Identification of Policy Indicators for Changing Transportation Modes to Reduce Environmental Pollution in the Iran

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Abstract

This study aims to identify and validate key policy indicators to facilitate the transition from conventional transportation modes to sustainable alternatives, with the goal of reducing environmental pollution in Iran. A qualitative approach was employed using the fuzzy Delphi method to achieve expert consensus on the critical dimensions and indicators of sustainable transportation policies. The study engaged 20 experts, including university professors and senior professionals from the transportation and environmental sectors, selected through purposive and snowball sampling methods. Data collection involved semi-structured interviews, and the analysis focused on coding and triangulation to identify relevant policy dimensions. Triangular fuzzy sets (l, m, u) were used to quantify expert opinions and address uncertainties, ensuring the reliability of the findings. The study identified six key dimensions for effective policymaking: the role of policymakers, policy approaches, mechanisms for creating dynamism, policymakers' capabilities, mastery of environmental conditions, and the provision and utilization of necessary data. Specific indicators under these dimensions include evidence-based policymaking, participatory approaches, collaboration with academic and professional experts, integration of reliable data, and alignment with contemporary scientific paradigms. The findings emphasize the importance of institutional frameworks, systematic approaches, and stakeholder engagement in fostering sustainable transportation systems. The proposed indicators achieved consensus among experts, with fuzzy scores exceeding the threshold for validation. The results provide a comprehensive framework for developing sustainable transportation policies that address environmental challenges. The identified dimensions and indicators align with global best practices and offer actionable insights for policymakers. By emphasizing participatory and evidence-based approaches, the findings can guide national efforts to reduce environmental pollution through the promotion of sustainable transportation modes.

Keywords: *Sustainable transportation, policy indicators, environmental pollution, fuzzy Delphi method, participatory policymaking, evidence-based policies.*

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1. Introduction

Transportation systems play a pivotal role in modern societies, facilitating the movement of goods and people while significantly contributing to economic growth and social integration. However, the environmental consequences of conventional transportation modes, such as private automobiles and fossil-fuel-dependent public transport, have prompted a growing need to rethink these systems. Globally, transportation contributes substantially to greenhouse gas (GHG) emissions, urban air pollution, and ecological degradation [1]. The adoption of sustainable and environmentally conscious transportation policies has become an imperative for mitigating these adverse impacts and fostering long-term environmental resilience.

One of the major challenges in achieving sustainability in transportation is identifying and implementing effective policy indicators for shifting transportation modes. The environmental impacts of various commuting modes, as revealed in Lisbon through a life-cycle assessment, highlight the critical need for strategies that address particulate matter emissions and their health implications [2]. Similarly, sustainable urban transportation requires a shift toward multimodal and low-carbon systems, integrating innovative solutions like bike sharing and electric vehicles [3-5].

Urbanization and population growth have intensified the demand for efficient transportation systems, emphasizing the urgency to reduce the environmental footprint of commuting. The role of infrastructure and automobile shifts in urban sustainability goals has been extensively studied, with findings underscoring the importance of positioning transit systems to minimize environmental impacts across their life cycle [6, 7]. Additionally, the environmental and economic benefits of intermodal freight transportation demonstrate the potential for bi-objective modeling approaches that optimize efficiency while addressing environmental concerns (Demir et al., 2019).

Innovations in urban transportation policies have been transformative, particularly in promoting active transportation modes such as cycling. In New York City, the environmental benefits of bike-sharing programs illustrate how integrating active and public transportation modes can significantly reduce emissions [8]. Likewise, the societal costs and benefits of commuter bicycling, modeled in Auckland, reveal the positive externalities associated with shifting from car dependency to active transportation [9]. These findings align with global trends emphasizing the role of cycling infrastructure and GIS-based route mapping in fostering environmentally friendly commuting options [10].

Sustainable transportation also involves addressing the dynamic interplay between policy, technology, and behavior. The adoption of autonomous vehicles, for instance, presents a dual-edged sword: while offering environmental benefits during the use phase, their overall sustainability depends on comprehensive policy frameworks that guide their implementation [4]. Similarly, electric mobility, as part of the broader transition to smart cities, highlights the European experience in integrating technology with policy to achieve low-carbon objectives [11].

Behavioral factors and incentives further influence the adoption of sustainable transportation modes. In the Washington, DC region, research has shown that providing amenities such as bike parking and public transportation benefits can significantly affect commuter mode choices [12]. These findings are consistent with evidence from holiday transport mode choices, where environmental commitment plays a crucial role in selecting sustainable options [13]. The rise of Mobility as a Service (MaaS) platforms demonstrates the potential for technology-driven solutions to encourage shifts toward sustainable modes by offering integrated and convenient travel options [14].

The global transportation sector's carbon reduction potential hinges on effective policy integration and stakeholder engagement. Studies in Tehran have demonstrated how urban air pollution can be addressed through system dynamics modeling, which integrates transportation, energy, and environmental dimensions [15]. Freight transportation, another critical area, requires policies that mitigate negative externalities while ensuring economic viability. Research on freight pricing in low-carbon economies and modeling of green intermodal freight transportation highlights the value of aligning economic incentives with environmental goals [16-18].

Moreover, tourism and globalization have further complicated the relationship between transportation and environmental sustainability. In Malaysia, the interplay of tourism, transportation, and environmental degradation underscores the need for policies that balance economic development with ecological preservation [19]. Inland waterway transport, a relatively underexplored mode, offers promising environmental benefits when effectively mapped and integrated into national transportation strategies [20].

The critical role of policymaking in achieving sustainable transportation cannot be overstated. Effective policy indicators must account for the diverse needs of users, environmental constraints, and technological advancements. For instance, cycle-transit facilities in Jakarta highlight the importance of infrastructure that seamlessly connects active and public transportation modes, ensuring accessibility and usability [6]. Furthermore, the optimization of multimodal mobility systems, incorporating ride-sharing and public transit, demonstrates the potential for reducing environmental impacts through integrated solutions [21].

This study aims to identify policy indicators that facilitate the transition to sustainable transportation modes, thereby reducing environmental pollution. Drawing on a comprehensive review of existing research, it explores the multifaceted dimensions of sustainable transportation, including active transportation, intermodal freight systems, autonomous vehicles, and policy-driven behavioral shifts. By integrating findings from diverse contexts and transportation modes, this research seeks to provide actionable insights for policymakers and stakeholders, enabling the development of robust frameworks for sustainable mobility.

2. Methodology

In this qualitative study, the target population consists of experts who possess comprehensive knowledge about policy-making related to changing transportation modes for reducing environmental pollution in the country. A purposeful sampling method was employed, along with the "snowball" technique, where initial participants referred other knowledgeable individuals. This method enabled the sample group to grow progressively, resembling a rolling snowball. The sample continued to expand until theoretical saturation was reached, a process guided by the logic of theoretical sampling, which focuses on the emergence of concepts during the analysis.

A total of 20 experts and managers with extensive experience in policy-making, transportation, and environmental issues were selected for interviews. These participants included faculty members with expertise in policy-making, as well as managers, deputies, and consultants in the transportation and environmental sectors. The key criteria for selecting participants were having more than ten years of experience in policy-making or the transportation and environmental industries, holding a master's or doctoral degree in related fields, and possessing management experience in these areas.

For identifying policy indicators and codes for changing transportation modes, semi-structured interviews were conducted with the experts using both structured and open-ended questions to enrich the findings. The interviews were analyzed using content analysis, which involved the exploration of theoretical and empirical frameworks, documentation review, and observational data. The data collected through these methods contributed to the design of an initial policy model, which was validated by experts to ensure its content and face validity.

The interviews were conducted either in person or via phone, with participants informed of the study's purpose beforehand and their consent obtained. In cases where participants had time constraints, they were provided with interview forms to complete at their convenience. Interviews lasted between 40 to 80 minutes. The interview questions were designed to explore key aspects of policy-making for transportation change, focusing on scientific expertise, political insight, and the interaction between policymakers and transportation/environmental specialists.

Following the interviews, the transcripts were carefully reviewed to identify main categories and subcategories, which were then refined through coding. This iterative process of data collection and analysis continued until no new categories emerged, indicating theoretical saturation. To ensure the credibility of the findings, the model was presented to five transportation and environmental experts for further refinement based on their feedback.

In terms of data analysis, content analysis was utilized alongside an inductive approach for categorizing the identified policy indicators. This allowed for the development of meaningful codes, which were systematically categorized and abstracted into higher-level themes and subcategories through constant comparison and theoretical saturation. The findings were then reviewed for coherence and consistency, ensuring that they aligned with the research objectives.

3. Findings and Results

The study on policy formulation was conducted with the input of 20 experts from academic institutions and key management positions in the fields of transportation and environmental sectors. Among the participants, 80% were male and 20% female. In terms of age distribution, 15% were between 30 to 40 years old, 45% were between 41 to 50 years old, and 40% were over 51 years old. Regarding professional experience, 10% had between 6-10 years of experience, 35% had 11-20 years, 30% had 21-30 years, and 25% had more than 31 years of work experience. As for educational qualifications, 25% held a master's degree, while 75% had a doctoral degree. In terms of professional roles, 55% were faculty members at universities, and 45% held senior management positions or were directors in the transportation or environmental sectors.

The findings of this study were obtained using the triangular fuzzy Delphi technique to ensure the accuracy and reliability of the dimensions, components, and indicators extracted from the interviews. This method facilitated consensus among the experts on the identified elements and validated the initial policy model to design the final framework. The fuzzy Delphi technique employed triangular fuzzy sets (l, m, u) to address uncertainties in expert opinions, where each indicator was represented by three values reflecting varying evaluations.

The expert panel consisted of 10 highly qualified participants, including four university professors and six professionals from the transportation and environmental sectors, all holding doctoral degrees. After gathering opinions, the fuzzy Delphi analysis confirmed the key components, showing high consensus among the experts across the two rounds of evaluation. The findings revealed no significant differences between the results of the first and second rounds, with the average scores exceeding 70%, indicating the validity of the identified indicators.

Table 1. Final Results of Qualitative Analysis (Second Round of Delphi Method)

Dimensions	Indicators	Fuzzy Scores (l,m,u)	S2	S1-S2
Policymakers (Data Users)	Policy-making authorities, transportation and environmental agencies, legal entities	(0.98, 0.81, 0.25)	0.770	0.020
	Ministry of Roads and Environmental Organization	(0.93, 0.82, 0.59)	0.777	0.020
	National terminals and Environmental Administration	(0.94, 0.82, 0.63)	0.797	0.010
	Legal policy-making by related authorities	(0.95, 0.82, 0.54)	0.770	0.060
	Clearly defined in national laws	(0.94, 0.70, 0.52)	0.720	0.003
Policy Approaches	Evidence-based policy-making supported by documented scientific evidence	(0.93, 0.85, 0.54)	0.773	0.010
	Situational approaches	(0.93, 0.78, 0.55)	0.753	0.030
	Systematic and contingency-based approaches	(0.96, 0.85, 0.57)	0.800	0.010
	Participatory and combined approaches	(0.93, 0.87, 0.55)	0.783	0.030
	Incorporating contemporary scientific perspectives	(0.93, 0.77, 0.53)	0.743	0.020
	Based on detailed scientific studies	(0.92, 0.78, 0.53)	0.760	0.010
Mechanisms for Creating Dynamism in Policy	Through interaction with experts	(0.95, 0.75, 0.55)	0.750	0.030
	Continuous and effective two-way communication with academic centers	(0.95, 0.74, 0.55)	0.746	0.040
	Utilizing statistical and research centers in the country	(0.93, 0.80, 0.53)	0.753	0.030
	Establishing educational programs to meet the real needs of the country	(0.94, 0.81, 0.61)	0.793	0.040
	Leveraging global academic experiences	(0.94, 0.78, 0.55)	0.763	0.040
	Utilizing the experience of professionals	(0.97, 0.78, 0.56)	0.770	0.010
Capabilities of Policymakers	Scientific competence and political knowledge	(0.95, 0.79, 0.53)	0.743	0.004
	Familiarity with the policy-making process	(0.97, 0.82, 0.57)	0.756	0.030
	Ability to identify organizational needs	(0.95, 0.76, 0.56)	0.750	0.007
	Academic and political experience	(0.94, 0.82, 0.56)	0.757	0.003
	Seeking appropriate statistics and documents	(0.93, 0.83, 0.57)	0.777	0.010
	Interest in using statistics and documents for policy-making	(0.94, 0.78, 0.55)	0.743	0.020
Proving Scientific Capability of Policymakers	Competence in systematic studies	(0.95, 0.81, 0.58)	0.780	0.010
	Competence in non-systematic studies	(0.96, 0.70, 0.51)	0.726	0.030
	Ability to analyze and examine one-dimensional data	(0.94, 0.83, 0.55)	0.780	0.020
	Experience in case-specific problem solving	(0.97, 0.70, 0.51)	0.727	0.030
	Competence in utilizing experts	(0.94, 0.72, 0.55)	0.736	0.000
	Completion of necessary scientific courses	(0.95, 0.76, 0.53)	0.750	0.040
Proving Mastery Over Environmental Conditions	Experience in political life	(0.93, 0.77, 0.54)	0.750	0.000
	Ability to evaluate diverse environmental conditions	(0.98, 0.85, 0.59)	0.806	0.000
	Practical political experience	(0.94, 0.83, 0.56)	0.700	0.050
	Access to diverse information	(0.94, 0.77, 0.53)	0.740	0.010
	Control over social resources	(0.96, 0.77, 0.57)	0.760	0.010
	Ability to form think tanks and lobbying systems	(0.96, 0.76, 0.52)	0.750	0.010
	Influence over religious leaders and gaining their support	(0.94, 0.77, 0.51)	0.740	0.010
	Possession and use of mass media	(0.94, 0.78, 0.55)	0.760	0.020
	Participation in civil societies	(0.93, 0.82, 0.53)	0.760	0.060
Dynamic Policy Development by Specialists	Interaction and collaboration with policy-making entities	(0.96, 0.81, 0.54)	0.770	0.030
	Exchange and development of discussions between the two	(0.95, 0.83, 0.57)	0.760	0.010
	Specialists understanding the required data for policymakers	(0.96, 0.81, 0.56)	0.787	0.010
	Policymakers clearly identifying needs	(0.95, 0.85, 0.55)	0.783	0.000
	Reflecting real problems accurately using studies and statistics	(0.98, 0.80, 0.53)	0.770	0.000
	Scientific outlook on issues without political or ideological biases	(0.97, 0.81, 0.56)	0.780	0.000

Providing Necessary Data	Based on the needs of policy-making entities	(0.92, 0.83, 0.52)	0.760	0.030
	Following global scientific advancements	(0.92, 0.83, 0.54)	0.760	0.010
	Conducting accurate scientific research	(0.94, 0.81, 0.55)	0.770	0.000
	Using the current scientific paradigm	(0.93, 0.79, 0.56)	0.760	0.000
Essential Data Types	Providing reliable data	(0.92, 0.85, 0.55)	0.773	0.060
	Presenting statistics and documents in a usable format	(0.94, 0.81, 0.54)	0.760	0.010
	Publishing documents effectively	(0.94, 0.81, 0.53)	0.760	0.000
	Broad dissemination of documents	(0.95, 0.78, 0.57)	0.770	0.010
	Making evidence available to policymakers	(0.95, 0.81, 0.55)	0.770	0.020
	Encouraging policymakers to utilize research findings	(0.94, 0.77, 0.53)	0.750	0.000

Key dimensions and components included policymakers' roles, policy approaches, mechanisms for fostering dynamism in transportation policy, policymakers' capabilities, and their ability to adapt to environmental conditions. The findings highlighted the importance of collaboration with academic centers, utilization of national research institutions, and systematic engagement with professionals and industry experts. The study also emphasized the role of reliable and accessible data tailored to policymaking needs, the adoption of current scientific paradigms, and the dissemination of findings to inform decisions effectively (Table 1).

The analysis confirmed that the identified indicators and dimensions are robust and align with the study's objectives. The results also validate the initial model for policymaking in transportation and environmental sustainability, providing a solid foundation for practical implementation and further research.

4. Conclusion

This study aimed to identify policy indicators for shifting transportation modes to reduce environmental pollution, employing a fuzzy Delphi method to gather expert consensus. The findings revealed several critical dimensions, including policymakers' roles, policy approaches, mechanisms for creating dynamism in policymaking, policymakers' capabilities, mastery of environmental conditions, and the provision and utilization of necessary data. These dimensions encompass specific indicators that align with global efforts to promote sustainable transportation systems.

The results underscore the significant role of policymakers as key stakeholders in the transition to sustainable transportation. Indicators such as the involvement of government bodies like the Ministry of Roads and environmental organizations resonate with findings from Chester et al. (2013), who highlighted the importance of integrating institutional frameworks to minimize the environmental impacts of urban transit systems [7]. Similarly, Nokelaynen (2018) emphasized the value of mapping environmental impacts for inland waterways, a strategy that can be adapted for other transportation modes [20]. The identified emphasis on legal policy-making by relevant authorities supports global calls for robust legislative frameworks to guide sustainable transportation policies.

The study also identified participatory and systematic approaches as effective policy strategies. These align with the work of Jang et al. (2020), who argued that Mobility as a Service (MaaS) platforms could contribute to sustainable transportation by fostering participatory planning and user engagement [14]. Furthermore, evidence-based policymaking, as identified in this study, reflects findings by Demir et al. (2019), who emphasized the importance of data-driven strategies in green intermodal freight transportation [16]. Such approaches ensure that policies are grounded in empirical evidence, enabling more effective implementation.

Mechanisms for fostering dynamism in transportation policymaking emerged as a critical dimension in this study. Indicators such as collaboration with academic centers and leveraging the expertise of professionals mirror findings from Kontar et al. (2022), who underscored the environmental benefits of integrating technology and expertise in transportation systems [5]. Hamre and Buehler (2014) similarly highlighted the role of infrastructure and incentives, such as bike parking and public transportation benefits, in encouraging dynamic shifts toward sustainable modes [12]. This study's findings further emphasize the importance of fostering continuous interaction between policymakers and data providers, a strategy supported by Yu et al. (2020), who demonstrated the effectiveness of optimized multimodal systems in reducing environmental impacts [21].

The capability of policymakers to understand and evaluate environmental conditions was another dimension highlighted in this study. Indicators such as political experience and the ability to evaluate diverse environmental scenarios are consistent with the findings of Ruggieri et al. (2021), who stressed the need for skilled governance in adopting electric mobility solutions within smart cities [11]. Similarly, Sharif et al. (2020) noted that transportation policies in Malaysia must consider environmental, economic, and cultural factors to achieve sustainable outcomes [19]. These findings collectively emphasize that policymakers must possess the technical and contextual knowledge necessary for informed decision-making.

The provision and utilization of reliable data were also identified as crucial in this study. Indicators such as conducting accurate research and disseminating findings effectively align with the work of Macmillan et al. (2014), who used system dynamics modeling to highlight the societal benefits of commuter bicycling [9]. Similarly, Mustapha (2023) emphasized the importance of GIS-based mapping in facilitating sustainable cycling infrastructure [10]. The emphasis on evidence dissemination supports findings by Demir et al. (2015), who argued that effective communication of research findings is vital for addressing negative externalities in freight transportation [17].

Overall, this study contributes to the growing body of literature by offering a comprehensive framework for identifying policy indicators that facilitate shifts in transportation modes. The findings align with global best practices and provide actionable insights for policymakers aiming to reduce environmental pollution through sustainable transportation strategies.

Despite its contributions, this study has certain limitations. The reliance on expert opinions through the fuzzy Delphi method, while valuable, may introduce biases based on the participants' expertise and perspectives. Additionally, the study's focus on qualitative methods limits its ability to generalize findings across diverse contexts. The absence of empirical testing of the proposed indicators also constrains the applicability of the results to real-world policymaking scenarios. Furthermore, the study primarily considers the environmental dimension of transportation without fully addressing economic and social implications, which are integral to sustainable development.

Future research should explore quantitative validation of the identified indicators through empirical testing in diverse regional and cultural contexts. Comparative studies examining the effectiveness of these indicators in different transportation systems and policy environments could provide more nuanced insights. Additionally, integrating economic and social dimensions with environmental indicators would offer a more holistic understanding of sustainable transportation policies. Exploring the role of emerging technologies, such as artificial intelligence and blockchain, in enhancing data-driven policymaking could also be a valuable avenue for future research.

Policymakers should adopt participatory approaches, engaging stakeholders across academia, industry, and civil society to ensure inclusive and comprehensive transportation policies. Emphasizing evidence-based decision-making, supported by accurate and accessible data, is critical for designing effective interventions. Capacity-building programs for policymakers, focusing on technical expertise and environmental awareness, can further enhance their ability to implement sustainable policies. Finally, fostering collaboration with international organizations and leveraging global best practices can help align national policies with global sustainability goals.

Authors' Contributions

Authors equally contributed to this article.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

All procedures performed in this study were under the ethical standards.

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