Sustainability assessment of electro-mobility transition

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Introduction

Transportation is the core pillar in urban development by facilitating access to education, markets, and other services [1]. Some of the most notable urban transportation problem in Iceland are environmental impacts, and the need to import fossil fuels [2,3]. Reykjavik is aiming to become carbon neutral by 2040. Considering the significant use of renewable sources for power generation and space heating, the main focus of policy-makers will be on the transportation sector and it was projected that all busses and more than half of the city's private cars will use sustainable energy in 2030. Therefore, in recent years the Icelandic government has introduced incentives such as tax exemptions and emission-differentiated vehicle taxes to promote the contribution of green vehicles in the transport sector [4]. Unfortunately, information is lacking on the economic and social implications of the proposed GHG emissions targets, and an in-depth analysis of rapid transitions to electro-mobility in Iceland is missing [5]. The results of previous analysis by the authors, has shown the capability of the advanced system dynamics model of the Icelandic energy and transportation system (UniSyD_IS) to assess different energy transition pathways for transportation sector [6–8]. In this study, the scope of the UniSyD_IS model was extended to assess the sustainability implications of electro-mobility transitions on the demand for fossil fuels, GHG emissions, as well as government revenues and expenditures.

While, trade-offs between contradictory purposes lie at the core of energy planning, stakeholders (such as engineers, and government agencies) use different attributes to assess the development trajectories for energy system [9]. Multi criteria decision analysis (MCDA) has been widely used in the sustainability literature [10,11], however an assessment framework for electro-mobility transitions that integrates system dynamics and MCDA methods, has not been developed before. Therefore, a multi-criteria decision analysis (MCDA) framework was developed based on a comprehensive list of attributes, covering all three aspects of sustainability (economic, social and environmental).

Method

The aim of this study is to link an energy system model and MCDA to assess the impacts of fiscal policies for EV adoption in Iceland on consumers and government.

Energy System Model

The integrated energy and transport system in Iceland is analyzed using the UniSyD_IS model as a partial-equilibrium system-dynamics model with a detailed description of energy technologies and vehicle fleets. The model takes into account the entire energy system, including fuel supply sectors, energy markets, refueling/recharging infrastructure and fuel demand [12]. In this study, UniSyD_IS is developed to simulate the implications of fiscal policies for EV adoption in Iceland during 2015-2050. Based on an earlier study [13], six scenarios are defined as shown in Table 1. The BAU scenario reflects current policies in Iceland.

Table 1: Definition of scenarios (adopted from previous work by authors [13])

Scenarios	taxes on fuels	taxes on vehicles	incentives and subsidies
BAU	current fuel tax constant carbon tax of $20/t	Current VAT & excise duty tax levies	Current VAT exemption for EVs
BAU+Tax	BAU assumptions + 100% rise in petrol excise tax+ carbon tax rise to $200/t by 2050	identical to BAU	identical to BAU
Subsidy	identical to BAU	identical to BAU	BAU assumption + price subsidy of 20% for BEV & PHEV within both LDV & HDV fleets
Subsidy+Tax	identical to BAU+Tax	identical to BAU	identical to Subsidy
Feebate	identical to BAU	BAU assumption+ purchase fee for ICEV & HEV equivalent to 20% of conventional ICEV price	BAU assumption + price subsidy for light-BEV & heavy-PHEV equivalent to 20% of conventional ICEV price
Feebate+Tax	identical to BAU+Tax	identical to BAU	identical to Feebate

MCDA Model

Several factors affect the choice of the MCDA method, including the type of decision problem, the expected outcome and the required input information. In this study, the purpose is to choose/rank the decision alternatives (fiscal policies), accounting for partial information on preferences of decision makers' (DMs). Thus, based on the classification by Ishizaka and Nemery [14], TOPSIS is a suitable method, because the primary concept is rational and comprehensible, while the approach is computationally simple [15]. The algorithm can be summarized in six steps: 1) Identify the decision criteria, 2) Create the decision matrix, where each element represents the performance of a fiscal policy in each criteria, 3) Normalize the decision matrix, 4) Define the ideal and negative ideal solutions, 5) Estimate weighted Euclidean distances from ideal and negative ideal solutions, and finally 6) Rank the alternatives based on the performance index (relative closeness to the ideal solution). While the total number of EV is an important indicator to compare the effectiveness of fiscal policies, in this study, the implications of EV adoption on government revenue, on consumer's vehicle ownership cost, on the GHG mitigation potential and on energy security are selected as four assessment criteria. Government revenue is the net tax revenue and subsidy expenditure from vehicles and fuels, while consumer's vehicle ownership cost represents the total vehicle and fuel costs. The GHG mitigation potential is defined as the reduction in GHG emissions compared to BAU, and energy security is represented by the share of domestic energy sources (here, electricity) in road transportation energy use. An important consideration in designing MCDA models is that criteria should be independent [14]. Here, two criteria of GHG mitigation potential and energy security are interrelated. However, excluding criteria that are perceived by stakeholders as central, because they are not completely independent can decrease the representability of real issues and limit the application of the model. Thus, these four criteria are used for the assessment of fiscal policies. After creating the decision matrix, Normalization is necessary to eliminate the anomalies with different measurement units. However, as noted in [16], normalization norms can affect the outcome of MCDA methods. Thus, in this study, three linear norms are used and the formulations are given in Table 2, where r_{ij} is the value of the i^{th} alternative (A_i: i = 1,...,m) with respect to the j^{th} criteria (X_j : j = 1,...,n), and n_{ij} is the normalized value.

Table 2: Normalization norms and mathematical formulations

	Norm 1	Norm 2	Norm 3
Mathematical formula	$n_{ij} = \frac{r_{ij}}{\sum_{i=0}^{m} r_{ij}}$	$n_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=0}^{m} r_{ij}^2}}$	$n_{ij} = \frac{r_{ij}}{\max\limits_{i} r_{ij}}$

The following step is to define the ideal and negative ideal solutions. The ideal solution is the solution that maximizes the benefit criteria (government revenue and GHG mitigation potential and energy security) and minimizes the cost criteria (consumer's cost), whereas the negative ideal solution is the solution that maximizes the cost criteria and minimizes the benefit criteria. To estimate the weighted Euclidean distances from the ideal and negative ideal solutions, the criteria weights need to be determined. Comprehensive review of subjective weighting methods [16] demonstrated that no single method can guarantee a precise outcome. Besides, considering the multidisciplinarity of the problem, it is challenging for DMs to agree on the relative importance of the criteria. To resolve these problems, objective weight is estimated based on the divergence in performance ratings of alternatives in that particular criteria [17]. In this study, four measurement methods are implemented to determine the objective weights: 1) Entropy Measure (EM) method [16], 2) CRiteria Importance Through Intercriteria Correlation (CRITIC) method [16], 3) Standard Deviation (SD) method [15] and 4) Mean weight (MW) method [15]. The final step is to estimate the performance index, which is defined as the relative closeness to the ideal solution.

Linking MCDA to ESM

Primarily, the UniSyD_IS model was applied to analyze the impacts of fiscal policies on the adoption of EVs, as well as on government revenue, consumer vehicle ownership cost, GHG emissions and fuel imports in Iceland during 2015-2050. Secondarily, the results are used to construct the decision matrix, using the estimated impacts of a fiscal policy in each criterion in 2050. Then, following the procedure explained in previous section, the fiscal policies are ranked using TOPSIS approach.

Results

The decision matrix is developed based on the performances of five policy scenarios (in addition to BAU scenario), estimated by the UniSyD_IS model in four criteria in 2050 (Table 3). The purpose is to identify the policy that maximizes the government revenue, energy security, GHG mitigation potential and minimizes the consumer cost.

Table 3: Decision Matrix

	Government revenue (M$)	Consumer cost (B$)	GHG mitigation potential (%)	Energy security (%)
BAU	498.2	2.6	0%	11%
BAU+Tax	674.0	2.7	21%	14%
Subsidy	290.0	2.4	9%	15%
Subsidy+Tax	444.9	2.5	28%	18%
Feebate	368.5	2.5	18%	19%
Feebate+Tax	492.2	2.6	35%	23%

The results show that all scenarios, except BAU+Tax will reduce the government revenue (in the range of 1% to 72%). From the consumer's point of view, as expected the subsidy will reduce the ownership cost (in the range of 4% to 13%), while the additional tax would marginally increase it by 6%. Table 4 shows the objective weights derived from four methods mentioned earlier. The results help the DM to identify the most important criterion (the energy security and government revenue in this case) in which the policy scenarios have the most divergent performance scores.

Table 4: Objective weights of the evaluation criteria

Measurement method	Government Revenue	Consumer Cost	GHG Emissions	Energy Security
EM	0.46	0.01	0.14	0.38
CRITIC	0.27	0.04	0.27	0.42
SD	0.38	0.06	0.21	0.35
MW	0.25	0.25	0.25	0.25

Based on three normalization norms, three normalized decision matrixes are generated. Using the objective weights presented in Table 4, and following the TOPSIS steps, the weighted Euclidean distances are estimated. Then, the performance index is calculated for each scenario representing the closeness of alternatives to the ideal solution using three normalization norms and different objective weights. According to the results illustrated in figure 1, Feebate+Tax scenario receives the highest rank, independent of selected normalization norms and objective weights.

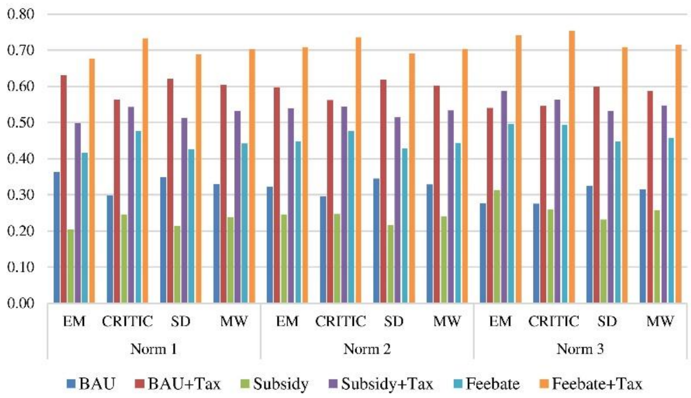

Figure 1: Performance index of policy scenarios using three normalization norms and four objective weights

Conclusion

In this study, by linking Multi-criteria decision analysis and energy system models, an evaluation framework of fiscal policies for the adoption of EVs was developed. Primarily, the energy system model for Iceland was applied to compare the impacts of five fiscal policy incentives with BAU until 2050, in terms of government revenue, consumer's vehicle ownership cost, the GHG mitigation potential and energy security. Then, the results were compared using the TOPSIS method. Based on the estimated performance indexes for policy scenarios, Feebate+Tax scenario receives the highest rank. This ranking is consistent across different normalization norms and objective weights.
In the next step, a survey will be implemented to measure importance weighting values (both quantitative and qualitative) for each of the decision criteria. Besides, the robustness of development strategies will be assessed under several possible scenarios that will be developed in collaboration with stakeholders such as Vegagerdin and Icelandic energy companies (such as Reykjavik Energy).

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