



Suitability Factors for Electric Vehicle Charging Stations using Analytic Hierarchy Process: A Case Study in Chonburi Thailand

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Abstract

This investigation employs the Analytical Hierarchy Process (AHP) to assess suitable locations for Electric Vehicle Charging Stations (EVCS) deployment in Chonburi province. The study rigorously evaluates three core dimensions—Physical, Environmental, and Economic and Social aspects—introducing nine sub-criteria for evaluation. Methodologically, comprehensive data collection via surveys and interviews engages energy management experts and key stakeholders in Chonburi province's development. Results underscore the predominant importance of Economic and Social aspects, constituting 60.8% of weighted significance using Geographic Information Systems (GIS) methodologies. Subsequently, the Physical aspect (25.7%) and Environmental aspect (13.5%) follow in significance. Factors like proximity to tourist destinations and population density align with Chonburi's pivotal tourism role. The study emphasizes the impact of local and non-local populations in determining EVCS placement for urban expansion. It establishes a foundation for similar methodologies in Thai urban areas. Future research leveraging these findings will aid decision-making for potential investors amid the projected surge in EV adoption, aligning with national economic and social objectives. The study's outcomes can serve as a model for other major Thai provinces.

Keywords: EVCS; Urban Planning; Analytic hierarchy process.

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1. Introduction

Presently, Thailand's policy endeavors to foster environmentally friendly renewable energy adoption in its transportation system, aligning with economic and social development initiatives. This incorporates the advancement of the energy sector, notably the electric vehicle (EV) innovation within the Next-generation Automotive industry—a prominent facet among the government's ten prioritized industries. The EV industry marks the initial phase of the automotive revolution, followed by autonomous vehicles in

the Eastern Economic Corridor; EEC special economic.^[1,2] Over a 20-year trajectory, divided into four phases, a comprehensive plan led by the EV infrastructure working group unfolds. Phase 1 (2016-2017) entails legal groundwork, permitting, and battery research, with the Bangkok Mass Transit Authority (BMTA) importing 20 electric buses for public transit by November, and 200 more planned for 2017. Concurrently, 5,000 tax-free electric vehicles are earmarked for market testing, accompanied by preparations for charging stations by the Department of Land Transport. Phase 2 (2018-2020) focuses on battery enhancement, EV proliferation, standardized charging fees, and private sector investment stimulation. Phase 3 (2021-2035) involves extensive research to boost personal EV adoption and manage electricity demand. The culmination, Phase 4 (2036 onward), anticipates complete EV integration, targeting 1.2 million EV by then.^[3]

This ambitious plan around 70,000 MW of electricity production, supported by 15-20% reserve capacity. To meet this demand, the (Electricity Generating Authority of Thailand; EGAT) envisions a *Smart Grid* to optimize electricity usage, curbing new power plant needs and accommodating EV trends. EGAT prioritizes research and development to advance EV

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technology.^[4-6]

EV offer a viable transportation option, with expanding technology trends driven by clean energy sources like solar, wind, and hydropower. However, limitations include energy density. Some EV still use internal combustion engines or hydrogen fuel cells for power. The type of EV to shown in Fig. 1.

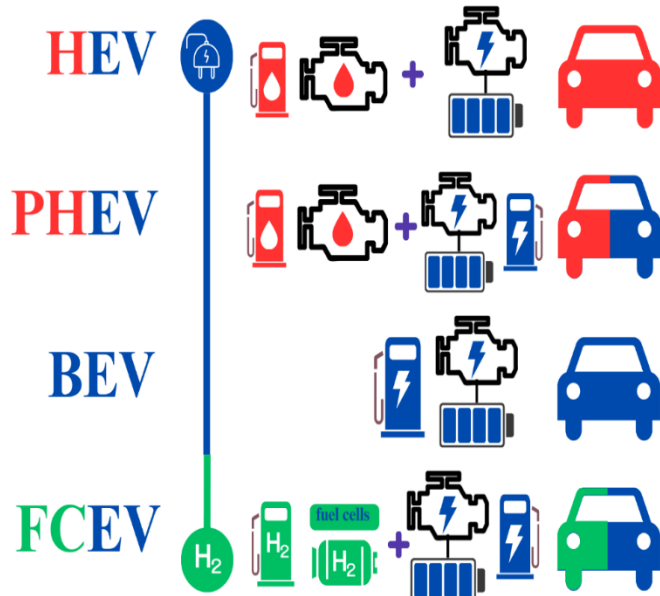


Fig. 1 Types of electric vehicles.

Governments globally support electric vehicles due to air pollution concerns, especially evident in China, where urgent measures were implemented. Incentives include tax reductions, subsidies, and free registration. China's EV adoption resulted in cleaner air and quieter streets. Europe emphasizes clean

energy sources, like wind, water, and solar, for charging, aiming to reduce Classification of EVCS Types:^[7-10] to shown in Table 1.

This research aims to utilize the analytical hierarchy process (AHP) to identify optimal sites fFor EVCS in Chonburi province. The assessment will encompass physical, environmental, and economic-social dimensions, aiding the selection of suitable locations. Data will be gathered from local experts, energy-related businesses, and relevant governmental, academic, and private entities. Employing the AHP,^[11,12] a multi-criteria decision-making methodology, the analysis intends to determine the most appropriate sites for EVCS deployment. This investigation emphasizes a comprehensive approach to assessing suitability factors for EVCS through the application of the AHP technique.^[13-19] The structure of this research to shown in Fig. 2.

In addition to studying factors to ascertain accurate research elements in all three stages as follows: Stage 1: Studied factors for analyzing suitable locations for installing electric vehicle charging stations.^[19,20] Stage 2: Applied a Geographic Information System to obtain spatial data and map visualization.^[21-24] Stage 3: Developed an online platform to present spatial data for government and private sector utilization in energy policy development.^[25]

Table 2 is linked to this study and delineates various methodologies and tools, notably the AHP, Fuzzy Technique for Order of Preference by Similarity to Ideal Solution Fuzzy TOPSIS, and GIS, utilized in the selection of sites for EVCS. The table underscores the incorporation of diverse criteria, encompassing factors like population density, proximity to essential services, and transportation hubs. The paper posits a systematic methodology intended to optimize efficiency and connectivity within the planning process for EVCS locations.

Table 1. The classification of EV charging station.

Classification	Description	Advantage	Disadvantage
Grid-connected EVCS.	Utilizes power grid electricity for charging services.	Efficiently uses electricity from the grid for vehicle charging.	Dependent on grid electricity availability and vulnerability to outages.
Hybrid grid-connected EVCS.	Integrates grid and off-grid power sources.	Utilizes both grid and off-grid power sources for flexibility.	Reliability depends on availability of off-grid power sources.
Grid-powered EVCS with energy Storage.	Incorporates energy storage systems alongside grid power. Similar to Type 2 but includes battery storage. Stored energy is used during low-cost electricity periods for efficient cost management.	Combines grid power and stored energy for cost-effective charging.	Requires additional investment for energy storage and maintenance.
Grid-Connected EVCS with Battery Energy Storage.	Involves a charging station linked to the grid and incorporating batteries. Stored energy supplements purchased electricity during cost-effective periods, managed by the charging station operator.	Uses stored battery energy during peak electricity costs.	Involves battery management and purchasing grid electricity.

Note: The selection of EVCS types should consider factors such as energy efficiency, service capability, and location requirements. Within the scope of this research undertaking, a thorough and exhaustive examination of relevant academic literature was conducted in the following manner.^[10]

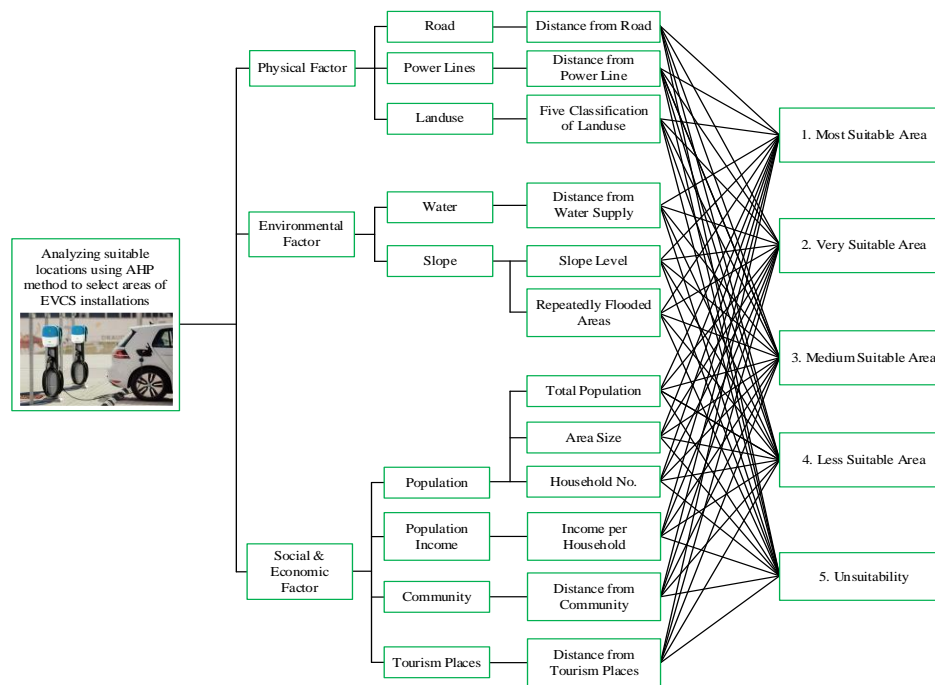


Fig. 2 The structure of suitability factors for EVCS with AHP in Chonburi, Thailand (Stage 1).

Table 2. Related works on the suitable factors of EV charger stations in various countries.

Country	Main Features	Ref.
UK	Utilizing AHP for EV charging station site selection, considering multiple criteria and station types. Involves data from experts, businesses, and government.	[26]
UAE	This paper proposes a systematic approach for EVCS location planning, addressing SCLP and MCLP, enhancing efficiency and connectivity.	[27]
Greece	This study recommends EVCS deployment with spatial model. It integrates AHP and GIS for decision support, addresses challenges, and considers factors like population density, proximity to services, transportation hubs, and parking facilities. The aim is to promote electric mobility, especially in areas with limited charging infrastructure. Limitations include data and stakeholder understanding. Future research should validate and use case studies.	[28,29]
India	Fuzzy methods rank 14 criteria based on customer needs, offering data flexibility and diverse rankings. TOPSIS results were mapped using Q-GIS for government consideration. Collaboration can enhance practicality. Future research should explore more criteria and accurate data.	[29,33,35]
China	T0 uses fuzzy TOPSIS for EVCS site selection with sustainability factors. Expert opinions set criteria weights. A2 in Beijing is the best. Fuzzy TOPSIS is effective and robust for EVCS site selection, offering practical insights.	[31,32]
Turkey	Integrates GIS and MCDM methods for electric vehicle charging station location selection. AHP and FAHP calculate criteria weights, and TOPSIS ranks alternative locations, offering a notable solution for policymakers.	[36,37]

It advocates for the deployment of EVCS employing spatial models to advance electric mobility, particularly in regions lacking adequate charging infrastructure. Moreover, it acknowledges and confronts challenges and limitations related to data availability and stakeholder comprehension. The research underscores the necessity for subsequent validation through case studies and advocates for the exploration of additional criteria to refine decision-making accuracy. Collaboration among various methodologies and tools is highlighted as a means to augment practicality, providing insights into sustainable site selections.

The rest of the paper is organized as follows. Section 2 describes the notable information of the study area. Section 3 proposes the methodology of the study. The obtained results are given in Section 4. Finally, Section 5 concludes the paper.

2. Case study explanation

Chonburi of Thailand, in eastern Thailand along the Gulf of Thailand coast, covers 2,772,785.25 acres (4,363.63 sq. km²), comprising 0.85% of Thailand's land. With 1,558,301 residents, Chonburi Municipality has the highest population, followed by Si Racha and Bang Lamung. Its varied geography

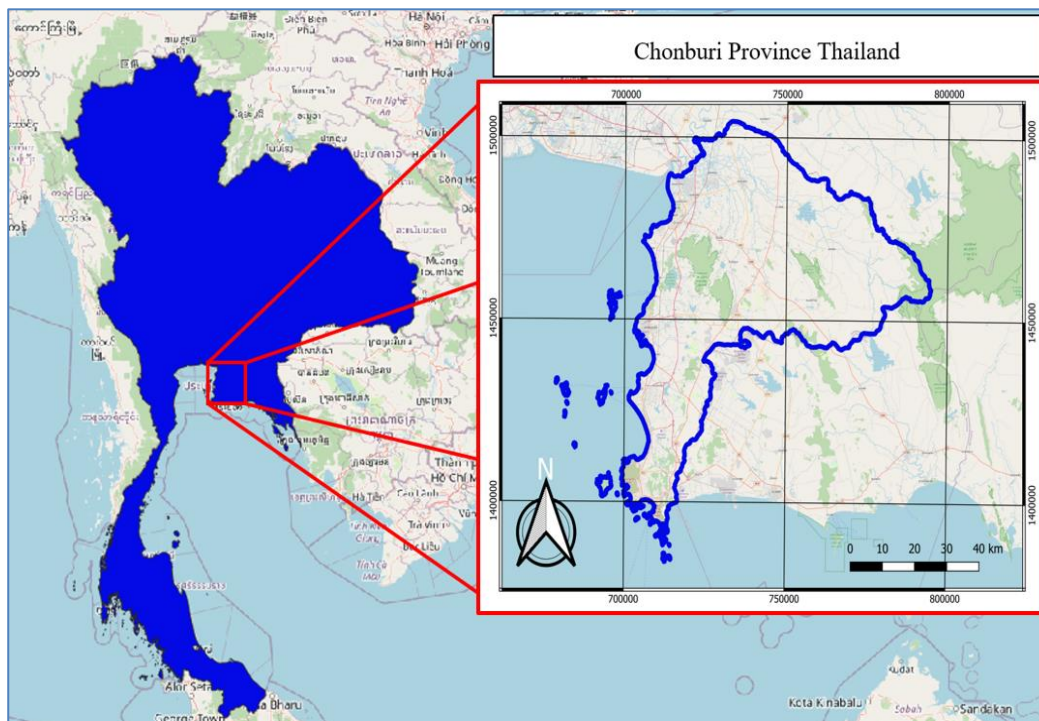


Fig. 3 The case study in Chonburi, Thailand.

includes coastlines, hills, and islands. A major industrial hub, it is known as the *Eastern Economic Corridor*. Chonburi is a popular tourist destination with attractions like Pattaya Beach. The region offers potential for growth through infrastructure investments like EV charging stations and urban expansion. The study area to shown in Fig. 3.

3. Methodology

In this section, sampling data and modeling related to our work are provided and intensively discussed.

3.1 Population and sampling

The study's population and sample encompass various stakeholders affiliated with the energy sector, including personnel from local oil companies, public sector professionals specializing in investment planning, area managers, and a selected group of 5 entrepreneurs drawn from 21 companies engaged in the electric vehicle charging station industry within Chonburi Province, Thailand. Furthermore, the area houses 10 government agencies. The sampling approach employed for this population was purposive sampling.^[33,34]

3.2 Analytic hierarchy process

The AHP serves as a decision analysis methodology employed to discern optimal alternatives. Initially devised by the authors, AHP functions as a tool assisting in intricate decision-making scenarios where quantifying decision options proves challenging.^[33] This approach involves deconstructing the problem's structure into hierarchical layers, starting with the Goal, followed by Criteria, Sub-criteria, and Alternatives. Subsequently, a series of pairwise comparisons among criteria

is conducted to aid in discerning their relative importance or preferences, thereby facilitating decision-making. Upon assigning scores to gauge the significance of criteria, the process extends to analyzing alternatives in pairwise comparisons across each criterion until comprehensive consideration of all criteria is achieved. Validating the consistency of importance scores or preferences allows for the prioritization of alternatives, ultimately leading to the determination of the most favorable choice.

AHP is a pairwise comparison analysis, making the selection of alternatives easier and more convenient. Currently, AHP is one of the methods for Multicriteria Decision-making that is widely preferred and used. Computer programs have been developed to facilitate the decision analysis process, making it more straightforward and convenient.

From studying theory and conducting research on factors influencing the Analysis of suitability factors for EVCS with AHP in Chonburi Province, Thailand, it is possible to summarize the factors and options used in the study, as shown in Fig. 3.^[30] The factors the analysis of suitability factors for EVCS with AHP in Chonburi province, Thailand are defined as 9 factors, compiled and analyzed from articles, research works, and ideas obtained from interviews with experts in energy management, development of infrastructure, and related fields, as shown in Table 3.^[36,37]

3.3 Designing the tool used for surveying data from experts and academics.

The research instrument employed is a questionnaire designed to ascertain the prioritization of factors impacting the sustainability assessment for EVCS suitability analysis in

Table 3. Factors and data source.

No.	Type main of Factor	Factor name Sub-criteria	Data Source
1	Physical	Landuse Data	Land Development Department of Thailand.
2	Physical	Transportation Data	Ministry of Transport Thailand.
3	Physical	Line Electric Power Data	Provincial Electricity Authority Head Office
4	Environment	Slop Data	Royal Irrigation Department
5	Environment	Water Data	Land Development Department of Thailand.
6	Social and Economic	Population Data	Statistical Office Chonburi Province of Thailand
7	Social and Economic	Income of population Data	Statistical Office Chonburi Province of Thailand
8	Social and Economic	Community Data	Land Development Department of Thailand.
9	Social and Economic	Tourism Place Data	Tourism and Sport Office Chonburi Province of Thailand

Chonburi province, Thailand. A pairwise comparison approach will be applied, wherein respondents assess the relative importance levels of these factors. The assessment will involve assigning numerical values to indicate the level of importance, as outlined in the preliminary ratio scale table. These assigned weights will be utilized for analyzing the suitability factors for EVCS, encompassing two sections:

Section 1: Basic Information

Section 2: Assessment of the significance weights of decision factors

The significance weightings of the key factors will be derived through pairwise comparisons, utilizing the weight values provided in Table 4. Consider by details in Table 3. And detail of sub-criteria weighted score in Table 9.

3.3.1 Survey response method

Each question in the questionnaire will begin with the question: 'How much more important do you consider factor *Physical Factors A* compared to *Environment Factors B*? In the process of comparing factors 1 and 2, if you find that factor 1 is much more important than factor 2, your response will be at 7 weight score (Factor 1 is much more important than Factor 2, rated at 7 weight score). For instance, in the question: Do you consider *Physical Factors A* to be much more important than *Environment Factors B*? as given by Table 5.

Table 4. Score for the importance of variable.

Importance scale	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another.
5	Strong importance	Experience and judgment strongly favor one element over another.
7	Very strong importance	One element is favored very strongly another, it domains of demonstrated.
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation.

Scales 2, 4, 6 and 8 can be to express intermediate values.

Table 5. Responding the much more important A more than B.

<i>i</i>	<i>J</i>	Factor name		More Important	Scale (1-9)
		A	B	A or B?	
1	2	Physical	Environment	<u>A</u> or B	<u>9</u>
1	3	Physical	Social and Economic	<u>A</u> or B	<u>7</u>
1	2	Physical	Social and Economic	<u>A</u> or B	<u>7</u>
2	3	Environment	Social and Economic	<u>A</u> or B	<u>7</u>

Table 6. Responding the much more important B more than A.

<i>i</i>	<i>J</i>	Factor name		More Important	Scale (1-9)
		A	B	A or B?	
1	2	Physical	Environment	A or <u>B</u>	<u>9</u>
1	3	Physical	Social and Economic	A or <u>B</u>	<u>7</u>
1	2	Physical	Social and Economic	A or <u>B</u>	<u>7</u>
2	3	Environment	Social and Economic	A or <u>B</u>	<u>7</u>

In the opposite direction, for the same question, if you believe that factor 2 *Environmental Factors (B)* is much more important than factor 1 *Physical Factors A* then your response will be 1/7. For example, in the question: 'Do you consider *Physical Factors A* to be much more important than *Environmental Factors B*? as seen in Table 6.

3.3.2 Numerical Synthesis from Questionnaire

a) Creating a pairwise comparison matrix involves comparing criteria used for decision-making in pairs, on an individual basis, based on the principle that the impact of one factor on another is to what extent. It is represented in matrix form, as shown in Table 7.

Table 7. Factors under the study.^[33]

Criteria or Factor	Factor 1	Factor 2	Factor n
Factor 1	1	a_{12}	a_{1n}
Factor 2	a_{21}	1	a_{2n}
Factor n	a_{n1}	a_{n2}	1

where a_{12} represents the importance ranking value of Factor 1

when compared to Factor 2 under the problem objective, and $1/a_{21}$ is the reciprocal portion. Under the decision-making criterion, Factor 1 is compared to Factors 2 through n in the horizontal row of Factor 1. The comparison is carried out similarly for Factor 2 in the second row.

b) Pairwise Criteria Comparison for Weight Determination. Pairwise comparison between criteria is performed to assign importance weight values. In this process, numerical values are assigned to quantify the comparative importance of each sub-criterion. The standard scale of importance levels ranging from 1 to 9 is suitable for rational reasoning and effectively capturing the relationships between criteria, as demonstrated in Table 8.

Table 8. Preference levels.^[33]

Preference level	Numerical value
Equally preferred	1
Equally to moderately preferred	2
Moderately Preferred	3
Moderately to strongly preferred	4
Strongly Preferred)	5
Strongly to very strongly preferred	6
Very strongly to extremely preferred	7
Very strongly to extremely preferred	8
Extremely preferred	9

3.3.3 Weighted factor analysis

Once the weight values have been determined by experts based on the diagnosed weight values, represented as numerical figures, the calculation of importance weight for each layer is performed. The analysis proceeds sequentially through each layer, from the top layer down to the bottom layer. The calculation method involves a step-by-step process of pairwise comparison within a matrix format. This involves comparing all criteria both horizontally and vertically. Subsequently, the Geometric Mean, which multiplies the desired numerical values together and then extracts the root according to the number of values, is calculated. This is represented by Equation (1),

$$V_i = \left(\prod_{j=1}^n a_{ij} \right)^{1/n}, \tag{1}$$

where a_{ij} is the numerical value in the matrix, V_i represents the geometric mean value and n denotes the values used to calculate the mean.

After obtaining numerical values from pairwise comparisons of factors, as shown in Table 4, the calculation of factor importance weights is performed. This is achieved by dividing the importance values within each vertical column by the sum of importance values within the same column. This yields a matrix of percentages. Subsequently, the average value within each horizontal row of the percentage matrix is calculated. This becomes the factor's importance weight for that row, as shown in Table 10.

The importance weight of criteria or alternatives in each layer can be derived from the data synthesis, and the

calculation is illustrated by Equation (2),

$$w_i = \frac{v_i}{\sum_{j=1}^n v_j}, \tag{2}$$

$$\sum_{i=1}^n w_i = 1.0, \tag{3}$$

where w_i is the weight of each criterion's score and v_i represents the average value.

3.3.4 The Consistency Index (C.I.) and The Consistency Ratio (C.R.) Assessments

The process of assessing consistency entails evaluating the alignment of scoring rationale across specified criteria. It encompasses multiplying the weights assigned to each criterion within a row by the sum of the averages within corresponding columns. This calculation yields the cumulative Eigenvalues (λ_{max}), when criteria consistency is complete, λ_{max} equals n as shown in Equation (4),

$$\lambda_{max} = \sum_{i=1}^n \left[\sum_{j=1}^n a_{ij} w_j \right]. \tag{4}$$

The C.I. is derived by multiplying factor weights by their row importance values and averaging them horizontally, generating a consistency assessment table (Equation 5). The C.R. is calculated by comparing the C.I. from the matrix with the Random Consistency Index (R.I.) as seen in Equation (5),

$$C.I. = \frac{(\lambda_{max} - n)}{(n-1)}. \tag{5}$$

Furthermore, the C.I. can be expressed by Equation (6) as,

$$C.I. = \frac{C.I.}{R.I.}, \tag{6}$$

where R.I. stands for the random consistency.

The random C.I. is an index value obtained from random sampling of the reciprocal matrix, which uses standard criteria for importance values ranging from 1 to 9. It calculates the average of the consistency index derived from experiments in each dimension of the matrix for $n = 5$ to 10, as shown in Table 11.

For the C.R. values equal to or below 0.10 are deemed acceptable; values exceeding 0.10 are unacceptable. We must reassess the weights assigned to criteria until an acceptable C.R. is achieved. Acceptable C.R. values should not exceed 10% when considering five or more factors, 9% for four factors, and 5% for three factors. Exceeding these standards signifies inconsistent reasoning, necessitating a reassessment by the evaluator to shown in Fig. 4.

4. Results and discussion

Through this study, the focus was on determining pivotal factors crucial for identifying optimal locations for the deployment of electric vehicle charging stations within Chonburi Province, Thailand—a coastal region prone to substantial rainfall and drainage challenges that impact its developmental prospects. The study's findings significantly correlate with the prevailing energy development policies of the nation. Furthermore, the prevalence of numerous tourist attractions in Chonburi renders it a suitable model for applying the identified factors to evaluate comparable major cities. These encompass the central (Bangkok Metropolitan), northern (Chiang Mai Province), northeastern (Khon Kaen

Table 9. Criteria and sub-criteria weighted score.

Criteria	Weighted value of sub-criteria	Weighted Score
C1: Distance from Road	<100 m	5
	100-250 m	4
	150-500 m	3
	500-750 m	2
	>750 m	1
C2: Distance from Line Electric Power	<5 m	5
	5-10 m	4
	10-15 m	3
	15-30 m	2
	>30 m	1
C3: Landuse (5 classifications)	U	5
	A	0
	F	0
	W	0
	M	0
C4: Distance from water and Slope	< 100 m	5
	100-250 m	4
	250-500 m	3
	500-750 m	2
	>750 m	1
C5: Population Totals (District)	> 300,000 persons	5
	200,000 – 100,000 persons	4
	50,000 – 100,000 persons	3
	20,000 – 50,000 persons	2
	< 20,000 persons	1
C6: Income of population per Household (District)	> 70,000 ₺/HH	5
	50,000 - 70,000 ₺/HH	4
	30,000 - 50,000 ₺/HH	3
	20,000 - 30,000 ₺/HH	2
	< 20,000 ₺/HH	1
C7: Distant from Community	< 500 m	5
	500-1500 m	4
	1500-3000 m	3
	3000-5000 m	2
	>5000 m	1
C8: Distant from Tourism Place	< 500 m	5
	500-1500 m	4
	1500-3000 m	3
	3000-5000 m	2
	>5000 m	1
(C9) Distant from Tourism Place	< 500 m	5
	500-1500 m	4
	1500-3000 m	3
	3000-5000 m	2
	>5000 m	1

Table 10. Factors under the study.^[33]

Criteria or Factor	Factor 1	Factor 2	Factor n
Factor 1	1	a ₁₂	a _{1n}
Factor 2	a ₂₁	1	a _{2n}
Factor n	a _{n1}	a _{n2}	1
Totals	X	Y	Z

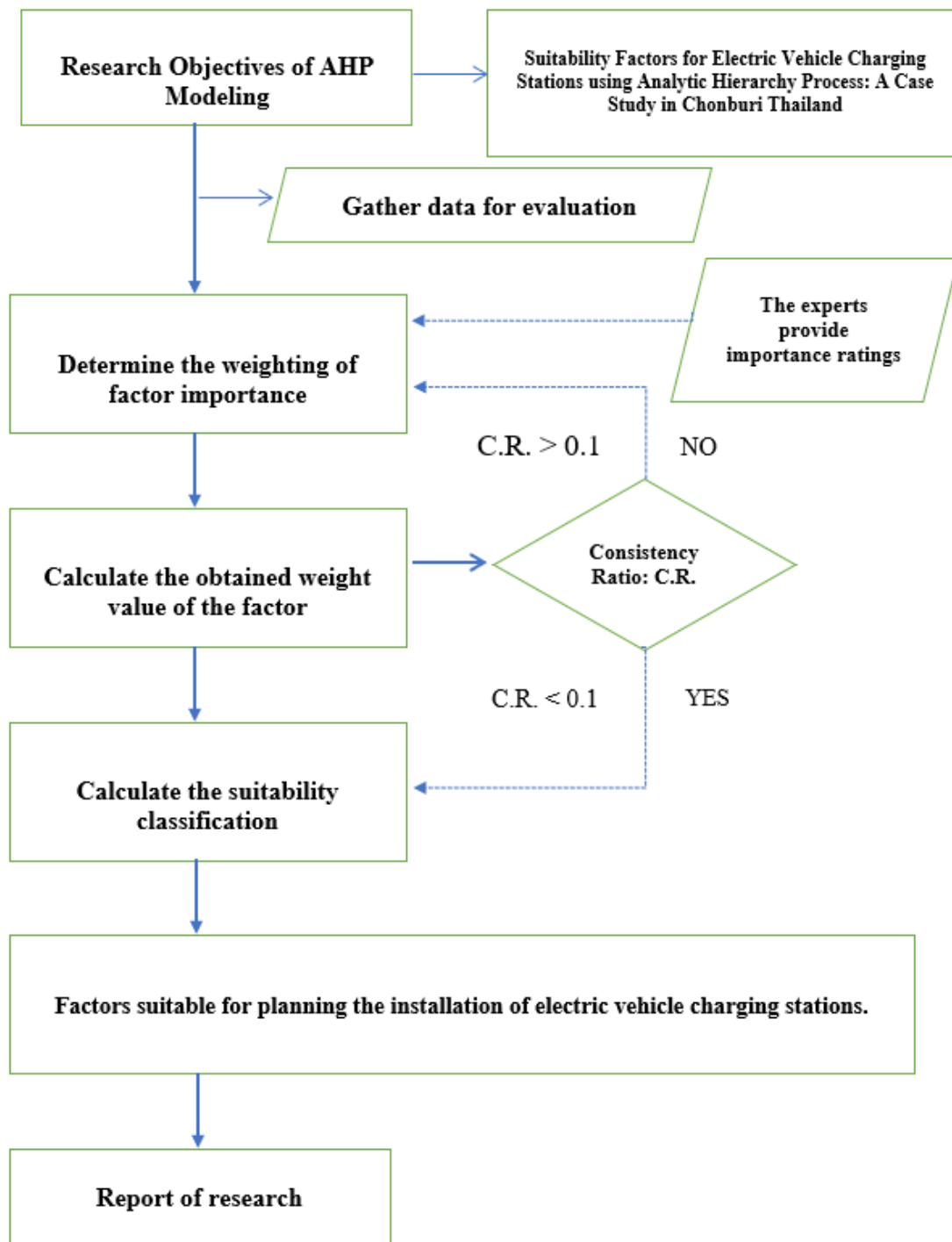


Fig. 4 Flowchart of the steps in considering factors.

Table 11. The R.I. value derived from randomly sampling.

N	1	2	3	4	5	6	7	8	9	10
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Province), and southern (Nakhon Si Thammarat Province and Phuket Province) regions. Leveraging congruence with geographical attributes, the installation scheme encompasses metropolitan zones, tourist destinations, rest areas, and community locales.

Conducted as a spatial analysis within the context of Chonburi Province, Thailand, this study employed AHP methodology to discern suitable locations for electric vehicle

charging station placement. The province's coastal nature, characterized by heavy rainfall and drainage challenges, posed distinct geographic intricacies. The research outcomes coincide with potential governmental policy considerations. The analysis encompassed three principal dimensions—Physical, Environmental, and Economic and Social factors—and nine subsidiary criteria: Transport routes, Powerline network, Land use classifications, Water, Slope, Population

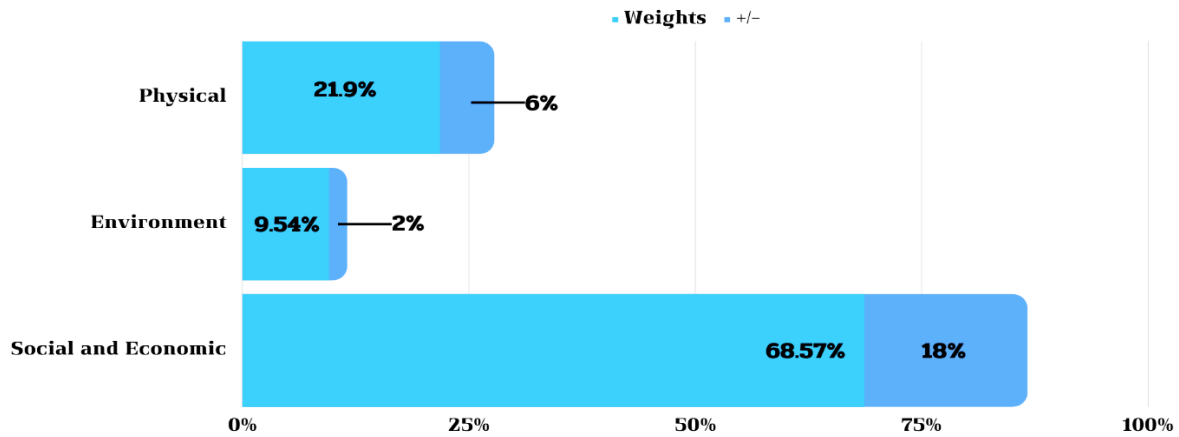


Fig. 5 The results of main weighted scores.

density, Income distribution, Community, and Tourism sites. Data were gathered through surveys and interviews involving experts in energy management and infrastructure development within Chonburi Province and related domains.

The results of the research indicated the importance ranking of factors for analyzing suitable areas, with Economic and Social factors (60.8%) being the most significant, followed by Physical factors (25.7%) and Environmental factors (13.5%). The weighted values of these factors were presented in a matrix (Fig. 5) in descending order of importance, showing factors such as proximity to tourist destinations (18.6%), transportation routes (15.7%), total income of the population in the area (13.3%), population density (12.2%), community resources (10.9%), water sources (10.3%), land use within 5 classifications (7.9%), proximity to powerline networks (7.4%), and slope categorization (3.7%), as seen in Fig. 6. These findings reflected the outcomes of this study and demonstrated the significance of the factors. The data presented in this study would be further utilized for spatial data analysis using Geographic Information Systems in the second stage of the study, supporting localized decision-making. This data analysis outcome would be instrumental in developing a platform for dissemination to investors. These

outcomes are subject to the limitations outlined in this stage of the study.

Table 12. Consolidated matrix main factors.

Matrix	Number of Factors	Physical	Environment	Social and Economic
Number of Factors		1	2	3
Physical	1		2.29	0.34
Environment	2	0.43		0.27
Social and Economic	3	2.92	3.67	

Table 12 illustrates significant relationships among data categories: physical data correlates with economic and social factors (0.34), environmental data links to physical data (0.43), and economic and social data associates strongly with environmental data (3.67). To summarize, Chonburi Province prioritizes economic and social data when expanding electric vehicle charging stations, ranking them highest, followed by physical area conditions and environmental data. This strategy supports urban growth and aligns with national charging station policy. Sub-criteria weightings are detailed in Table 13.

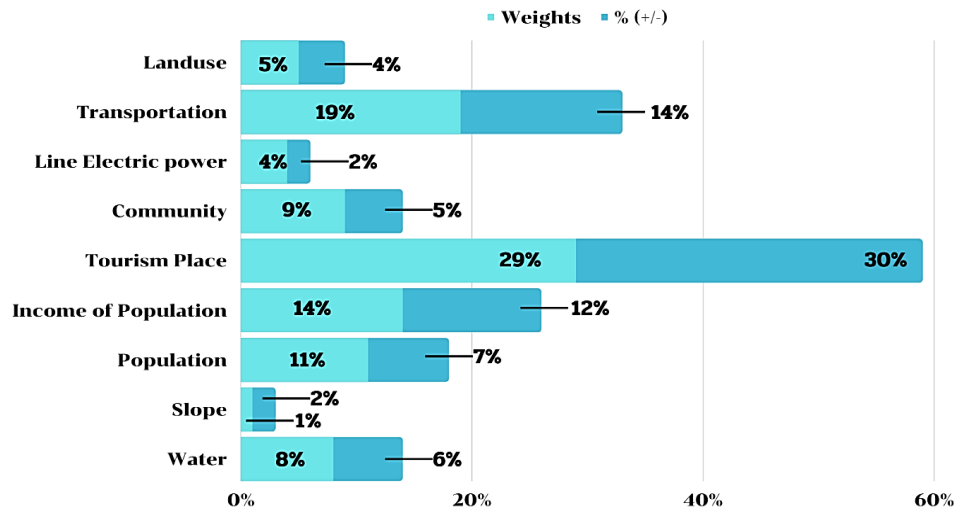


Fig. 6 Main factors based on several criteria.

Table 13. Consolidated matrix main factors sub-criteria.

Matrix	No. Sub-criteria	Landuse	Transportation	Line Electric power	Community	Tourism Place	Income of Population	Population	Slope	water
No. Sub-criteria		1	2	3	4	5	6	7	8	9
Landuse	1		0.98	0.98	0.46	0.19	0.47	0.64	3.54	3.54
Transportation	2	1.03		1.80	2.34	1.44	1.61	1.25	4.17	4.17
Line Electric Power	3	1.03	0.56		0.56	0.56	0.77	0.35	1.68	1.68
Community	4	2.17	0.43	1.79		0.60	0.72	0.97	4.06	4.06
Tourism Place	5	5.24	0.69	1.78	1.65		2.17	1.15	6.85	6.85
Income of Population	6	2.13	0.62	1.30	1.39	0.46		2.34	4.56	4.56
Population	7	1.56	0.80	2.89	1.03	0.87	0.43		4.36	4.36
Slope	8	0.28	0.24	0.60	0.25	0.15	0.22	0.23		8.68
water	9	0.62	1.78	1.39	4.56	1.80	1.68	0.43	0.62	

5. Conclusion

At present, Thailand hosts a variety of 21 brands and 28 primary models of EVs, with several companies contemplating setting up manufacturing facilities within the country. As of the current year, the registration count for BEV has surged to 36,796 units, a substantial increase from the preceding year's 7,249 units, signifying remarkable growth driven by governmental policies aimed at establishing Thailand as a regional hub for electric vehicle production.^[1] These initiatives foster engagement across sectors associated with the transitioning energy landscape. Notably, the EV charging station service emerges as a pivotal infrastructure in steering the country towards widespread electric vehicle adoption. Thailand's policy framework outlines the "Electric Vehicle Charging Station Development Plan," orchestrated by the Energy Policy and Planning Office and the National Electric Vehicle Policy Committee. Projections aim to install 2,200-4,400 public Fast Charge electric charging stations by 2025, expanding to 12,000 stations by 2030, strategically located across metropolitan areas, tourist destinations, rest stops, and community zones.^[2]

This study applies the AHP to assess factors influencing the selection of Electric Vehicle Charging Stations, aligning with Thailand's EV promotion in line with national socioeconomic policies prioritizing clean energy initiatives. The research presents a comprehensive analysis yielding valuable insights and recommendations:

- **Electric Vehicle Adoption Trends:** Empirical data demonstrates an upward trend in EV adoption in Thailand, aligning with national energy policies.
- **Government Initiatives Encouraging EV Usage:** Incentives like tax reductions and price discounts for electric vehicles have significantly increased EV registrations.
- **Impact on Infrastructure:** EV adoption policies have spurred infrastructure changes, fostering urban expansion and sustainable growth.

- **Chonburi as an Exemplar:** Chonburi serves as a successful example of EV integration, stimulating entrepreneurship and urban development.
- **Charging Station Strategy:** Utilizing AHP, this study strategically deploys charging stations, considering multifaceted factors.
- **Geospatial Mapping:** This research creates geospatial datasets for clean energy adoption and economic efficiency, categorizing areas for future applications.

Future research will focus on establishing a blueprint for supporting clean energy policies and urban expansion, potentially attracting investments and promoting entrepreneurship within Thailand.

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Conflict of Interest

There is no conflict of interest.

Supporting Information

Not applicable.

References

[1] Electronic Power Policy Office Thailand, Report on the Development Plan for the Electricity Infrastructure to Support Thailand's Electric Vehicle (EV) Initiative, 2023.
 [2] Electronic Power Policy Office Thailand, Thailand 20-Year Energy Efficiency Development Plan, 2023.
 [3] I. S. Bayram, S. Bayhan, Location analysis of electric vehicle charging stations for maximum capacity and coverage, *2020 IEEE 14th International Conference on Compatibility*,

- Power Electronics and Power Engineering (CPE-POWERENG)*, 2020, **1**, 409-414, doi: 10.1109/CPE-POWERENG48600.2020.9161639.
- [4] S. Paudyal, C. A. Cañizares, K. Bhattacharya, Optimal operation of industrial energy hubs in smart grids, *IEEE Transactions on Smart Grid*, 2015, **6**, 684-694, doi: 10.1109/TSG.2014.2373271.
- [5] P. Prakobkaew, S. Sirisumrannukul, Practical grid-based spatial estimation of number of electric vehicles and public chargers for country-level planning with utilization of GIS data, *Energies*, 2022, **15**, 3859, doi: 10.3390/en15113859.
- [6] Thailand: Making Transport More Energy Efficient, World Bank, 2023.
- [7] A. Allouhi, S. Rehman, Grid-connected hybrid renewable energy systems for supermarkets with electric vehicle charging platforms: Optimization and sensitivity analyses, *Energy Reports*, 2023, **9**, 3305-3318, doi: 10.1016/j.egy.2023.02.005.
- [8] M. Bilal, I. Alsaidan, M. Alaraj, F. M. Almasoudi, M. Rizwan, Techno-economic and environmental analysis of grid-connected electric vehicle charging station using AI-based algorithm, *Mathematics*, 2022, **10**, 924, doi: 10.3390/math10060924.
- [9] R. Verma, S. K. Sharma, P. Singh, J. K. Bhutto, A. R. A. Alharbi, Analysis and sizing of charging stations in kota city, *Sustainability*, 2022, **14**, 11759, doi: 10.3390/su141811759.
- [10] W. Qiu, Q. Hao, S. H. K. Annamareddy, B. B. Xu, Z. Guo, Q. Jiang, Electric vehicle revolution and implications: ion battery and energy, *Engineered Science*, 2022, **20**, 100-109, doi: 10.30919/es8d772.
- [11] J. Asamer, M. Reinthaler, M. Ruthmair, M. Straub, J. Puchinger, Optimizing charging station locations for urban taxi providers, *Transportation Research Part A: Policy and Practice*, 2016, **85**, 233-246, doi: 10.1016/j.tra.2016.01.014.
- [12] Y. Charabi, A. Gastli, PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation, *Renewable Energy*, 2011, **36**, 2554-2561, doi: 10.1016/j.renene.2010.10.037.
- [13] N. Andrenacci, R. Ragona, G. Valenti, A demand-side approach to the optimal deployment of electric vehicle charging stations in metropolitan areas, *Applied Energy*, 2016, **182**, 39-46, doi: 10.1016/j.apenergy.2016.07.137.
- [14] A. Awasthi, K. Venkitesamy, S. Padmanaban, R. Selvamuthukumar, F. Blaabjerg, A. K. Singh, Optimal planning of electric vehicle charging station at the distribution system using hybrid optimization algorithm, *Energy*, 2017, **133**, 70-78, doi: 10.1016/j.energy.2017.05.094.
- [15] D. A. Q. Badang, C. F. Sarip, A. P. Tahud, Geographic information system (GIS) and multicriteria decision making (MCDM) for optimal selection of hydropower location in rogongon, iligan city, 2018 IEEE 10th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management (HNICEM). Baguio City, Philippines. IEEE, 2018, 1-5, doi: 10.1109/HNICEM.2018.8666266.
- [16] M. Campaña, E. Inga, J. Cárdenas, Optimal sizing of electric vehicle charging stations considering urban traffic flow for smart cities, *Energies*, 2021, **14**, 4933, doi: 10.3390/en14164933.
- [17] S. Pradhan, D. Dipanjan, Shabbiruddin, Planning and design of optimal locations for electric vehicle charging stations: a case study, *IEEE Transactions on Sustainable Energy*, 2021, **14**, 418, doi: 10.1080/19397038.2020.1862347.
- [18] M. Bilal, I. Alsaidan, M. Alaraj, F. M. Almasoudi, M. Rizwan, Techno-economic and environmental analysis of grid-connected electric vehicle charging station using AI-based algorithm, *Mathematics*, 2022, **10**, 924, doi: 10.3390/math10060924.
- [19] J. Li, X. Sun, Q. Liu, W. Zheng, H. Liu, J. A. Stankovic, Planning electric vehicle charging stations based on user charging behavior, 2018 IEEE/ACM Third International Conference on Internet-of-Things Design and Implementation (IoTDI). Orlando, FL, USA. IEEE, 2018.
- [20] Ö. Kaya, A. Tortum, K. D. Alemdar, M. Y. Çodur, Site selection for EVCS in Istanbul by GIS and multi-criteria decision-making, *Transportation Research Part D: Transport and Environment*, 2020, **80**, 102271, doi: 10.1016/j.trd.2020.102271.
- [21] R. Garg, R. Kumar, S. Garg, MADM-based parametric selection and ranking of E-learning websites using fuzzy COPRAS, *IEEE Transactions on Education*, 2019, **62**, 11-18, doi: 10.1109/TE.2018.2814611.
- [22] H. Z. Al Garni, A. Awasthi, Solar PV power plant site selection using a GIS-AHP based approach with application in Saudi Arabia, *Applied Energy*, 2017, **206**, 1225-1240, doi: 10.1016/j.apenergy.2017.10.024.
- [23] D. Ghose, S. Naskar, Shabbiruddin, A. K. Roy, An open source software, *International Journal of Open Source Software and Processes*, 2019, **10**, 49-68, doi: 10.4018/ijjosp.2019010104.
- [24] H. Iravani, A multicriteria GIS-based decision-making approach for locating electric vehicle charging stations, *Transportation Engineering*, 2022, **9**, 100135, doi: 10.1016/j.treng.2022.100135.
- [25] A. J. Bokolo, Examining the adoption of sustainable eMobility-sharing in smart communities: diffusion of innovation theory perspective, *Smart Cities*, 2023, **6**, 2057-2080, doi: 10.3390/smartcities6040095.
- [26] J. Raposo, A. Rodrigues, C. Silva, T. Dentinho, A multicriteria decision aid methodology to design electric vehicles public charging networks, *AIP Advances*, 2015, **5**, 057123, doi: 10.1063/1.4921087.
- [27] N. Shahraki, H. Cai, M. Turkay, M. Xu, Optimal locations of electric public charging stations using real world vehicle travel patterns, *Transportation Research Part D: Transport and Environment*, 2015, **41**, 165-176, doi: 10.1016/j.trd.2015.09.011.
- [28] L. Anthopoulos, P. Kolovou, A multi-criteria decision process for EV charging stations' deployment: findings from Greece, *Energies*, 2021, **14**, 5441, doi: 10.3390/en14175441.

- [29] S. Guo, H. Zhao, Optimal site selection of electric vehicle charging station by using fuzzy TOPSIS based on sustainability perspective, *Applied Energy*, 2015, **158**, 390-402, doi: 10.1016/j.apenergy.2015.08.082.
- [30] L. A. Zadeh, Fuzzy sets, *Information and Control*, 1965, **8**, 338-353, doi: 10.1016/s0019-9958(65)90241-x.
- [31] H. Cai, X. Jia, A. S. F. Chiu, X. Hu, M. Xu, Siting public electric vehicle charging stations in Beijing using big-data informed travel patterns of the taxi fleet, *Transportation Research Part D: Transport and Environment*, 2014, **33**, 39-46, doi: 10.1016/j.trd.2014.09.003.
- [32] B. Ozorhon, A. Batmaz, S. Caglayan, Generating a framework to facilitate decision making in renewable energy investments, *Renewable and Sustainable Energy Reviews*, 2018, **95**, 217-226, doi: 10.1016/j.rser.2018.07.035.
- [33] S. Guo, H. Zhao, Optimal site selection of electric vehicle charging station by using fuzzy TOPSIS based on sustainability perspective, *Applied Energy*, 2015, **158**, 390-402, doi: 10.1016/j.apenergy.2015.08.082.
- [34] T. L. Saaty, How to make a decision: the analytic hierarchy process, *European Journal of Operational Research*, 1990, **48**, 9-26, doi: 10.1016/0377-2217(90)90057-i.
- [35] D. Guler, T. Yomralioglu, Suitable location selection for the electric vehicle fast charging station with AHP and fuzzy AHP methods using GIS, *Annals of GIS*, 2020, **26**, 169-189, doi: 10.1080/19475683.2020.1737226.
- [36] P. Hummler, C. Naumzik, S. Feuerriegel, Web Mining to Inform Locations of Charging Stations for Electric Vehicles Companion Proceedings of the Web Conference 2022. Virtual Event, Lyon France. ACM, 2022.
- [37] R. Wang, X. Li, C. Xu, F. Li, Study on location decision framework of electric vehicle battery swapping station: using a hybrid MCDM method, *Sustainable Cities and Society*, 2020, **61**, 102149, doi: 10.1016/j.scs.2020.102149.

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