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RESEARCH ARTICLE

Using SWARA II for Subjective Evaluation of Transport Emissions Reduction Policies

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Abstract:

Background:

Transportation is a significant contributor to greenhouse gas emissions, necessitating the implementation of effective policies to mitigate its environmental impact. The use of Multi-Criteria Decision-Making (MCDM) methods is crucial for evaluating policies that aim to reduce transport emissions and for assigning importance or prioritization to various options. These techniques are valuable because they allow for unbiased and thorough evaluations of policies in a systematic way.

Objective:

This study aims to address the evaluation of transport emissions reduction policies, while considering varying levels of budget constraints.

Methods:

An MCDM technique, called SWARA II (Stepwise Weight Assessment Ratio Analysis II), is presented to evaluate the effectiveness of different policies across three budget scenarios. This study provides a framework for addressing the challenges associated with transport emissions reduction policies.

Results:

The evaluation results show that at a low and medium-budget level mode, increasing active and public transport trip share and reducing trip demand could be a feasible policy for implementation. As a result of the analyses, the weight of this criterion is 0.207 at the low-budget level and 0.204 at the medium-budget level. Moreover, switching from fossil-fuelled vehicles to low or zero-emission vehicles is a suitable policy at the high-budget level. This criterion has a weight of 0.247, according to the results.

Conclusion:

This study offers insights into the evaluation of transport emissions reduction policies while considering the impact of varying budget levels. The findings contribute to the development of informed policy strategies that optimize emission reduction efforts within financial constraints.

Keywords: Transport emissions, Environmental policies, Sustainable transport, MCDM, SWARA, Greenhouse gas emissions.

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1. INTRODUCTION

Greenhouse gas emissions from the transport sector are a major contributor to global greenhouse gas emissions, and as such, it is a critical component in the fight against climate change. The transportation sector has been identified as the fastest-growing source of greenhouse gas emissions globally, with a steady increase year after year [1, 2]. In this context, this sector's use of fossil fuels and the associated greenhouse gas emissions has emerged as a significant environmental issue. One of the main challenges that greenhouse gas emissions from the transport sector pose is their impact on climate change. Increased levels of carbon dioxide, methane, and other greenhouse gases increase the levels of heat-trapping atmospheric gas, which can contribute to global warming [3, 4]. A warmer climate can have far-reaching impacts, including damage to ecosystems, intensified weather patterns, and negative impacts on human health, particularly in tropical and subtropical climates. Another major issue related to greenhouse gas emissions from the transport sector is air pollution. As the transportation sector emits greenhouse gases, it also produces a wide range of air pollutants that have negative impacts on human health, particularly in densely populated urban areas with heavy traffic. These air pollutants, which include particulate matter, volatile organic compounds, and nitrogen

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oxides, can lead to respiratory problems, cardiovascular disease, cancers, and other health issues [5 - 8].

Policies can play a pivotal role in encouraging the adoption of low-carbon forms of transportation. Governments can implement various policies to incentivize sustainable choices by introducing carbon pricing, fuel standards, and other measures aimed at reducing pollution from transportation. For instance, providing subsidies for public transportation, creating more bike lanes, and imposing congestion charges can help discourage the use of cars and promote low-carbon options [9 - 11]. The allocation of different levels of budgets, ranging from low to medium to high, plays a critical role in the successful implementation of transport emissions reduction policies. Even with a low-budget allocation, it is essential to initiate and prioritize the actions that contribute to reducing transport emissions. While the resources may be limited, governments can invest in key areas such as public awareness campaigns, educational programs, and basic infrastructure improvements [12, 13].

The evaluation of transport emissions reduction policies is crucial at all budget levels as it provides policymakers with valuable insights to improve the implementation process. Evaluations serve as a powerful tool for assessing the effectiveness, efficiency, and impact of policies, regardless of the budget allocated. Evaluations help policymakers determine the effectiveness of transport emissions reduction policies in achieving their intended goals. They provide feedback on whether the policies are generating the desired outcomes, such as reduced carbon emissions, improved air quality, or increased adoption of sustainable transportation modes [14 - 16]. By evaluating the effectiveness of policies, policymakers can identify successful interventions and strategies that can be expanded or replicated to achieve greater impact. Evaluations shed light on barriers and challenges that hinder the successful implementation of transport emissions reduction policies. They help policymakers understand why certain interventions may not yield the expected results or face resistance from stakeholders. By identifying these barriers, policymakers can develop targeted measures to overcome challenges, address concerns, and improve the implementation process. Evaluations can highlight the need for additional resources, supportive infrastructure, or policy adjustments to overcome obstacles. Evaluations provide insights into the efficiency of resource allocation and utilization. Policymakers can assess whether the allocated budget is being effectively utilized and identify areas where resources can be reallocated for better outcomes [17 - 19]. Evaluations can inform decisions on reallocating funds towards interventions that have proven to be more effective in reducing transport emissions. This allows policymakers to optimize the use of limited resources and ensure that the allocated budget is effectively contributing to emissions reduction goals. Evaluations help policymakers make informed decisions about policy adjustments and refinements. By analyzing evaluation findings, policymakers can identify areas where policies may need to be modified, strengthened, or expanded. For example, evaluations may reveal the need for stricter regulations, additional incentives, or targeted measures to address specific challenges [20 - 22]. Policymakers can use evaluation insights to refine policy design, improve implementation strategies, and enhance the overall effectiveness of transport emissions reduction policies. Evaluations provide an opportunity for stakeholder engagement and participation. They allow policymakers to involve various stakeholders, such as community members, experts, and industry representatives, in the evaluation process. Engaging stakeholders helps gather diverse perspectives, identify local needs, and enhance the legitimacy and acceptance of policies. Furthermore, evaluations promote transparency by sharing evaluation findings with the public, building trust, and ensuring accountability in the implementation of transport emissions reduction policies. By utilizing evaluation insights, policymakers can refine strategies, allocate resources more effectively, and enhance the overall impact of policies on reducing transport emissions [23 - 25].

Multi-Criteria Decision-Making (MCDM) techniques are important in evaluating transport emissions reduction policies and determining the weight or importance of different options. The significance of MCDM techniques lies in their ability to provide a comprehensive, objective, and systematic approach to policy evaluation [25 - 31]. MCDM techniques assist in efficient resource allocation by identifying policies that offer the highest potential for emissions reduction per unit of investment. By optimizing resource allocation, decision-makers can maximize the impact of their efforts in reducing transport emissions. These techniques enable informed decision-making, ensuring that policies are effective, efficient, and aligned with the overarching goal of mitigating climate change through substantial emissions reductions in the transport sector [32 - 34].

In this study, an MCDM approach is presented to evaluate transport emissions reduction policies for implementation at three budget levels (low, medium, and high). The MCDM approach is a modified version of the SWARA method, which is called SWARA II hereafter. Based on the literature, six central transport emissions reduction policies and several options related to them are considered for evaluation. The evaluation process is made based on SWARA II and the opinions of a group of experts. One of the advantages of SWARA II is its ability to use linguistic terms to obtain experts' opinions. This feature enables decision-makers to incorporate their diverse opinions into the decision-making processes effectively. The use of linguistic terms makes it easier for decision-makers to understand and interpret the results of the analysis, further enhancing the method's appeal. SWARA II is simple to use and can be applied in various fields of study. Its ability to obtain subjective weights of criteria based on experts' opinions and subjective assessments, use of linguistic terms, flexibility in handling different uncertain environments, and ability to be integrated into different MCDM techniques make it an ideal method for complex decision-making scenarios. Moreover, it does not require complex mathematical calculations, extensive knowledge of advanced decision-making techniques, and specialized software to implement.

The rest of the paper is organized as follows. Section 2 presents a review of some of the recent studies on the application of MCDM approaches to the environmental aspects of the transport sector. Section 3 describes the methodology and the steps of using SWARA II for the evaluation process. Results and discussion are presented in Section 4. Conclusions are presented in Section 5.

2. MATERIALS AND METHODS

Transport systems play a critical role in shaping our modern society, enabling the movement of people and goods across vast distances. However, the environmental impacts of these systems have become increasingly evident and concerning in recent years. The application of MCDM techniques in the realm of environmental aspects of transport systems has garnered significant attention in both academic and practical domains. As societies strive for sustainable development, the need to minimize the ecological footprint of transportation becomes increasingly urgent. MCDM techniques offer a robust framework for decision-making that goes beyond the conventional single-criterion approaches, enabling the consideration of multiple environmental factors simultaneously.

2.1. Recent Studies

This section aims to provide a brief overview of some recent studies on MCDM techniques applied to environmental aspects in the context of transport systems.

To address sustainability concerns in the transport industry, several studies proposed different frameworks and methods. Hasan *et al.* [35] proposed a framework that considered analyzing traffic flow patterns, evaluating the life-cycle cost and environmental impact of proposed automated vehicles (AVs)-based alternatives compared to existing systems, and incorporating stakeholder expert opinions through multiple criteria decision-making (MCDM). The framework highlighted the significance of taking into account user preferences, cost, energy, and emissions in decision-making processes. López *et al.* [36] investigated how technological innovations adopted by urban bus companies improved cities' sustainability, using a combined Importance Performance Analysis (IPA)-Analytic Hierarchy Process (AHP) method. This allowed the environmental and social sustainability effects to be separately represented through hierarchical structures. The importance and performance ratings of technological innovations in each sustainability dimension were estimated, and subsequently, two IPA grids were generated. Kumar and Ramesh's [37] study examined the importance of social sustainability (SS) indicators in the Indian freight transport industry. They proposed a validated SS assessment framework that considered four SS dimensions and 25 indicators and computed the importance weights of SS dimensions and indicators using a fuzzy best-worst method (FBWM). The study found that the contribution to community health and education programs was the most valuable SS indicator, followed by the prevention of child and forced labor. In addition, Yang *et al.* [38] aimed to develop a testing and scoring mechanism to assess buyers' behaviors in purchasing green vehicles. They designed a Key Green Performance Indicator (KGPI) framework that compared all the relevant factors influencing consumer choices of green vehicles, including emission damages, buyer cost, car performance, and other incentives, to generate a single score that represented vehicle cleanliness and guided buyer decision-making. All these studies highlight the importance of considering sustainability factors when making decisions in the transport industry.

Boca Santa *et al.* [39] developed a sustainable airport model that identified ten indicators and 58 sub-indicators, which serve as strategic objectives for the implementation of sustainable practices in different areas of airport operations and infrastructure. The model utilized descriptive methods to establish characteristics of a sustainable airport, resulting in a comprehensive approach that emphasized sustainability practices. Kumar and Anbanandam [40] presented a hierarchical framework which integrated the grey-Decision-Making Trial and Evaluation Laboratory (DEMATEL) with the Analytic Network Process (ANP) to identify interrelationships and priority weights of dimensions and attributes related to the Indian intermodal railroad (IRR) system. The Influential Network Relation Map (INRM) developed from the framework provided useful policy suggestions for enhancing the share of intermodal services in the Indian freight industry. Bi *et al.* [41] developed a comprehensive and environmentally friendly city distribution mode using end crowdsourcing service stations (ECSSs). The study utilized node centrality indices from complex network theory to assess the importance of existing terminal distribution outlets. A three-scale AHP and Technology for Order Preference by Similarity to an Ideal Solution (TOPSIS) methods were employed to derive comprehensive weights for the indices, enabling the identification of candidate nodes for ECSSs.

Kumar [42] utilized a two-step methodology involving a grey clustering (GC) algorithm and a compromise ranking method called ViseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) to prioritize environmentally responsible transport practices (ERTPs) performance. The GC algorithm classified ERTPs based on their impact on selected transport processes, resulting in twenty-one high-priority and fourteen moderate-priority practices according to the GC algorithm. Türk, *et al.* [43] introduced a multi-criteria decision-making method based on interval type-2 fuzzy sets to select optimal locations for electric charging stations. The method was enhanced by applying Simulated Annealing to obtain the optimal configuration of interval type-2 membership function parameters. Additionally, two different aggregation operators, linguistic weighted sum and average, were employed. The proposed approach was applied to a real-world public transport problem involving the municipal bus company in Istanbul. Gupta [44] conducted a multi-criteria decision-making analysis using fuzzy set theory to evaluate various policy options for reducing CO_2 emissions from road transport in India. The study identified low-emissions vehicles and sustainability-oriented behavior as the most preferred options for effectively reducing CO_2 emissions from road transport. These studies proposed different frameworks and methods to address sustainability and environmental concerns in various modes of transportation, such as airports, intermodal railroad systems, city distribution modes, electric charging stations, and road transport. The utilization of descriptive methods, multi-criteria decision-making methods, and complex network theory enabled the identification of strategic objectives, priority weights, and optimal solutions for sustainability practices in transportation.

Pathak *et al.* [45] presented an integrated performance assessment framework (PAF) for sustainable freight transportation (SFT) systems based on competitive priorities. The framework used a unified approach that involved fuzzy group decision-making, fuzzy evidential reasoning, and the expected utility concept. This approach was applied to evaluate critical success factors of SFT in relation to four competitive priorities. The proposed model's applicability was demonstrated through a case example, and sensitivity analysis was conducted to assess its robustness. Similarly, Pamucar *et al.* [46] developed an MCDM methodology for prioritizing different alternative fuel vehicles (AFVs) in sustainable transport. As the assessment of AFVs involves multiple conflicting criteria, the authors introduced a novel methodology based on the fuzzy Full Consistency Method (FUCOM-F) and neutrosophic fuzzy Measurement Alternatives and Ranking according to the Compromise Solution (MARCOS) framework. The proposed methodology was applied to prioritize AFVs in New Jersey, U.S. The evaluation findings revealed that purchase cost, energy cost, and social benefits were the most significant drivers for AFV selection. Wang *et al.* [47] utilized a hybrid multi-criteria method combining the fuzzy analytic hierarchy process and fuzzy VIKOR methods to assess influential and conflicting criteria related to economic, service level, environmental, social, and risk aspects. The authors employed linguistic variables to handle uncertain levels in criteria weights, considering fuzzy information in the decision-making process. Reliability and delivery time, voice of the customer, logistics cost, network management, and quality of service were identified as the most influential factors in the logistics outsourcing problem.

In addition, Bajec *et al.* [48] proposed a distance-based analytic hierarchy process/data envelopment analysis (AHP-DEA) super-efficiency approach. This approach adapted DEA to predefined groups by incorporating slack variables and considering that not all outputs positively impact the final outcome. The approach allowed decision-makers to directly define the hierarchical structure of criteria importance based on the responses of the selected group. A case study in Slovenia illustrated the application of the approach, demonstrating its effectiveness in supporting investor decision-making in selecting electric bike-sharing systems providers that aligned with sustainability goals and met stakeholder requirements. David *et al.* [49] provided a comprehensive overview of container shipping development on the selected route. Utilizing the least square method, the study presented a trend analysis based on the statistics, indicating a slight projected increase in the number of containers transported between North America and Europe in the near future. Furthermore, the paper discussed the environmental impact of maritime transport, referencing various studies published in recent years. It underscored the significance of this factor in customer preferences and emphasized the use of MCDM to assess the impact on the environment. These studies highlight the importance of developing effective methodologies and frameworks to assess sustainable transport systems and their impact on various stakeholders.

Pamucar *et al.* [50] extended the Best-Worst Method and TODIM method using D numbers to prioritize actions outlined in London's strategy document for achieving a zero-carbon city. The study found that introducing zero-emission zones should be the first initiative to be implemented due to its potential to have the greatest impact on the modal shift from cars to sustainable modes of transportation, lower operational and implementation costs, and greater public support. Kumar and Anbanandam [51] developed an integrated MCDM framework using the fuzzy best-worst method and fuzzy logic approach to evaluate current sustainability performance and identify obstacles to achieving a sustainable freight transportation system. Golnar and Beškovnik [52] developed a three-phase approach using a distance-based AHP-DEA approach to evaluate the sustainability of intermodal transport chains. The results of a case study focusing on transport chains between Asia and the northern Adriatic demonstrated the potential of the approach. Hezam *et al.* [53] aimed to rank and select suitable alternative fuel vehicles for a private home healthcare service provider in Chandigarh, India, using a multi-attribute decision-analysis framework based on the intuitionistic fuzzy-MEREC (MEthod based on the Removal Effects of Criteria), RS (Ranking Sum), and the DNMA (Double Normalization-based Multi-Aggregation) methods. The assessment outcomes highlighted the potential of electric vehicles to reduce carbon emissions and mitigate environmental impacts. Korucuk *et al.* [54] proposed a model based on picture fuzzy level-based weight assessment (PF-LBWA) and picture fuzzy combined compromise solution (PF-CoCoSo) methods to select a smart network strategy and determine the criteria weights for green transportation indicators. The proposed model aims to focus on green logistics, benefiting the environment, economy, and society by efficiently utilizing limited resources and ensuring a sustainable environment for future generations. Anastasiadou and Gavanas [55] developed a decision-support tool using two-hybrid MCDM models to rank land use and transportation policies within the framework of urban sustainability, with a particular focus on public space, aiming to assist policymakers and decision analysts in promoting sustainable urban and transport planning. Evaluating and selecting sustainable transportation strategies is a complex task that requires the consideration of multiple criteria. The MCDM methods proposed by various researchers provide decision-makers with a framework to evaluate and prioritize different strategies based on their potential impact, cost-effectiveness, and public support. Selecting the right approach can help reduce carbon emissions, mitigate environmental impacts, and promote sustainable logistics practices, benefiting the environment, economy, and society.

2.2. Summary

The studies presented highlight the importance of applying MCDM techniques in various aspects of the transport sector to address the complex and conflicting nature of decision-making in urban sustainability. These studies demonstrate the value of MCDM models in assessing and prioritizing different alternatives, technologies, and policies to promote sustainable practices, reduce emissions, and enhance efficiency in transport systems. The use of MCDM frameworks allows for the comprehensive evaluation of different factors, ranging from technological innovations and environmental indicators to land use policies and smart network strategies. The following are some important points that can be inferred from the reviewed studies:

• Sustainable transportation requires a comprehensive approach that involves considering user preferences, environmental impact, and cost-effectiveness.

• Stakeholders need to be involved in decision-making processes to ensure that their opinions and preferences are taken into account.

• Technological innovations have a significant impact on the sustainability of urban transportation.

• Sustainability needs to be evaluated in different dimensions to understand the overall impact of technological innovations.

• Social sustainability indicators are crucial in the freight transport industry, and contribution to community health and education programs can be considered as a valuable indicator.

• Buyers' behaviors in purchasing green vehicles are influenced by various factors, including environmental impact, cost, and car performance.

• Sustainable practices are significant in the transportation industry, particularly in the intermodal railroad system, to enhance intermodal services and reduce carbon emissions.

• Sustainable practices are important in the logistics industry to reduce carbon emissions and enhance the efficiency of city distribution.

• Decision-making methods are useful in evaluating ERTPs, locations for electric charging stations, policy options to reduce carbon emissions, performance of sustainable freight transportation systems, *etc.*

• AHP, TOPSIS, VIKOR, FUCOM, DEA, CoCoSo, MARCOS, MEREC, and BWM are some of the MCDM approaches used by researchers.

• MCDM can help decision-makers to consider the impact of their decisions on the environment and support sustainability goals. Utilizing these approaches has the potential to moderate the natural effect of transportation, decrease fuel costs, and advance sustainable economic development.

• Sustainable transportation is a critical issue that requires the development and application of various approaches to evaluate and promote sustainable practices in the transportation sector.

3. METHODOLOGY

Various methods are available to determine subjective criteria weights. The modified version of the SWARA technique, which is presented in this section, involves fewer comparisons and provides a more straightforward approach when compared to other methods. The structure of the newly modified version, SWARA II, is the same as its previous version, and it utilizes a procedure that includes sorting and criteria preferences. However, some modifications in the approach have been included to make it more practical and easier for decision-makers. Below are the steps to be used in determining subjective criteria weights with SWARA II. Let's say we are faced with a problem that requires multi-criteria decision-making with n number of possible alternatives and m criteria to evaluate their worthiness.

$$X = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1j} & \dots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2j} & \dots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{im} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nj} & \cdots & x_{nm} \end{bmatrix} \quad (1)$$

Step 1. The first step in determining the subjective criteria weights using SWARA II involves sorting the criteria by importance in descending order. This means that the most important criterion is placed at the top of the sorted list, while the least important criterion is placed at the bottom. In the sorted list, the symbol t_j is used to denote the rank or position of *j*th criterion ($t_j \in \{1,2,\dots, m\}$). The rank of the first criterion is assigned the value of 1, and the ranks increase sequentially for all other criteria in descending order of importance. Therefore, the most crucial criterion has a rank of 1, and the other criteria are assigned positions based on their relative importance, with the least important receiving the highest rank.

Table 1. Linguistic variables and their corresponding values.

Linguistic Variable	Value
VVL (Very Very Low)	1
VL (Very Low)	2
L (Low)	3
ML (Medium-Low)	4
M (Medium)	5
MH (Medium-High)	6
H (High)	7
VH (Very High)	8
VVH (Very Very High)	9

Step 2. To proceed with the second step of determining the subjective criteria weights using SWARA II, the decision-maker is requested to express the relative preference (RP) for each criterion they are tasked to consider. The RP is identified by comparing the current criterion with the next one in the sorted list obtained in Step 1. The decision-maker is asked to state their preference and provide a response using a question such as the following, "How much importance would you assign to criterion A relative to criterion B?" By doing so, the decision-maker is providing a comparison between criteria in terms of their relative importance, thereby establishing the degree of relative preferences towards the overall weighting of the criteria.

To find an accurate response to the question at hand, the use of linguistic variables and the Likert scale could be highly beneficial. The utilization of these methods enables researchers to gauge subjective opinions and values related to the question through a defined set of terms and values which are provided in a comprehensive table. In this particular study, the researchers utilized the specific linguistic variables laid out in Table **1** and their corresponding values to derive information that would be difficult if not impossible to obtain using other methods. This approach can help to provide a better understanding of the subjective assessments involved in the question and, therefore, offer valuable insights to the research endeavor.

Step 3. In order to make an accurate assessment of the preference degree (*PD*) of each criterion, a specific method is required. As a first step, the relative preferences of Step 2 must be quantified in order to determine the values of *PD*. The quantified value of the relative preference of the $[t_j]$th criterion is denoted as $P_{[tj]}$. Thus, the values of *PD* can be determined gradually, based on the quantified relative preferences.

$$PD_{[t_j]} = u\left(P_{[t_j]}\right) \quad (2)$$

In this study, the researchers used a utility function u, which can transform the quantified values of the relative preferences into scaled values within the range of 0 to 1. This process enables researchers to obtain a more comprehensive view of the preference degree under consideration. In accordance with this approach, the function set out in Eq. (**3**) was utilized as the nonlinear utility function in this particular study. However, based on the problem's characteristics and the decision-makers' opinions, other types of functions can be defined and employed as utility functions for other studies.

$$u(x) = \left(\frac{x}{10}\right)^2 \quad (3)$$

As outlined in Table **1**, a diagram of the utility function that was defined in Eq. (**3**) can be found in Fig. (**1**).

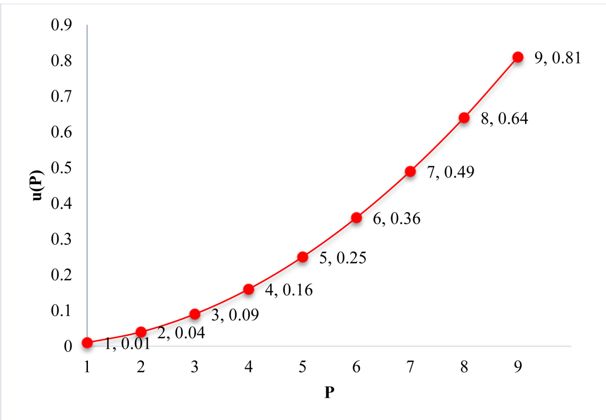

Fig. (1). The diagram of the utility function.

Step 4. The calculation of relative weighting coefficients is an important step in gaining a comprehensive understanding of the studied criteria. These coefficients are calculated based on both the position of each criterion within the sorted list and the respective values of *PD* assigned in the prior step. To denote these relative weighting coefficients, the researchers used the variable. $V_{[tj]}$. To calculate these values, the process starts with the *m*th criterion, and the following equation is used.

$$V_{[t_j-1]} = \left(1 + PD_{[t_j-1]}\right) \times V_{[t_j]}$$
$$\text{where } 1 \leq V_{[t_j]} \leq 2 \text{ and } V_m = 1. \quad (4)$$

Step 5. The process of determining the subjective weights of the criteria represents a crucial step in understanding the relative importance of the different factors under consideration. In utilizing Eq. (**5**), the relative weighting coefficients previously calculated are scaled to determine the subjective weights assigned to each criterion. This process enables the researchers to make informed and accurate judgments regarding the significance of each criterion based on their calculated weight.

$$w_j^s = \frac{V_{[t_j]}}{\sum_{t_j=1}^{m} V_{[t_j]}} \quad (5)$$

4. RESULTS AND DISCUSSION

The results and discussion section of the paper is divided into two subsections, focusing on the application of the methodology to evaluate transport emissions reduction policies, as well as the challenges and limitations of transport emissions reduction.

4.1. Application of the MCDM Approach

This section focuses on the assessment of the transport emissions reduction policies for implementation at three different budget levels: low, medium, and high. The goal of this study is to identify the most feasible transport policies which will be effective in decreasing transport emissions. The policies considered for evaluation are shown in Fig. (**2**). These policies were presented in a study made by Hasan *et al.* [56]. The main policies are considered as the criteria and the policies' options are considered as the sub-criteria. SWARA II is used in this section to evaluate the policies at low, medium, and high-budget levels. A low-budget level can be used to raise awareness about the environmental impacts of transportation and promote sustainable behavior changes among individuals. It can also support the development of pilot projects and small-scale initiatives that demonstrate the benefits of adopting sustainable transportation options. Although the scope of interventions may be limited, a low-budget represents a starting point for progress. A medium-budget level allows for more substantial advancements in implementing transport emissions reduction policies. With increased financial resources, governments can invest in critical areas. It can contribute to the transition towards a more sustainable and environmentally friendly transportation system. A high-budget level demonstrates a strong commitment and recognition of the urgency to address transport emissions comprehensively. With ample financial resources, governments can pursue ambitious targets and implement a wide range of policies and projects.

Firstly, the main policies, including C_1 to C_6 were assessed by three experts (D_1 to D_3) at three budget levels. SWARA II was used to determine the weights of these policies for each expert. Tables **2** to **4** present the elements of the evaluation procedure for different experts at different budget levels, and the average weights which are considered the overall importance of each policy, are shown in Table **5**.

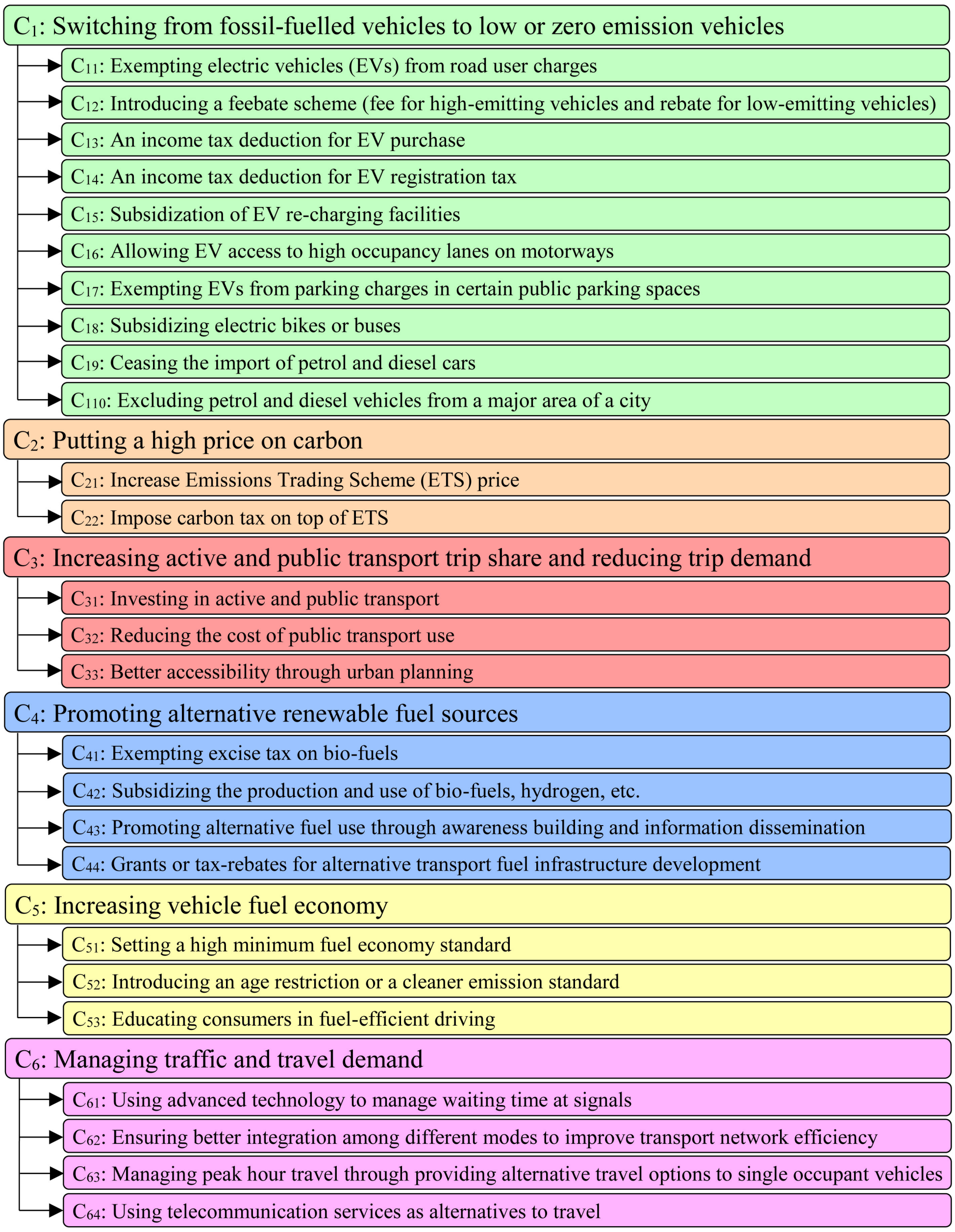

Fig. (2). Different policies for transport emissions reduction.

Table 2. Evaluation of transport emissions reduction policies for the low-budget level.

Experts	Sorted Criteria (C_j)	t_j	*RP*	$PD_{[tj]}$	$V_{[tj]}$	w_j^s
D_1	C_5	1	L	0.09	1.93	0.223
	C_6	2	L	0.09	1.77	0.204
	C_3	3	M	0.25	1.63	0.187
	C_4	4	M	0.25	1.30	0.150
	C_1	5	VL	0.04	1.04	0.120
	C_2	6	—	—	1	0.115
D_2	C_3	1	M	0.25	1.66	0.231
	C_5	2	ML	0.16	1.33	0.185
	C_6	3	L	0.09	1.14	0.159
	C_4	4	VL	0.04	1.05	0.146

(Table 2) contd.....

Experts	Sorted Criteria (C_j)	t_j	*RP*	$PD_{[tj]}$	$V_{[tj]}$	w_j^s
	C_1	5	VVL	0.01	1.01	0.140
	C_2	6	—	—	1	0.139
D_3	C_5	1	VL	0.04	1.84	0.210
	C_3	2	VL	0.04	1.77	0.202
	C_6	3	M	0.25	1.70	0.194
	C_4	4	M	0.25	1.36	0.155
	C_1	5	L	0.09	1.09	0.124
	C_2	6	—	—	1	0.114

Table 3. Evaluation of transport emissions reduction policies for the medium-budget level.

Experts	Sorted Criteria (C_j)	t_j	*RP*	$PD_{[tj]}$	$V_{[tj]}$	w_j^s
D_1	C_1	1	VVL	0.01	1.66	0.202
	C_3	2	VL	0.04	1.64	0.200
	C_4	3	M	0.25	1.58	0.192
	C_5	4	ML	0.16	1.26	0.153
	C_2	5	L	0.09	1.09	0.132
	C_6	6	—	—	1	0.121
D_2	C_3	1	VL	0.04	1.81	0.198
	C_1	2	VVL	0.01	1.74	0.191
	C_4	3	ML	0.16	1.72	0.189
	C_5	4	L	0.09	1.48	0.163
	C_2	5	MH	0.36	1.36	0.149
	C_6	6	—	—	1	0.110
D_3	C_3	1	VL	0.04	2.11	0.213
	C_1	2	VL	0.04	2.03	0.205
	C_5	3	M	0.25	1.95	0.197
	C_4	4	M	0.25	1.56	0.158
	C_6	5	M	0.25	1.25	0.126
	C_2	6	—	—	1	0.101

Table 4. Evaluation of transport emissions reduction policies for the high-budget level.

Experts	Sorted Criteria (C_j)	t_j	*RP*	$PD_{[tj]}$	$V_{[tj]}$	w_j^s
D_1	C_1	1	MH	0.36	1.95	0.247
	C_3	2	ML	0.16	1.43	0.182
	C_4	3	VL	0.04	1.24	0.156
	C_5	4	L	0.09	1.19	0.150
	C_6	5	L	0.09	1.09	0.138
	C_2	6	—	—	1	0.127
D_2	C_1	1	M	0.25	2.02	0.246
	C_3	2	M	0.25	1.62	0.197
	C_4	3	L	0.09	1.30	0.158
	C_5	4	L	0.09	1.19	0.145
	C_6	5	L	0.09	1.09	0.133
	C_2	6	—	—	1	0.122
D_3	C_1	1	MH	0.36	1.95	0.248
	C_3	2	L	0.09	1.43	0.182
	C_4	3	ML	0.16	1.31	0.167
	C_5	4	L	0.09	1.13	0.144

(Table 4) contd.....

Experts	Sorted Criteria (C_j)	t_j	*RP*	$PD_{[tj]}$	$V_{[tj]}$	w_j^s
	C_6	5	VL	0.04	1.04	0.132
	C_2	6	—	—	1	0.127

Table 5. The weights of the main policies at different budget levels.

Budget levels	Main Policies	D_1	D_2	D_3	AVG.
Low	C_1	0.120	0.140	0.124	0.128
	C_2	0.115	0.139	0.114	0.123
	C_3	0.187	0.231	0.202	0.207
	C_4	0.150	0.146	0.155	0.150
	C_5	0.223	0.185	0.210	0.206
	C_6	0.204	0.159	0.194	0.186
Medium	C_1	0.202	0.191	0.205	0.199
	C_2	0.132	0.149	0.101	0.128
	C_3	0.200	0.198	0.213	0.204
	C_4	0.192	0.189	0.158	0.179
	C_5	0.153	0.163	0.197	0.171
	C_6	0.121	0.110	0.126	0.119
High	C_1	0.247	0.246	0.248	0.247
	C_2	0.127	0.122	0.127	0.125
	C_3	0.182	0.197	0.182	0.187
	C_4	0.156	0.158	0.167	0.160
	C_5	0.150	0.145	0.144	0.146
	C_6	0.138	0.133	0.132	0.134

At the low-budget level mode, $C_3$was identified as the most critical criterion. It holds a weight of 0.207 and pertains to increasing active and public transport trip share while simultaneously reducing trip demand. This indicates that encouraging alternative modes of transport, such as cycling or public transport, may have the most significant impact on reducing transport emissions at a low-budget mode. C_5 follows closely with a weight of 0.206, focusing on increasing vehicle fuel economy. C_4, which promotes alternative renewable fuel sources, holds a weight of 0.150 and is also an essential criterion. The remaining three criteria, including C_1, C_2, and C_6, are comparatively less important, with weights ranging from 0.123 to 0.186, suggesting that although they are significant in their own way, their overall impact on reducing transport emissions may not be as significant compared to the preceding criteria.

The evaluation results of the medium-budget level mode show that the most important criterion is C_3, with a weight of 0.204. This highlights the significance of increasing the usage of alternative modes of transport and reducing the reliance on private vehicles as an effective way to reduce transport emissions at a medium-budget mode. C_1, which has a weight of 0.199, stresses the importance of switching to low or zero-emission vehicles to reduce the reliance on fossil fuels. C_4 also has a significant weight of 0.179 and emphasizes promoting alternative renewable fuel sources. The remaining three criteria, including C_2, C_5, and C_6, have comparatively lesser weights ranging from 0.119 to 0.171, indicating that their contribution to transport emission reduction may be limited compared to the preceding criteria. Therefore, this analysis highlights the importance of focusing on the promotion of alternative modes of transport, the use of low or zero-emission vehicles and renewable fuel sources to reduce transport emissions at a medium-budget mode effectively.

The results of the high-budget level mode indicate that C_1 is the most important criterion with a weight of 0.247, highlighting the significance of switching from fossil-fueled vehicles to low-emission or zero-emission vehicles. C_3 follows next in importance with a weight of 0.187, stressing the importance of promoting active and public transport and reducing trip demand. C_4, with a weight of 0.160, emphasizes promoting alternative renewable fuel sources. The remaining criteria, C_2, C_5, and C_6, have comparatively lesser weights (ranging from 0.125 to 0.146), suggesting that their contribution to transport emission reduction may be limited compared to the preceding criteria. Overall, the analysis indicates that at a high-budget mode, investment in low or zero-emission vehicles, promotion of public and active transport and renewable fuel sources may be the most effective strategies to reduce transport emissions.

The final results of the evaluation of sub-criteria (options of the main policies) are presented in Table **6**. Due to limitations in space, the details of the evaluation procedure are provided as supplementary material [57].

Table 6. The weights of sub-criteria at different budget levels.

	Low				Med.				High			
	D_1	D_2	D_3	AVG	D_1	D_2	D_3	AVG	D_1	D_2	D_3	AVG
C_{11}	0.171	0.136	0.140	0.149	0.138	0.136	0.142	0.139	0.126	0.116	0.118	0.120
C_{12}	0.100	0.108	0.114	0.107	0.206	0.171	0.136	0.171	0.125	0.136	0.113	0.125
C_{13}	0.096	0.104	0.132	0.111	0.110	0.099	0.099	0.103	0.120	0.117	0.093	0.110
C_{14}	0.095	0.079	0.061	0.078	0.079	0.091	0.075	0.082	0.104	0.093	0.109	0.102
C_{15}	0.137	0.148	0.133	0.140	0.095	0.118	0.120	0.111	0.147	0.149	0.160	0.152
C_{16}	0.136	0.125	0.139	0.133	0.082	0.108	0.096	0.095	0.103	0.092	0.094	0.096
C_{17}	0.065	0.083	0.066	0.071	0.078	0.073	0.095	0.082	0.055	0.085	0.065	0.068
C_{18}	0.076	0.068	0.067	0.070	0.077	0.069	0.082	0.076	0.102	0.068	0.085	0.085
C_{19}	0.065	0.082	0.084	0.077	0.074	0.072	0.064	0.070	0.075	0.089	0.081	0.082
C_{110}	0.059	0.067	0.064	0.063	0.060	0.063	0.065	0.063	0.044	0.055	0.082	0.060
C_{21}	0.502	0.498	0.502	0.501	0.522	0.522	0.522	0.522	0.478	0.490	0.444	0.471
C_{22}	0.498	0.502	0.498	0.499	0.478	0.444	0.478	0.467	0.522	0.510	0.556	0.529
C_{31}	0.430	0.402	0.377	0.403	0.352	0.352	0.359	0.354	0.357	0.395	0.352	0.368
C_{32}	0.316	0.321	0.346	0.328	0.348	0.338	0.356	0.347	0.315	0.290	0.310	0.305
C_{33}	0.253	0.277	0.277	0.269	0.300	0.310	0.285	0.298	0.328	0.316	0.338	0.327
C_{41}	0.257	0.248	0.247	0.250	0.260	0.228	0.254	0.247	0.263	0.257	0.286	0.269
C_{42}	0.247	0.257	0.238	0.247	0.271	0.288	0.264	0.274	0.286	0.280	0.275	0.281
C_{43}	0.259	0.268	0.287	0.271	0.239	0.264	0.251	0.252	0.224	0.236	0.218	0.226
C_{44}	0.237	0.227	0.229	0.231	0.230	0.219	0.231	0.227	0.227	0.227	0.220	0.225
C_{51}	0.290	0.297	0.313	0.300	0.348	0.305	0.338	0.330	0.346	0.410	0.369	0.375
C_{52}	0.316	0.345	0.342	0.334	0.352	0.362	0.352	0.355	0.333	0.262	0.292	0.296
C_{53}	0.395	0.358	0.345	0.366	0.300	0.333	0.310	0.314	0.320	0.328	0.339	0.329
C_{61}	0.217	0.220	0.227	0.221	0.268	0.279	0.231	0.259	0.263	0.256	0.239	0.253
C_{62}	0.277	0.290	0.268	0.278	0.279	0.268	0.279	0.275	0.358	0.320	0.356	0.345
C_{63}	0.254	0.250	0.257	0.254	0.231	0.222	0.268	0.240	0.211	0.188	0.206	0.202
C_{64}	0.252	0.240	0.248	0.246	0.222	0.231	0.222	0.225	0.168	0.235	0.198	0.201

4.2. Challenges and Limitations

Transport emissions reduction is a world problem that different countries around the world are tackling. The sector contributing large shares of worldwide greenhouse gas emissions to the transportation sector comprises land, sea and air transport for any activity. To bring about this challenge, the current study has looked at six policies and their options for evaluation, including switching from fossil-fuelled vehicles to low or zero-emission vehicles (C_1), putting a high price on carbon (C_2), increasing active and public transport trip share and reducing trip demand (C_3), promoting alternative renewable fuel sources (C_4), increasing vehicle fuel economy (C_5), and managing traffic and travel demand (C_6). While some of them could be more preferable in different situations, the implementation of these policies is not without challenges and limitations.

The first policy (C_1), switching from fossil-fuelled vehicles to low or zero-emission vehicles, is a common approach to reducing transportation emissions. The policy includes promoting hydrogen-fueled vehicles and electric vehicles as efficient alternatives to conventional diesel and gasoline vehicles. However, there are several challenges and limitations in the way of implementation of this policy. Infrastructure issues for electric and hybrid vehicles could be a major challenge. Charging stations and hydrogen stations are expensive, and the lack of infrastructure can discourage buyers from purchasing these vehicles. Additionally, vehicles with electricity and operating fuel costs are still relatively high compared to conventional vehicles, which may discourage use. Moreover, electric vehicle batteries require the use of rare earth metals, which are difficult to supply and can cause environmental damage during extraction and mining [58, 59].

The second policy (C_2), putting a high price on carbon, at times seeks to encourage the reduction of greenhouse gas emissions by making carbon-intensive activities costly. The implementation of this policy might prove difficult as it leads to economic impacts like higher costs for consumers and businesses. Moreover, policymakers must ensure that the design and implementation of the policy are done in such a manner so as not to impact low-income households disproportionately. The third policy (C_3), increasing active and public transport trip share and reducing trip demand, seeks to incentivize people to use public transport, cycling and walking as alternatives to private vehicles. However, this policy goes through serious challenges in its implementation as it requires huge investments in public transport infrastructure, such as the bus and train networks. Moreover, policymakers must ensure that there is adequate accessibility and affordability for all people particularly low-income households who use public transport services [60 - 62].

The fourth policy (C_4) is to increase the use of alternative renewable fuel sources like biofuels in vehicles. In this policy, there are many challenges and limitations. It has a limited supply as well as a high cost for biofuels. Also, producing biofuels can lead to land-use changes and deforestation. The fifth policy (C_5) is increasing vehicle fuel economy for the reduction of greenhouse gas emissions. This is done through promoting fuel-efficient vehicles. However, the policy is faced with several challenges like the cost of fuel-efficient vehicles and infrastructure limits for charging electric vehicles. Moreover, policymakers ought to ensure that measures under the policy do not promote using bigger and heavier vehicles as this can nullify whatever gains from increased fuel efficiency. The sixth policy (C_6) is traffic and travel demand management, where measures like congestion pricing, carpooling and telecommuting are used to reduce the number of vehicles on roads. However, its implementation is difficult since it will require significant investments in intelligent systems of transport and other related infrastructure. Moreover, policymakers must ensure that the policy does not disproportionately affect low-income households and that it is designed and implemented in a way that has no adverse effects on economic growth [63 - 65].

Overall, there are several challenges and limitations in the implementation of policies for transport emissions reduction. The main challenges include the lack of infrastructure for low or zero-emission vehicles, economic impacts of putting a high price on carbon, massive investment in public transport infrastructure, availability issues and high cost of biofuels, high cost of fuel-efficient vehicles as well as considerable investments in intelligent transport systems. Moreover, policymakers must also ensure that these policies are designed and implemented so as to inflict the least disproportionate effect on households at low-income levels. At the same time however, they must not undermine economic growth with such policies. Addressing these challenges and limitations calls for a multi-faceted approach involving collaboration between policymakers, industry stakeholders, as well as the public.

CONCLUSION

Greenhouse gas emissions from the transport sector are a significant contributor to global greenhouse gas emissions, leading to negative impacts on climate change and air quality. Governments have been working towards incentivizing low-carbon forms of transportation through policies such as carbon pricing, fuel standards, subsidies for public transportation, and creating more bike lanes. To ensure the successful implementation of these policies, different levels of budgets need to be allocated so that policymakers can invest in key areas such as public awareness campaigns, educational programs, and basic infrastructure improvements. Evaluations are essential tools that serve to assess the effectiveness, efficiency, and impact of policies, regardless of the budget allocated. This study presented the use of a modified version of the SWARA method, called SWARA II, to evaluate the transport emissions reduction policies for implementation at three budget levels (low, medium, and high). The evaluation process was based on the opinions of a group of experts. The results of this study showed that C_3, which pertains to increasing active and public transport trip share while simultaneously reducing trip demand, was identified as the most critical criterion at the low-budget level mode. At the medium-budget level mode, C_3 was also the most important criterion, with the significance of increasing the usage of alternative modes of transport and reducing the reliance on private vehicles. Finally, at the high-budget level mode, C_1 was the most important criterion, highlighting the significance of switching from fossil-fueled vehicles to low-emission or zero-emission vehicles. Overall, the results of this study suggest that policymakers should prioritize policies that incentivize the use of low-carbon modes of transportation, reduce trip demand, and encourage the adoption of low-emission or zero-emission vehicles. While budgetary constraints may limit the extent of such policies, low-budget allocations can still be allocated towards public awareness campaigns, educational programs, and essential infrastructure improvements. Evaluations should continue to be used to assess policy effectiveness and guide policymakers in their implementation process. Only by working together towards reducing transport emissions can we hope to mitigate climate change and improve air quality for future generations. Future research can focus on macroeconomic, financial, environmental and technological aspects of this field of study and conduct more comprehensive research. Moreover, SWARA II can be integrated with different MCDM techniques in future research, making it an even more powerful tool for decision-making. The method's integration with other MCDM techniques can provide a more comprehensive and accurate analysis of the decision problem, thus reducing the risk of making erroneous decisions. SWARA II can also be extended in various ways to handle different types of uncertainty, such as fuzzy environments. This flexibility makes SWARA II an adaptable method that can be used in various fields of study, particularly those dealing with complex and uncertain problems.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

The data and supportive information are available within the article.

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