Source of data		
[34]	Environmentally sustainable transportation	Environmental assessment, economic assessment, MCA	Authors	Authors	Stake-holders	Quantitative Qualitative	Modelling, Stakeholders	×	×
[4]	Clean vehicle fleet	Scenario analysis, MCA	Stakeholders	Stakeholders	√	Qualitative	Stakeholders	×	×
[3]	Low carbon mobility	Scenario analysis, MCA	Experts & policymakers	?	?	Quantitative	Modelling	In the initial assessment	×
[49]	Local climate governance	Participatory approach	Stakeholders	Stakeholders	×	Qualitative	Focus group	×	Policymakers
[37]	Low carbon mobility	Environmental assessment, economic assessment, scenario analysis, participatory approach	Stakeholders	×	×	Quantitative	Modelling	×	Stakeholders
[38]	Low carbon mobility	Environmental assessment, economic assessment, scenario analysis, participatory approach	Stakeholders	×	×	Quantitative	Modelling	×	Civil society
[39]	Low carbon mobility	Environmental assessment, economic assessment, scenario analysis, MCA, participatory approach	Authors	Authors	Experts	Quantitative Qualitative	Modelling, Stakeholders	×	×

Note: X means that this step was not performed in the study, √ means that the mentioned step was performed in the study, ? means that there is no clear evidence of performing/not performing the mentioned step

Table 2: Assumptions used to build the mitigation scenarios

Mitigation alternative	Scenario	Assumptions
Hybrid cars	Low penetration (L HC)	Penetration target of 1% by 2030 with average fuel economy of 17.7 km/L per car
	High penetration (H HC)	Penetration target of 40% by 2030 with average fuel economy of 17.7 km/L per car
CNG cars	Low penetration (L CNG)	Penetration target of 1% by 2030 with average fuel economy of 13.2 km/L per car
Fuel economy standards	Low (L FE)	Average fuel economy target of 15.4 km/L by 2030 for passenger vehicles which is equivalent to the USA's target for 2015
	High (H FE)	Average fuel economy target of 23.5 km/L by 2030 for passenger vehicles which is equivalent to the USA's target for 2025
Registration fees (using price elasticity of demand of -0.4)	Original (RF Original)	- The CO_2e limits are not tightened over time (starting from <141 until>300, with 20 g CO_2e intervals) - Fees start from 0 up to USD 600
	100 (RF 100)	- The CO_2e limits are not tightened over time (starting from <141 until>300, with 20 g CO_2e intervals) - Fees start from 0 up to USD 100
	190 (RF 190)	- The CO_2e limits are not tightened over time (starting from <141 until>300, with 20 g CO_2e intervals) - Fees start from 0 up to USD 190
Public transport	(PT)	- Introducing light rail transit (LRT) system and improving the current bus rapid transit (BRT) system. - 2.8 billion vehicle-kilometre is saved

Source:[123]

Table 3: Criteria and sub-criteria weights

Criteria	Criteria weight	Sub-criteria	Sub-criteria weight	Sub-criteria %
Economic	24.9	The cost-effectiveness	24.9	100
Environmental	31	Extent of CO_2e emissions reduction	14.6	47.1
		Amount of energy saved	16.4	52.9
Political	12.4	Policy makers preferences	6.2	50
		Legislative framework	6.2	50
Social	21	Social preferences	12.7	60.5
		Jobs creation	8.3	39.5
Other	10.7	Land / infrastructure availability	5.4	50.4
		Weather	2.5	23.4
		Availability of the fuel	2.8	26.2

Table 4: Performance scores of mitigation scenarios based on quantitative criteria under the multi-AHP models (normalised)

Scenario	Economic criteria	Environmental criteria	
	Cost-effectiveness	Energy saved	CO_2e emission reduction
L CNG	0.16	0.04	0.04
L HC	0.16	0.04	0.04
H HC	0.16	0.19	0.19
L FE	0.16	0.18	0.18
H FE	0.16	0.38	0.38
PT	0.01	0.05	0.05
RF original	0.16	0.10	0.10
RF 100	0.16	0.05	0.05
RF 190	0.16	0.06	0.06

Notes: L CNG means low penetration of natural gas cars, L HC means low penetration of hybrid cars, H HC means high penetration of hybrid cars, L FE means setting low fuel economy standards, H FE means setting high fuel economy standards, PT means improving public transport system, RF original means setting registration fees system scenario in which maximum fee is USD 600, RF 100 means setting registration fees system scenario in which maximum fee is USD 100, RF 190 means setting registration fees system scenario in which maximum fee is USD 190

Table 5: Performance scores of mitigation scenarios based on social criteria under the multi-AHP models (normalised)

Scenario	Original RF AHP		RF 100 AHP		RF 190 AHP	
	General public preferences	Jobs creation	General public preferences	Jobs creation	General public preferences	Jobs creation
L CNG	0.13	0.05	0.11	0.23	0.08	0.44
L HC	0.14	0.26	0.15	0.12	0.12	0.15
H HC	0.12	0.26	0.11	0.12	0.11	0.15
L FE	0.18	0.05	0.15	0.06	0.18	0.04
H FE	0.17	0.05	0.16	0.06	0.17	0.04
PT	0.18	0.26	0.18	0.34	0.18	0.15
RF	0.07	0.05	0.12	0.06	0.16	0.04

Notes: Original RF AHP means Analytic Hierarchy Process model where the maximum annual vehicle Registration Fee is USD 600, RF 100 AHP means Analytic Hierarchy Process model where the maximum annual vehicle Registration Fee is USD 100, RF 190 AHP means Analytic Hierarchy Process model where the maximum annual vehicle Registration Fee is USD 190, L CNG means low penetration of natural gas cars, L HC means low penetration of hybrid cars, H HC means high penetration of hybrid cars, L FE means setting low fuel economy standards, H FE means setting high fuel economy standards, PT means improving public transport system, RF means setting annual vehicle registration fees based on CO_2 emissions

Table 6: Performance scores of mitigation scenarios based on political criteria under the multi-AHP models (normalised)

Scenario	Original RF AHP		RF 100 AHP		RF 190 AHP	
	Policymakers preferences	Legislative framework	Policymakers preferences	Legislative framework	Policymakers preferences	Legislative framework
L CNG	0.09	0.15	0.07	0.19	0.09	0.12
L HC	0.13	0.15	0.11	0.19	0.17	0.32
H HC	0.10	0.15	0.12	0.19	0.12	0.32
L FE	0.20	0.04	0.17	0.04	0.16	0.04
H FE	0.26	0.04	0.19	0.04	0.15	0.04
PT	0.15	0.43	0.17	0.31	0.16	0.12
RF	0.08	0.04	0.17	0.04	0.15	0.04

Notes: Original RF AHP means Analytic Hierarchy Process model where the maximum annual vehicle Registration Fee is USD 600, RF 100 AHP means Analytic Hierarchy Process model where the maximum annual vehicle Registration Fee is USD 100, RF 190 AHP means Analytic Hierarchy Process model where the maximum annual vehicle Registration Fee is USD 190, L CNG means low penetration of natural gas cars, L HC means low penetration of hybrid cars, H HC means high penetration of hybrid cars, L FE means setting low fuel economy standards, H FE means setting high fuel economy standards, PT means improving public transport system, RF means setting annual vehicle registration fees based on CO_2 emissions

Table 7: Performance scores of mitigation scenarios based on other criteria under the multi-AHP models (normalised)

Scenario	Original RF AHP			RF 100 AHP			RF 190 AHP		
	Land availability	Weather	Fuel availability	Land availability	Weather	Fuel availability	Land availability	Weather	Fuel availability
L CNG	0.07	0.16	0.09	0.05	0.11	0.03	0.05	0.16	0.02
L HC	0.07	0.16	0.09	0.09	0.20	0.15	0.05	0.16	0.19
H HC	0.07	0.16	0.09	0.09	0.20	0.15	0.05	0.16	0.19
L FE	0.26	0.16	0.09	0.25	0.14	0.15	0.26	0.16	0.14
H FE	0.26	0.16	0.09	0.25	0.15	0.15	0.26	0.16	0.14
PT	0.03	0.03	0.45	0.04	0.03	0.21	0.05	0.03	0.19
RF	0.26	0.16	0.09	0.25	0.14	0.15	0.26	0.16	0.14

Notes: Original RF AHP means Analytic Hierarchy Process model where the maximum annual vehicle Registration Fee is USD 600, RF 100 AHP means Analytic Hierarchy Process model where the maximum annual vehicle Registration Fee is USD 100, RF 190 AHP means Analytic Hierarchy Process model where the maximum annual vehicle Registration Fee is USD 190, L CNG means low penetration of natural gas cars, L HC means low penetration of hybrid cars, H HC means high penetration of hybrid cars, L FE means setting low fuel economy standards, H FE means setting high fuel economy standards, PT means improving public transport system, RF means setting annual vehicle registration fees based on CO_2 emissions

Table 8: Results of the multi-AHP models

Criteria	Original RF AHP		RF 100 AHP		RF 190 AHP	
	Normalised %	Ranking	Normalised %	Ranking	Normalised %	Ranking
L CNG	10.41	7	11.08	7	11.46	7
L HB	13.97	5	13.16	5	14.11	4
H HB	15.05	4	14.07	4	14.97	3
L FE	15.84	2	15.20	3	15.94	2
H FE	18.78	1	18.24	1	17.91	1
PT	15.44	3	15.66	2	12.04	6
RF	10.52	6	12.59	6	13.58	5

Notes: Original RF AHP means Analytic Hierarchy Process model where the maximum annual vehicle Registration Fee is USD 600, RF 100 AHP means Analytic Hierarchy Process model where the maximum annual vehicle Registration Fee is USD 100, RF 190 AHP means Analytic Hierarchy Process model where the maximum annual vehicle Registration Fee is USD 190, L CNG means low penetration of natural gas cars, L HC means low penetration of hybrid cars, H HC means high penetration of hybrid cars, L FE means setting low fuel economy standards, H FE means setting high fuel economy standards, PT means improving public transport system, RF means setting annual vehicle registration fees based on CO_2 emissions

Table 9: Analysis results of the plausibility survey

Scenario Packages			Policymakers and experts	General Public	Scenario packaging results
No. of participants			40	40	-
Overall ranking	SP 1	• H FE • RF 100	5	4	5
	SP 2	• H FE • H HC • RF 100	3	3	4
	SP 3	• H FE • L HC • PT • RF 100	1	1	3
	SP 4	• H FE • H HC • PT • RF 100	2	2	2
	SP 5	• H FE • H HC • PT • RF 190	4	5	1
Final Kendall's W coefficient			0.566	0.674	Friedman's test=1.077
Significance			0.000	0.000	0.584

Notes: SP means scenario package, H FE means setting high fuel economy standards, RF 100 means setting registration fees system scenario in which maximum fee is USD 100, H HC means high penetration of hybrid cars, L HC means low penetration of hybrid cars, PT means improving public transport system, RF 190 means setting registration fees system scenario in which maximum fee is USD 190

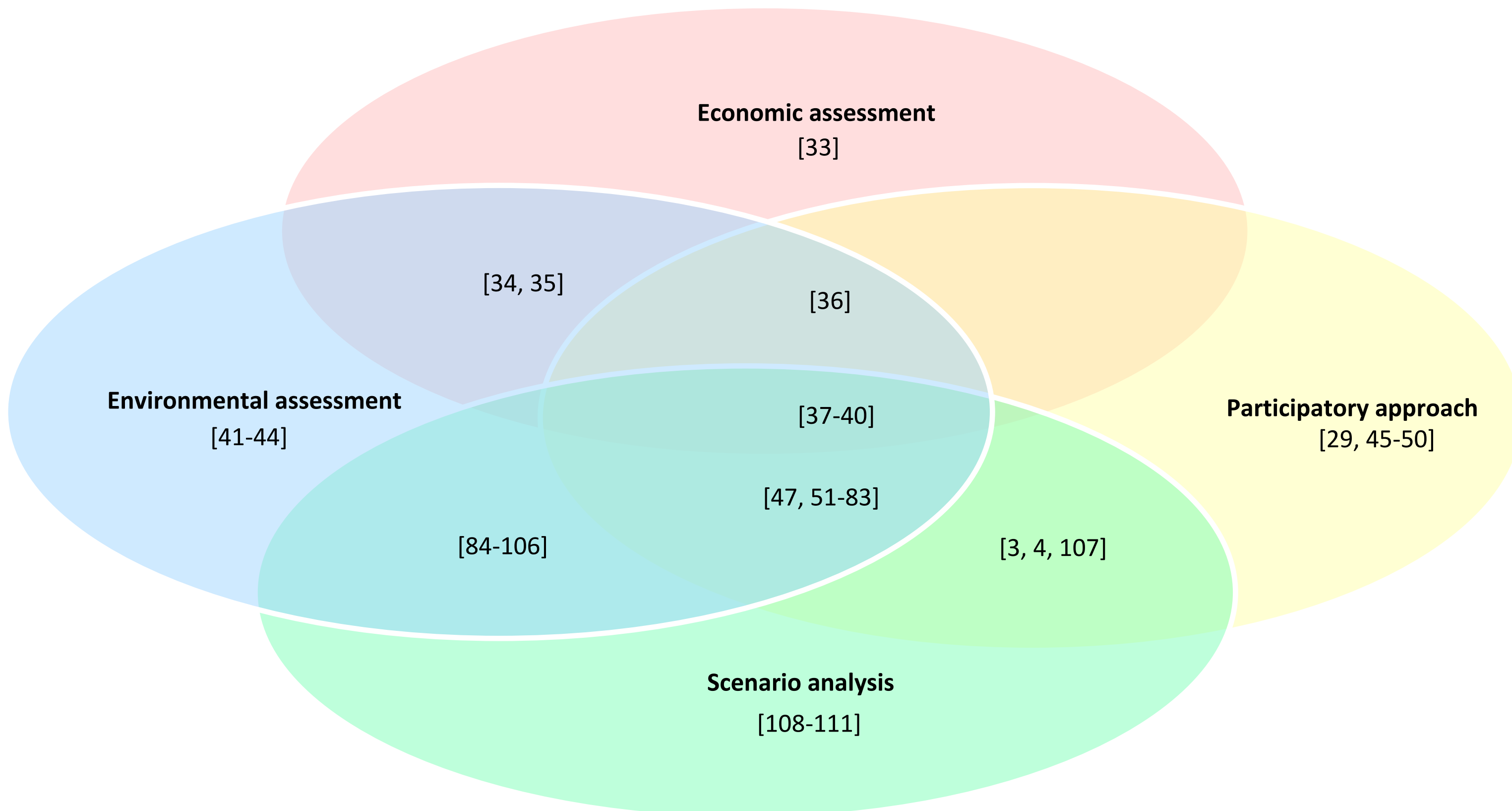

Fig. 1: Assessment approaches used in selected relevant peer-reviewed literature on the assessment of CO_2 mitigation measures for transport sector

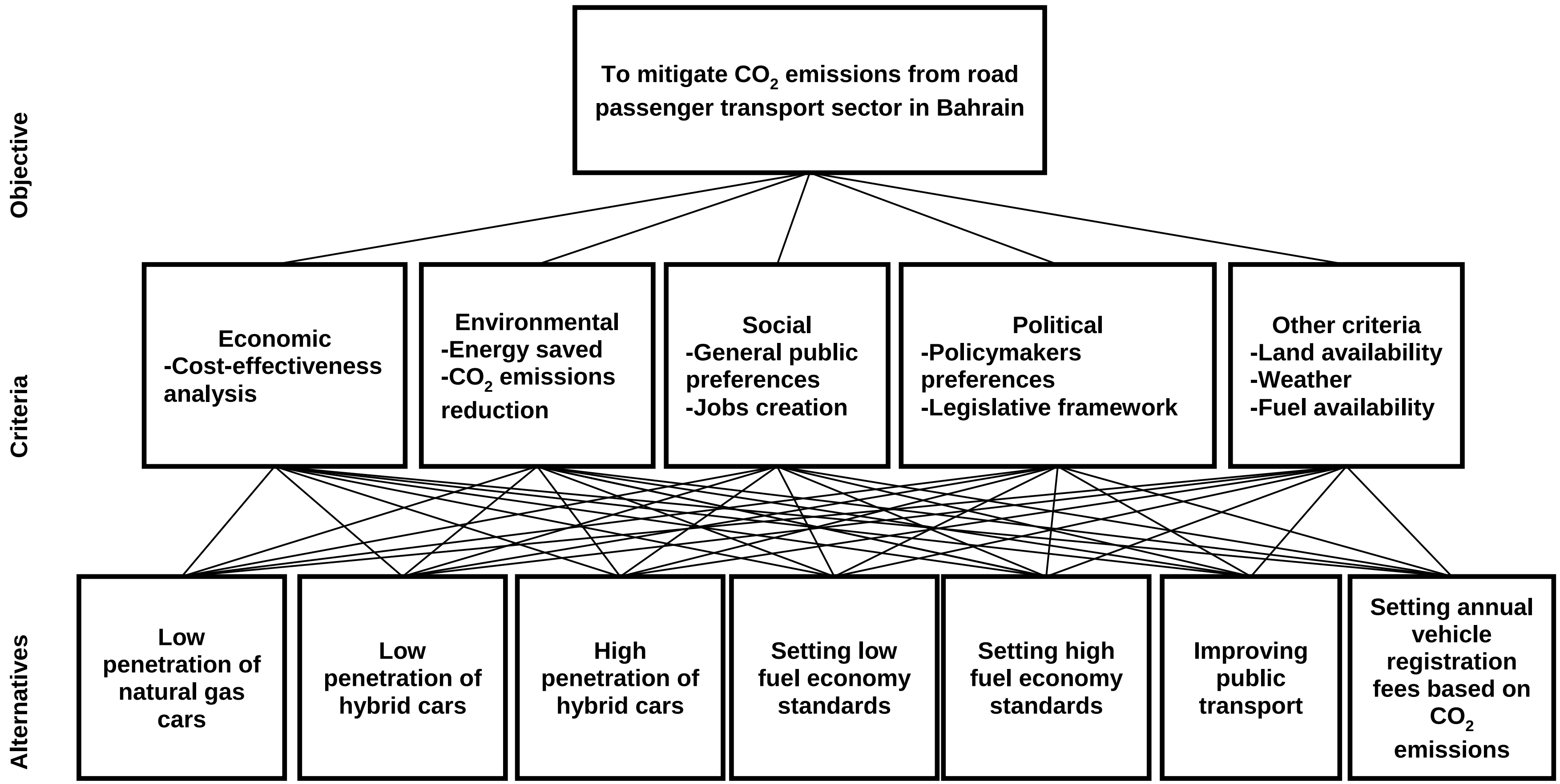

Fig. 2: Structure of the AHP models in this paper