Sainteks: Jurnal Sain dan Teknik
E-ISSN: 2685-8304
Volume 8, Nomor 02, 2026
http://ejournal.uicm.ac.id/index.php/sainteks/

Developing an analytical hierarchy process conceptual framework for fuel cell electric vehicle adoption in indonesia: evidence from literature synthesis

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Abstract: *Fuel Cell Electric Vehicles (FCEV) are a zero-emission vehicle technology that has the potential to support the decarbonization of the road transportation sector in Indonesia. However, their adoption rate remains very low due to limited hydrogen infrastructure, the lack of specific policies, and the low readiness of the supporting ecosystem compared to battery-based electric vehicles. This study aims to develop a conceptual framework for the Analytical Hierarchy Process (AHP) based on literature synthesis to identify and prioritize factors influencing FCEV adoption in Indonesia from a multi-stakeholder perspective, particularly policymakers. The study uses a qualitative approach through literature synthesis of twelve relevant scientific articles. The synthesis results are used to construct a decision hierarchy structure consisting of four main criteria: policy, economic, socio-environmental, and technical aspects, with a total of 15 sub-criteria. The results show that policy aspects are the main priority in supporting FCEV adoption, primarily through the provision of fiscal incentives, reducing hydrogen production costs, harmonizing cross-sector regulations, developing a National Hydrogen Roadmap specifically for the transportation sector, and hydrogen pricing and subsidy policies. Economic aspects are the second priority, followed by socio-environmental and technical aspects. Because no expert survey was conducted in this conceptual study, these finding do not represent empirically measured AHP weights. The resulting conceptual framework provides a systematic basis for the application of the AHP method in further research and can be used as a reference in formulating strategies and policies to accelerate the gradual and sustainable adoption of FCEVs in Indonesia.*
Keywords: *Fuel Cell Electric Vehicle; Analytical Hierarchy Process; Literature Synthesis; Hydrogen Technology Adoption; Transportation Policy*

DOI: https://doi.org/10.37577/sainteks.v8i02.1167
Received: 08, 2026. Accepted: 09, 2026. Published: 09, 2026

INTRODUCTION

The transportation sector is one of the main contributors to global greenhouse gas emissions, so the transition to a low-carbon transportation system is a strategic agenda in various countries. Indonesia, as an archipelagic country with a population of more than 270 million people, faces a major challenge in reducing emissions from the transportation sector without reducing people's mobility and economic activities (Bhirowo et al., 2025) . Transportation electrification efforts are one of the main strategies implemented through the development of battery-based electric vehicles (Battery Electric Vehicles/BEV) and hydrogen fuel cell-based electric vehicles (FCEVs) (Pathak et al., 2023)(Pamungkas, 2025)

FCEV uses Proton Exchange Membrane Fuel Cell (PEMFC) technology that converts hydrogen chemical energy into electrical energy with final emissions in the form of water vapor. Compared to BEVs, FCEVs have several advantages in the form of relatively short refueling times, high energy density, good thermal efficiency, and are more suitable for vehicles with long mileage and heavy load needs such as buses, trucks, and logistics fleets. These characteristics make FCEVs one of the important alternatives in supporting the decarbonization of road transportation. (Li & Taghizadeh-Hesary, 2022)(Vijayakumar et al., 2021)(Hassan et al., 2023)

However, the adoption rate of FCEV in Indonesia is still very low. Indonesia has great potential in the development of green hydrogen because it is supported by renewable energy sources such as geothermal, hydropower, solar, and biomass. However, until 2024 there will only be one hydrogen refueling station (HRS) operating in Senayan, Jakarta (Bhirowo et al., 2025; Pamungkas, 2025) . This condition is very different compared to countries that have developed hydrogen ecosystems, such as China, Japan, South Korea, Germany, the United States, and France which already have to build HRS (Park & Kim, 2025) . The limited infrastructure has led to the emergence of the chicken-and-egg phenomenon, namely the low number of vehicles hindering infrastructure development, while the lack of infrastructure hinders the increase in the number of vehicles (Damman et al., 2021).

In addition to infrastructure limitations, other challenges come from the policy aspect. Electric vehicle regulations in Indonesia through Presidential Regulation Number 55 of 2019 and Presidential Regulation Number 74 of 2021 are more oriented towards the development of BEV, while FCEV have not received specific fiscal policy and technical regulatory support. As a result, the development of the national hydrogen ecosystem, especially in the transportation sector, is still lagging behind the industrial and power generation sectors.(Bhirowo et al., 2025)

Various previous studies have examined the adoption of hydrogen vehicles from various perspectives. explaining the technical characteristics of FCEV along with the safety aspects of using hydrogen (Puig-Samper et al., 2024) . analyze the of FCEV and show that high investment costs are still a major obstacle (Xu et al., 2025) . highlighting the importance of hydrogen production costs as well as HRS capacity optimization in improving the economic viability of hydrogen infrastructure (Park & Kim, 2025) . In terms of policy, it shows the importance of cross-stakeholder collaboration in the development of hydrogen ecosystems, while proposing an Open Collaborative Innovation Framework approach involving governments, industry, academia, society, and investors.(Bethoux, 2020)

The Analytical Hierarchy Process (AHP) method has been widely used as a multicriteria decision-making approach in electric vehicle research (Guven & Kayalica, 2024; Zhang, Chen, et al., 2024) . implement AHP to analyze Indonesian consumers preferences for HEV, BEV, and hydrogen vehicles based on aspects of cost, maintenance, and government incentives (Bhirowo et al., 2025) . Meanwhile, AHP is used to evaluate the potential adoption of FCEVs in Tokyo based on five main dimensions, namely vehicle performance, economic cost, social aspects, fuel availability, and policy support (Zhang, Chen, et al., 2024) . until now, there is no conceptual framework for AHP that is specifically designed based on a synthesis of literature to prioritize the success factors of FCEV adoption in the Indonesian context from the perspective of policy makers.

Based on these gaps, this study aims to build a conceptual framework of the Analytical Hierarchy Process based on literature synthesis to identify the priority factors influencing the adoption of FCEV in Indonesia. A synthesis was carried out against twelve relevant scientific articles to compile a decision hierarchy structure consisting of main criteria and subcriteria. The resulting conceptual framework is expected to be the basis for quantitative research using AHP and provide recommendations for the government in formulating strategies to accelerate FCEV adoption in a systematic, gradual, and sustainable.

METHOD

Research Design

This study uses a qualitative literature synthesis approach (Shaikh et al., 2024) to develop a conceptual framework of the Analytical Hierarchy Process (AHP) for identifying priority factors influencing the adoption of Fuel Cell Electric Vehicle (FCEV) in Indonesia. Unlike an a conventional AHP research that uses primary data through questionnaires to experts, this study utilizes the results of previous research as the basis for the preparation of a decision hierarchy structure, therefore no experts participated in the present study. This approach was chosen because there is still limited empirical research on FCEV in Indonesia (Bhirowo et al., 2025) , so that the synthesis of the literature can provide a conceptual basis before validation using expert assessment.

Literature Search

To ensure a systematic and reproducible review, a structured literature search was conducted. The search was performed using the following academic databases: Scopus, Google Scholar, and ScienceDirect. The keywords used in the search included combinations of: *"Fuel Cell Electric Vehicle" OR "FCEV" OR "Hydrogen Vehicle"* AND *"Adoption" OR "Implementation"* AND *"Analytical Hierarchy Process" OR "AHP" OR "Multi-Criteria Decision Making"* AND *"Indonesia" OR "Developing Countries"*. The search period was limited to publications from 2020 to 2025 to capture the most recent developments in hydrogen technology and policy.

The literature was selected specifically based on its suitability for the research objectives. Inclusion criteria include: (1) discussing FCEV or hydrogen technologies for the transportation sector; (2) discuss economic, policy, infrastructure, or multi-criteria decision-making aspects; (3) published in reputable scientific journals (accredited or indexed by Scopus/Web of Science); and (4) relevant to the context of hydrogen vehicle development or energy transition. Based on these criteria, 12 scientific articles were obtained that became the basis for the synthesis. The twelve articles cover the technological, economic, policy, hydrogen infrastructure, business models, energy transition, and decision-making methods that form the basis for the preparation of the AHP conceptual framework (Bethoux, 2020; Bhirowo et al., 2025; Hannan et al., 2025; Hansson et al., 2025; Li & Taghizadeh-Hesary, 2022; Rozzi et al., 2024; Vijayakumar et al., 2021; Wijayasekera et al., 2024; Wolf et al., 2025; Zhang, Wang, et al., 2024)

Literature Synthesis Procedure

Literature synthesis is carried out through four stages (as illustrated in Figure 1):

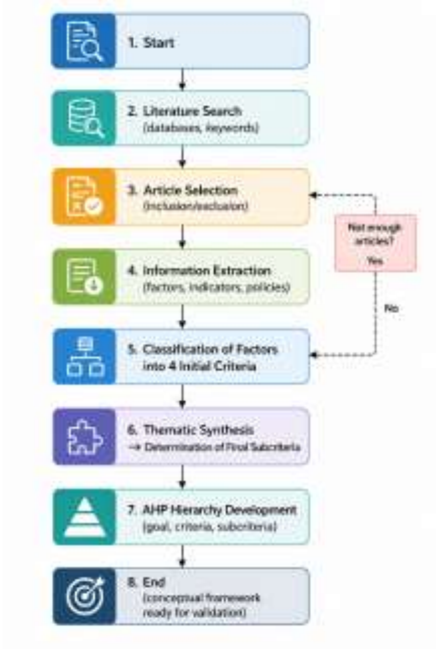

Figure 1. *Research Methodology Flowchart for Developing the AHP Conceptual Framework*

1. **Identification of the literature**, i.e. collecting articles relevant to the development of FCEV, hydrogen, and AHP methods.

2. **Information extraction**, which is identifying variables, success factors, indicators, and policy recommendations reported in each study.
3. **Factor classification**, which is to group all factors into four main criteria that have similar characteristics, namely policy aspects, economic aspects, socio-environmental aspects, and technical aspects.
4. **The preparation of the AHP hierarchy**, which is to compile a decision structure consisting of objectives, criteria, and subcriteria as a conceptual framework that will be used in advanced research based on expert assessment.

Analysis Technique and AHP Calculation Pattern

The analysis used descriptive qualitative with a thematic synthesis approach. Information extracted from each article included the study focus, variables or factors, indicators and policy implications. This approach follows literature-synthesis procedures that emphasize systematic data extraction, comparison, categorization, and synthesis before developing an integrative conceptual framework (Hossain Bhuiyan & Siddique, 2025). The results of the synthesis are then translated into an AHP hierarchical structure consisting of one main objective, four criteria, and fifteen subcriteria. Because this study is conceptual and does not contain expert judgements, there is no empirical AHP priority weights are calculated. The subsequent empirical study will follow these steps (Guven & Kayalica, 2024) :

1. **Decomposition** : Breaking down the decision problem into a hierarchy (Goal -> Criteria -> Sub-criteria).
2. **Pairwise Comparisons** : Experts will compare elements at the same level using the Saaty scale (1 = equal importance to 9 = extreme importance) to construct a comparison matrix.
3. **Eigenvector Calculation** : Compute the priority weights by normalizing the matrix and calculating the principal eigenvector.
4. **Consistency Check**: Calculate the Consistency Ratio (CR) using the formula:
   - $CI = \frac{\lambda_{max} - n}{n-1}$ (1)
   - $CR = \frac{CI}{RI}$ (2)
   - Where $\lambda_{max}$is the largest eigenvalue, $n$is the matrix size, and $RI$is the Random Index for the corresponding n. A CR ≤ 0.1 is considered acceptable.

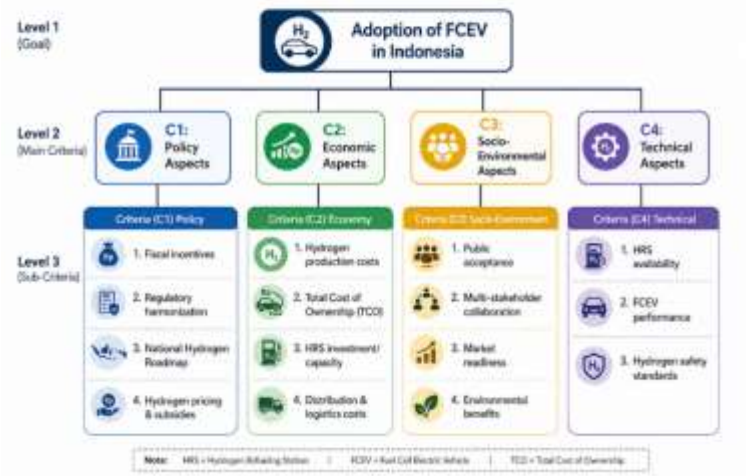

Figure 2. *Proposed AHP Hierarchical Structure for FCEV Adoption in Indonesia*

Figure 2 presents the proposed Analytical Hierarchy Process (AHP) framework for evaluating the adoption of Fuel Cell Electric Vehicles (FCEV) in Indonesia. The hierarchy consists of three levels. The first level represents the overall goal, namely FCEV adoption in Indonesia. The second level includes four main criteria: Policy, Economic, Socio-Environmental, and Technical aspects. These criteria were identified through a systematic literature review and thematic synthesis.

At the third level, each criterion is divided into several sub-criteria. The Policy criteria includes fiscal incentives, regulatory harmonization, the National Hydrogen Roadmap, and hydrogen pricing and subsidies. The Economic criterion consists of hydrogen production costs, total cost of ownership (TCO), HRS investment and capacity, and distribution and logistics costs. The Socio-Environmental criterion includes public acceptance, multi-stakeholder collaboration, market readiness, and environmental benefits. Finally, the Technical criteria comprises HRS availability, FCEV performance, and hydrogen safety standards.

This hierarchical structure provides a clear and systematic basis for conducting pairwise comparisons in the AHP analysis and supports the identification of the most influential factors affecting FCEV adoption in Indonesia.

After establishing the AHP hierarchy, pairwise comparisons will be conducted in the subsequent empirical validation stage to determine the relative importance of the criteria. In the AHP method, experts compare elements at the same hierarchical level using Saaty fundamental nine point scale, in which numerical judgments represent the relative importance of one element over another. The resulting comparison matrixs are used to derive priority weights and evaluate the consistency of expert judgements.

Because the present study does not involve an expert survey, the pairwise comparison matrix presented in Table 1 is a hypothetical and is included solely to demonstrate the AHP calculation procedure. The priority weights in Table 1 should therefore not be interpreted as empirical findings or as the preferences of Indonesian stakeholders.

Table 1. **Illustrative AHP Pairwise Comparison Matrix for the Main Criteria Using Hypothetical Judgments**

Criteria	Policy	Economy	Sosial	Technical	Priority Weight
Policy	1	3	5	7	0.557
Economy	1/3	2	3	5	0.263
Sosial	1/5	1/3	1	3	0.121
Technical	1/7	1/5	1/3	1	0.056

Table 1 presents an illustrative pairwise comparison matrix using hypothetical data to demonstrate the AHP calculation procedure. The matrix shows the relative importance of the four main criteria Policy, Economic, Socio-Environmental, and Technical aspects together with their corresponding priority weights. Furthermore, the consistency of the judgments is assessed through the maximum eigenvalue (λmax), Consistency Index (CI), and Consistency Ratio (CR). Since the calculated CR is below the acceptable threshold of 0.10, the comparison matrix is considered consistent. This example is intended solely to illustrate the analytical procedure and serves as a reference for the empirical pairwise comparison and expert evaluation that will be conducted in the subsequent stage of this research.

RESULT AND DISCUSSION

Based on the process of identifying and extracting information from 12 scientific articles, each study is mapped based on the focus of the study, the main findings, and its contribution to the preparation of the AHP criteria and subcriteria, The results of the mapping are presented in Table 2.

Table 2. Literature Synthesis as the Basis for the Preparation of the Conceptual Framework

Goal	Criteria	Sub-Criteria	Sources
Adoption of FCEV in Indonesia	**Policy (C1)**	1. Fiscal incentives (tax reduction, purchase subsidies)	(Bhirowo et al., 2025; Zhang, Wang, et al., 2024)
		2. Harmonization of cross-sector regulations (transportation, energy, industry)	(Damman et al., 2021; Pamungkas, 2025)
		3. National Hydrogen Roadmap specifically for transportation	(Pamungkas, 2025; Wijayasekera et al., 2024)
		4. Hydrogen pricing and subsidy policies	(Hansson et al., 2025; Li & Taghizadeh-Hesary, 2022)
	Economy (C2)	1. Hydrogen production costs (green vs. grey)	(Li & Taghizadeh-Hesary, 2022; Wijayasekera et al., 2024)
		2. Total Cost of Ownership (TCO) of FCEV vehicles	(Bhirowo et al., 2025; Wolf et al., 2025)
		3. HRS investment and capacity optimization	(Wijayasekera et al., 2024; Wolf et al., 2025)
		4. Hydrogen distribution and logistics costs	(Hansson et al., 2025; Wijayasekera et al., 2024)
	Socio-Environmental (C3)	1. Public/community acceptance and awareness	(Damman et al., 2021; Hannan et al., 2025)
		2. Multi-stakeholder collaboration (Penta-helix)	(Damman et al., 2021; Hannan et al., 2025)
		3. Market readiness (industry and consumer)	(Hansson et al., 2025; Zhang, Wang, et al., 2024)
		4. Environmental benefits (decarbonization impact)	(Hassan et al., 2023; Pathak et al., 2023)
	Technical (C4)	1. HRS availability and distribution network	(Wijayasekera et al., 2024; Wolf et al., 2025)
		2. FCEV technology performance and durability	(Bethoux, 2020; Hassan et al., 2023)
		3. Hydrogen safety standards and protocols	(Bethoux, 2020; Rozzi et al., 2024)

Table 2 presents the final AHP hierarchical structure developed to evaluate the adoption of Fuel Cell Electric Vehicles (FCEVs) in Indonesia. The hierarchy was constructed based on the findings of the systematic literature review and thematic synthesis, ensuring that each criterion and sub-criterion is supported by relevant and recent studies.

The overall goal of the hierarchy is FCEV adoption in Indonesia, which is evaluated through four main criteria: Policy (C1), Economy (C2), Socio-Environmental (C3), and Technical (C4). Each criterion is further represented by a set of sub-criteria that capture the key factors influencing FCEV adoption.

The Policy criteria includes fiscal incentives, regulatory harmonization, the National Hydrogen Roadmap, and hydrogen pricing and subsidy policies, highlighting the importance of government support in accelerating FCEV deployment. The Economic criterion focuses on hydrogen production costs, total cost of ownership (TCO), HRS investment and capacity, and hydrogen distribution and logistics costs, reflecting the financial feasibility of the technology. The Socio-Environmental criterion comprises public acceptance, multi-stakeholder collaboration, market readiness, and environmental benefits, emphasizing the role of social acceptance and sustainability in technology adoption. Finally, the Technical criterion includes HRS availability, FCEV performance and durability, and hydrogen safety standards, representing the technological readiness required for successful implementation.

The cited references for each sub-criterion demonstrate that the proposed hierarchy is grounded in the existing body of knowledge rather than subjective judgment. Therefore, this hierarchical structure provides a comprehensive and theoretically supported foundation for the subsequent AHP analysis and expert-based empirical validation.

Priority of Criteria and Sub-Criteria from Literature Synthesis

The synthesis of 12 scientific articles resulted in four main criteria that affect the adoption of Fuel Cell Electric Vehicle (FCEV) in Indonesia, namely policy aspects, economic aspects, socio-environmental aspects, and technical aspects. The grouping is carried out through the process of identifying themes, extracting factors, and classifying based on similarities in concepts that appear consistently in the literature.

The results of the synthesis show that the policy aspect is the most dominant criterion. The majority of research emphasizes that the successful implementation of FCEV is highly dependent on the existence of supportive regulations, fiscal incentives, hydrogen pricing policies, and national hydrogen development roadmaps. These findings show that the main challenge for FCEV development in Indonesia is not solely technological readiness, but the government's commitment to building a hydrogen ecosystem.

The economic aspect occupies the second priority because the high cost of FCEV vehicles, the cost of hydrogen production, and investment in the construction of Hydrogen Refueling Station (HRS) are still the main obstacles to technological competitiveness. Furthermore, socio-environmental aspects play a role in increasing public acceptance, strengthening multi-stakeholder collaboration, and supporting the decarbonization agenda of the transportation sector. The technical aspect is the last priority because most of the literature states that fuel cell technology has reached an adequate level of maturity, so the development of FCEV is more influenced by policy and economic factors than by technical constraints.

Based on the results of the synthesis, 15 subcriteria were obtained that formed the structure of the AHP hierarchy. The five subcriteria that received the strongest emphasis in the literature were fiscal incentives for vehicle purchases, hydrogen production costs, harmonization of cross-sector regulations, the preparation of a National Hydrogen Roadmap specifically for transportation, and hydrogen pricing and subsidy policies. The dominance of these subcriteria suggests that successful FCEV adoption requires government intervention that is integrated with hydrogen economic development strategies.

Policy Implications
The results show that the strategy to accelerate the adoption of FCEV in Indonesia needs to be focused on strengthening policies as the main foundation for the development of the hydrogen ecosystem. The provision of fiscal incentives, the preparation of a hydrogen roadmap for the transportation sector, the harmonization of cross-sector regulations, and the hydrogen price policy are the first steps that need to be prioritized before extensive infrastructure expansion.
On the economic side, governments and industry players need to encourage a reduction in the cost of hydrogen production through the use of domestic renewable energy and the development of financially viable HRS business models. Furthermore, increasing multi-stakeholder collaboration, public education, and human resource capacity building are supporting factors to accelerate the adoption of FCEV technology.
The findings complement previous research that has mostly focused on consumer preferences, regional case studies, or cause-and-effect relationship analysis. The main contribution of this study is the preparation of a conceptual framework of AHP based on literature synthesis that integrates four main criteria and fifteen subcriteria as the basis for the preparation of pairwise comparison instruments in the next empirical research.

CONCLUSIONS

This study succeeded in building a conceptual framework of the Analytical Hierarchy Process (AHP) based on literature synthesis to identify and prioritize the factors influencing the adoption of Fuel Cell Electric Vehicle (FCEV) in Indonesia. Based on the synthesis of 12 scientific articles, four main criteria were obtained, namely policy aspects, economic aspects, socio-environmental aspects, and technical aspects, which were further elaborated into 15 subcriteria. The results of the synthesis show that the policy aspect is the most dominant factor in supporting the acceleration of FCEV adoption, especially through the provision of fiscal incentives, harmonization of cross-sector regulations, the preparation of a National Hydrogen Roadmap for transportation, as well as hydrogen price and subsidy policies.

The economic aspect ranks next priority as the high cost of vehicles, hydrogen production, and infrastructure development remain major challenges. Meanwhile, socio-environmental aspects and technical aspects play a supporting role in strengthening technology acceptance, multi-stakeholder collaboration, and readiness for FCEV implementation in Indonesia.
The main contribution of this research is the preparation of the conceptual framework of AHP that integrates the various findings in the literature into a systematic hierarchical structure. The framework provides a conceptual basis for the preparation of pairwise comparison instruments in empirical research and can be an initial reference for governments and stakeholders in formulating strategies for the development of the hydrogen ecosystem and the adoption of FCEVs in Indonesia.

This study has limitations because it uses a literature synthesis approach without involving primary data through expert or stakeholder assessment. Therefore, the resulting priority order represents the results of conceptual synthesis based on the literature and has not produced quantitative weights as in the empirical application of AHP. In addition, the literature sources used are still limited to twelve scientific articles that meet the research criteria, so there may still be other factors that have not been identified.

Further research is recommended to validate this conceptual framework through the AHP method by involving experts from government elements, academia, industry, transportation operators, and hydrogen infrastructure providers. Research development can also be carried out by combining AHP with the Decision-Making Trial and Evaluation Laboratory (DEMATEL), Analytic Network Process (ANP), or Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods to analyze the relationship between criteria and determine policy priorities more comprehensively. In addition, an empirical study that considers regional characteristics, green hydrogen production potential, and infrastructure readiness in various regions in Indonesia is expected to produce more applicable policy recommendations and support the acceleration of the transition to a low-emission transportation syste

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