Computers & Intelligent Decision Applications

Journal homepage: www.cidai-journal.org
eISSN: 3123-125X

Beyond Cost: An Interview-Based AHP Prioritisation of Barriers to Small Modular Reactor Deployment for ITS-Driven Data Centre Demand in Türkiye

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ARTICLE INFO

Article history:
Received 12 June 2026
Received in revised form 27 July 2026
Accepted 22 August 2026
Available online 26 August 2026

Keywords:
Small modular reactor; Intelligent transportation systems; Data centre; Analytic hierarchy process; Multi-criteria decision making; Energy infrastructure.

ABSTRACT

Rapid technological advances in the Internet of Things, machine learning and artificial intelligence have produced a marked expansion of Intelligent Transportation Systems, and with it, a growth in data-centre capacity and in the electricity these facilities consume. Although the significance of this demand is increasingly recognised, infrastructure options capable of meeting it—small modular reactors in particular—have not been assessed in the specific context of ITS-driven data-centre load. This study addresses that gap by evaluating the suitability of small modular reactors as an energy-infrastructure response, using a three-level Analytic Hierarchy Process model comprising one goal, four main criteria and twenty-two sub-criteria. The criterion set was derived from in-depth interviews rather than from a predefined checklist, and importance ratings were then collected from a purposively assembled panel of eight experts drawn from academia and from public- and private-sector institutions in transportation and ITS. Pairwise comparison matrices were constructed from the ratios of the resulting mean scores, priority weights were obtained using the eigenvector method, and every matrix was verified against the accepted consistency threshold. At the level of the main criteria, the legal dimension carried the highest weight, followed closely by the environmental dimension, with the financial dimension only third. In the global ranking, however, four of the five highest-ranked factors were environmental, led by carbon footprint reduction, while the seven legal sub-criteria were dispersed across the middle of the ranking. A sensitivity analysis confirmed that this ordering is stable. The findings indicate that adoption in this context is governed less by cost than by environmental legitimacy and the adequacy of the regulatory framework, and that, because the regulatory obstacle is structural rather than local, a comprehensive framework covering the SMR–data centre–ITS relationship is required in place of piecemeal amendment.

1. Introduction

In metropolitan and developing cities, emerging technologies are being leveraged to address issues of population density and infrastructure demands [1]. Following the striking results obtained

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in the initial applications, city administrations shifted their focus from large-scale, populist investments in infrastructure to Intelligent Transportation Systems, fiber, and R&D investments [2]. Thanks to these investments, they were able to use their budgets more effectively and utilize the infrastructure they established to address other problems in the city [3]. A comparable example may be seen in London, where the congestion-charging plan, which was implemented in 2003, reduced central-city congestion using technology-based traffic management and reinvested the proceeds in public transportation upgrades [4]. A similar application can be clearly seen in the Istanbul Transportation Master Plans carried out by the Istanbul Metropolitan Municipality between 2000 and 2010 [5].

The results of research studies that have been carried out specifically on urban areas indicate that an escalating demand for energy, which is a direct consequence of the technologies employed, is a matter of considerable concern. It has been determined that developing countries are especially vulnerable to the structural and economic challenges associated with meeting this energy demand [6]. Despite their capacity to undertake technological planning and infrastructure design at a level comparable to that of developed countries, these nations face significant challenges in achieving the desired energy production rates. The high expenses and protracted construction and commissioning periods associated with risky energy infrastructure [7] often prove to be insurmountable obstacles.

Countries have been compelled to reevaluate their current generation capacity and use a range of generation technologies due to the rise in energy consumption in metropolitan areas. Some have chosen to quickly increase their capacity for renewable energy [8], while others have looked to alternatives that can deliver a steady and consistent baseload [6]. Expert-based evaluations have revealed that the land space and power production constraints of renewable energy sources have influenced this decision, especially in developing nations, as shown by Deveci *et al.,* [9].

A salient discrepancy between developed and developing countries with regard to energy infrastructure pertains to the utilization of nuclear energy technologies. Energy production systems reliant upon fossil fuels cause considerable harm to ecosystems throughout their entire life cycle, and such systems are considered to be among the primary factors accelerating global climate change [10]. However, renewable energy sources, including solar, wind, hydroelectric, and advanced turbine and motor technologies, have not yet demonstrated the capacity to meet the entire energy demand at the national level in a continuous and uninterrupted manner. Energy demand is exhibiting exponential growth trends rather than following a linear trajectory, particularly attributable to the advancement of technology and the intensive utilization of information technology infrastructures, data centers, and smart city systems in urban areas [11]. This development signifies that systems reliant exclusively on renewable energy sources may prove to be inadequate in the long term.

In the given context, nuclear energy systems are regarded as a feasible and strategic solution to the escalating urban energy requirements due to their advantages, including low carbon emissions, high energy density, and continuous base load generation capacity [12]. Nuclear energy possesses the potential to bolster energy supply security, diminish external dependency, and facilitate sustainable growth that is consistent with climate goals, particularly for developing countries [13]. An examination of the production methods employed to meet energy supply in developed countries reveals a pronounced disparity in the number of nuclear reactors and the total energy generated by these reactors when compared to the rest of the world, as reported by Jenkins *et al.,* [14].

Renewable energy systems might prove inadequate to fulfill the anticipated incessant and large-scale energy generation requirements independently [15]. This situation enhances the attractiveness of nuclear energy, which exhibits reduced carbon emissions throughout its life cycle in comparison to fossil fuels [16]. As demonstrated by recent studies in the field, small modular reactors (SMRs) and advanced reactor designs offer distinct advantages over traditional nuclear power plants with respect to safety and environmental impact [17,18]. According to Hong *et al.,* [19], enhancing the safety and sustainability of the nuclear fuel cycle broadens the applicability of these technologies in data centers, industrial facilities, and large metropolitan areas.

A joint evaluation of contemporary transportation technologies, with a particular emphasis on autonomous vehicles that are facilitated by artificial intelligence and vehicle-to-everything (V2X) communication systems, reveals that the energy and digital infrastructure requirements of these technologies have escalated considerably beyond current investment levels [20]. As Creutzig *et al.,* [21] note, if the increasing demand cannot be met appropriately, countries risk losing their competitive advantage in the effective use of advanced transportation technologies and their energy production capacities.

1.1 The Energy–IT Dilemma in Intelligent Transportation Systems

While Intelligent Transportation Systems (ITS) were initially considered only as sensor networks that optimize traffic flow worldwide, current literature indicates that these systems are now defined as massive mobile data factories, because big data technologies play a critical role in real-time data production and analytics in ITS applications [22]. The proliferation of smart transportation systems, particularly in metropolitan areas, has led to significant reductions in traffic congestion, time loss, and operational inefficiencies [23-25]. Nevertheless, the capacity of IT infrastructure and the need to process large-scale data remain significant challenges, and energy efficiency and sustainable energy requirements are among the key obstacles to achieving ITS energy and environmental goals [26].

Data is transferred to centralized cloud systems for processing in traditional ITS design [27]. However, as autonomous vehicles and V2X communication proliferate, research has demonstrated that the current network bandwidth is inadequate to handle this data load. Studies that use edge computing rather than cloud-centric methods verify that workloads relying on the cloud experience latency and bandwidth problems that impair real-time application performance [27,28]. This restriction is crucial because traffic safety necessitates millisecond-level processing, which centralized data centers are unable to supply. In response, the literature has turned to the concept of edge data centers, which enable data to be processed at the source. A primary challenge confronted during the planning and construction of such facilities pertains to the difficulty faced by countries and companies in meeting the substantial demand with their prevailing energy production and transmission infrastructure; the energy generation is inadequate to meet the requirements of new technology facilities [23,24].

1.2 Small Modular Reactors

According to the International Atomic Energy Agency [29], small modular reactors are nuclear fission reactors that can produce up to 300 MWe per unit, or about one-third of a conventional reactor's capability. Rather than being exclusive to a single design, the name covers a variety of cooling technologies; reduced scale is treated as a conscious engineering decision, which unites these technologies. Three implications follow. A large percentage of the assembly process is transferred from the building site to a manufacturing line when components are produced as standardized modules in a factory and then assembled on site [17]. Instead of committing capacity all at once, it might be commissioned gradually as demand arises, as shown in the study of Locatelli *et al.,* [18]. Additionally, a smaller core produces less decay heat after shutdown, allowing for a greater dependence on passive safety systems and, in some designs, a smaller emergency planning zone that would enable siting nearer to metropolitan load centers [13].

These benefits are contingent. Since economies of scale are less beneficial for a smaller unit, it is expected that the capital cost per kilowatt will be higher than that of a large reactor; the economic justification is instead predicated on serial production producing learning effects strong enough to counteract the scale penalty [18]. In most jurisdictions, module certification and serial licensing remain unresolved because current licensing frameworks also require site-built construction and a plant-by-plant procedure [13]. However, there is a significant operational association with the demand profile described above: continuous supply, lifecycle emissions like those of renewable energy [16], and the ability to follow load [14].

The integration of this technology with data-center load is justified by the compatibility of its features with the needs of such facilities. Without reinforcement, which necessitates a substantial time commitment, urban distribution networks often show an incapacity to handle the additional strain imposed by intelligent transportation systems and electric vehicle charging. This restriction is circumvented by generation located at the facility. Another reason incremental deployment is crucial is that data center capacity is commissioned in phases. Proximity is the third factor, since edge architectures draw processing capacity towards the metropolitan area they serve, and therefore towards residential development. In such cases, the reduced emergency planning zone is of particular significance, and the technical case is most dependent on regulatory acceptance as opposed to engineering performance alone [18].

1.3 The Turkish Context

The central focus of the literature on modern ITS in Türkiye is the National Intelligent Transportation Systems Strategy Document and Action Plan, for which preparatory work was completed in 2019 and which entered into force in 2020 [30,31]. This document provides three key reference points. First, it adopts an integrated system approach that moves away from a fragmented structure toward centralized data, establishing the need for high-capacity regional data centers capable of managing large volumes of traffic data as a legal requirement [30]. Second, its emphasis on energy and the environment requires that ITS components contribute to energy efficiency and minimize carbon emissions [30,32,33]. Finally, the emphasis on digital infrastructure security indirectly reinforces the need for the physical locations where data is processed to be powered by a reliable and uninterrupted energy source [32].

Türkiye's 2053 net-zero emissions target has taken the relationship between ITS and energy to a new level. On the one hand, the widespread adoption of ITS infrastructure such as smart intersections, sensor networks, and V2X, combined with electric vehicles, will place a significant load on the urban power grid [11,32]. On the other hand, within the scope of the national nuclear energy strategy, small modular reactors are proposed not only for electricity generation but also to meet the baseload needs of data-intensive strategic facilities such as data centers [18,29]. In parallel, the requirement to keep strategic transportation data within the country's borders highlights the need for low-cost and sustainable data centers [34,35], and there has been an acceleration in the literature regarding SMR-supported data center site selection and cyber-physical security protocols tailored to the geographic and demographic structure of the country [36].

1.4 Research Gap and Objective

The integration of ITS, edge data centers, and small modular reactors is a socio-technical issue that brings together the disciplines of information technology, energy, and urban planning. For this reason, such topics are examined in the literature not only through engineering calculations but also through hybrid methods that translate expert opinions into analytical models. One of the most frequently cited methods for weighting complex criteria is the Analytic Hierarchy Process (AHP), which is widely used to compare SMRs with alternative energy sources and to support data center site selection, as in Shrestha *et al.,* [37] and Ayyildiz *et al.,* [38]. This method is preferred for such problems because it converts conflicting criteria — such as initial investment cost, cybersecurity, carbon emissions, and the need for uninterrupted base load — into objective numerical weights through expert pairwise comparisons. Studies that rely solely on numerical cost analysis or traffic simulation fall short in addressing the strategic and legal dimensions of the issue [39].

Various infrastructure solutions, especially small modular reactors, have not been thoroughly assessed in the context of ITS-driven data-center demand, despite the rising recognition of the importance of the increasing energy demand from these systems. A comparable framework has been used in Türkiye to locate compact modular reactors [38,40]; the present study, however, focuses on the electricity consumption produced by data centers and smart transportation systems rather than on the site selection problem. This study therefore aims to rank the variables that affect the appropriateness of small modular reactors as an energy infrastructure solution for the power demand produced by ITS and the data centers that go along with them. The assessment is carried out using four primary criteria that address the environmental, financial, legal, and managerial aspects of the technology, together with twenty-two related sub-criteria, evaluated by a panel of eight experts from the public and private sectors as well as academia within a three-level AHP model.

2. Methodology

In this study, the relative significance of the factors relevant to the adoption of small modular reactors as an energy-infrastructure response to the electricity demand of ITS-driven data centers was assessed using the Analytic Hierarchy Process of Saaty [41]. AHP is a popular multi-criteria decision-making technique that uses pairwise comparisons to establish priorities after breaking down a decision problem into a hierarchical structure. One aim, four primary criteria, and a total of twenty-two sub-criteria connected to these primary criteria comprised the three-level hierarchy in which the evaluation was carried out.

A two-stage design was used. The parameters that are critical in the field cannot be obtained from available data, since the legislation governing the integration of small modular reactors into urban data centers is still being developed. As a result, expert interviews yielded four primary criteria and twenty-two sub-criteria. At this point, the hierarchy was expanded to include difficulties that quantitative modeling is unable to identify, such as fragmented legislation, cybersecurity, and administrative bottlenecks. In the second phase, the consistency ratio determines whether the assessments are internally consistent, and the AHP uses pairwise comparisons to translate these evaluations into numerical priorities [40]. The AHP establishes the weight given to each factor, whereas the interviews decide which factors should be weighed.

2.1 Construction of the Decision Hierarchy

The Analytic Hierarchy Process was used in seven steps in this study. The suitability of small modular reactors for satisfying the energy requirements of data centers powered by intelligent transportation systems was identified as the decision problem. A three-level hierarchy comprising one objective, four primary criteria, and twenty-two sub-criteria was then established. A panel of eight experts provided importance ratings on a scale of 1 to 9, and the ratios of the mean of these judgments were used to generate pairwise comparison matrices. The matrices were used to determine local and global priority weights, and each matrix was evaluated for consistency. It was intended to send matrices that exceeded the threshold to the panel for reevaluation, but because none of the matrices did, this was not required. Finally, a sensitivity analysis was performed on the resulting priorities. Figure 1 provides a summary of these procedures.

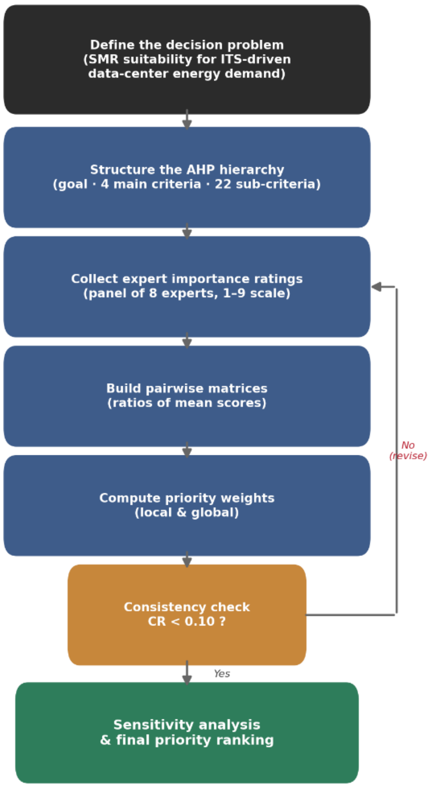

Fig. 1. Flowchart of the AHP methodology

Figure 2 shows the problem's decision hierarchy. The objective is at the top of the hierarchy; the four primary criteria — environmental (MC1), financial (MC2), legal (MC3), and managerial (MC4) — are at the second level; and the twenty-two sub-criteria (C1–C22) that are connected to these primary criteria are at the bottom level.

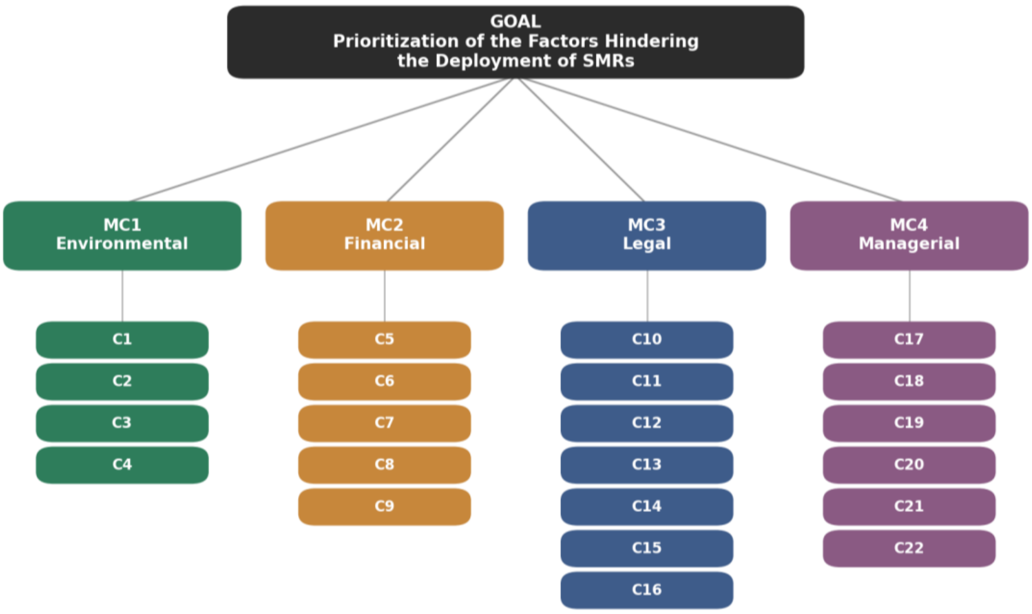

Fig. 2. The AHP decision hierarchy

2.2 Pairwise Comparisons and the Evaluation Scale

The relative importance of the elements within each cluster was quantified using the fundamental 1–9 scale of Saaty [41], given in Table 1. Rather than eliciting direct pairwise judgments, each element was rated for importance on this scale; the entries of the pairwise comparison matrices were then obtained as the ratios of the resulting mean scores.

Table 1
Fundamental 1–9 comparison scale

Intensity of importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values

2.3 Data Collection and Expert Evaluation

The data for these ratings were collected through a structured expert-judgment survey supported by in-depth interviews, both organized around the decision hierarchy established above. Since the decision problem addresses SMR deployment specifically as an energy-infrastructure response to the growing electricity demand generated by ITS and their associated data-center loads, the expert panel was composed of specialists in transportation and ITS, whose domain covers the origin of this demand chain. The panel consisted of eight experts, drawn in approximately equal proportions from academia and from public- and private-sector institutions, and was assembled through purposive sampling, as the AHP method requires domain expertise rather than a statistically representative sample.

Meetings with the Strategy Directorate and the ministry leadership at the Ministry of Transport and Infrastructure were especially informative, and additional discussions were conducted with the chief executive and founder of the company that operates the largest highway ITS infrastructure in Türkiye. Information was then obtained through online surveys and consultation with the academic community, which has a major influence on national initiatives. The responses obtained from these engagements were analyzed through cross-comparison to identify differences in perspective among the experts, and the two groups of respondents were found to complement and validate one another. The primary criteria for selecting the experts were a strong background in transportation and ITS together with active involvement in major projects; for the academic participants, the decisive characteristic was that they were current with, and at the global forefront of, their respective fields.

The survey was structured around the twenty-two sub-criteria organized under the four main criteria. The experts first evaluated the four main criteria and then assessed the sub-criteria within each cluster, with the hierarchy linking the two levels so that the relative importance of the main criteria is propagated to the sub-criteria. Each expert assigned an importance score to every criterion; the mean score of each criterion was then computed, and the pairwise comparison values populating the AHP matrices were derived as the ratios of these mean scores.

2.4 Derivation of the Priority Weights and Consistency Analysis

The eigenvector method based on column normalization was used to determine the priority weights for each pairwise comparison matrix [41]. The matrix was first normalized by dividing each column by its own total. The weight of each element was then determined by taking the arithmetic mean of each row. The weight vector for a matrix with n elements is given in Eq. (1).

$$W_i = (1 / n) \cdot \Sigma_j (a_{ij} / \Sigma_k a_{kj}) \quad (1)$$

The final global weights of the sub-criteria were then obtained by multiplying the local weight of each sub-criterion within its cluster by the weight of the main criterion to which it belongs, as given in Eq. (2).

$$\text{Global Weight}_i = \text{Local Weight}_i \times \text{Main Criterion Weight}_i \quad (2)$$

By calculating the consistency ratio for each matrix, the internal consistency of the pairwise comparisons was examined [41]. This was accomplished by first calculating the greatest eigenvalue of the matrix, then using the random index to determine the consistency index and consistency ratio given in Eq. (3) and Eq. (4).

$$CI = (\lambda max - n) / (n - 1) \quad (3)$$

$$CR = CI / RI \quad (4)$$

According to the threshold accepted in the literature, a CR value below 0.10 is sufficient for the corresponding matrix to be considered consistent. All pairwise comparison matrices constructed in this study satisfied this criterion.

3. Results

The results of the Analytic Hierarchy Process study are shown in four phases in this section. The intra-cluster local weights of the sub-criteria inside each cluster are given after the weights of the four primary criteria. The global weights and overall ranking of the twenty-two factors are obtained by combining these two values. The section continues with a sensitivity analysis that examines how much the ranking is dependent on the weight given to the prevailing major criterion. Every pairwise comparison matrix's consistency index was computed, and it stayed below the 0.10 cutoff at the main criteria level as well as in every sub-criterion cluster.

3.1 Weights of the Main Criteria

Table 2 lists the primary criteria's priority weights together with the corresponding consistency ratio; Figure 3 displays the weights' graphical distribution. The results show that the legal dimension (0.296) is the primary criterion with the highest weight, followed by the environmental (0.284), financial (0.222), and managerial (0.198) dimensions, in that order. The main-criteria matrix's consistency ratio stayed below the 0.10 cutoff.

Table 2
Weights of the main criteria (CR of the main-criteria matrix = 0.000 < 0.10)

Main criterion	Weight (W)
MC3 Legal	0.296
MC1 Environmental	0.284
MC2 Financial	0.222
MC4 Managerial	0.198

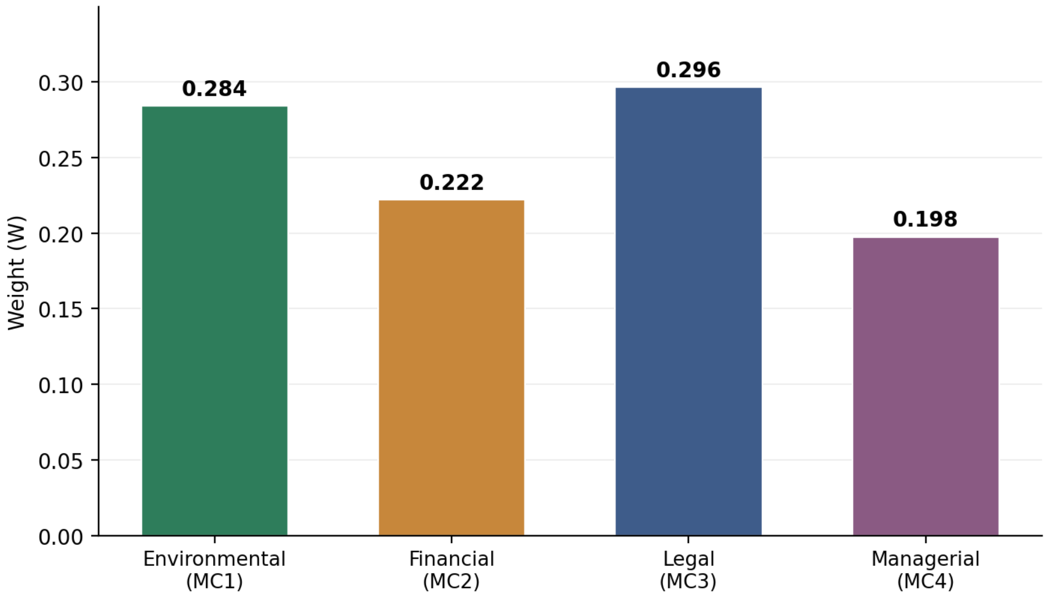

Fig. 3. Priority weights of the main criteria

3.2 Local Weights of the Sub-Criteria

The local within-cluster weights of the sub-criteria under the four main criteria are presented in Table 3. The consistency ratio remained below the 0.10 threshold in all clusters, confirming the internal consistency of the comparisons.

Table 3
Local weights of the sub-criteria within each cluster

Cluster	Sub-criterion	Local weight
MC1 Environmental	C4 Carbon footprint reduction	0.309
	C2 Energy production pollution	0.270
	C1 Raw material production pollution	0.235
	C3 Raw material transportation pollution	0.186
MC2 Financial	C6 New technology cost	0.253
	C7 Government purchase guarantees	0.227
	C8 Financial institutions' interest	0.224
	C5 Know-how cost	0.170
	C9 Raw material price instability	0.126
MC3 Legal	C11 Lack of communication	0.168
	C13 Safety and security concerns	0.158
	C12 Corruption	0.147
	C10 Outdated legislation	0.142
	C14 Slow legislative process	0.142
MC4 Managerial	C17 Know-how investments	0.194
	C22 Lack of scientific/advisory board	0.176
	C19 Specialized fields	0.167
	C20 Slow implementation	0.161
	C18 Pilot region teams	0.152

3.3 Global Weights and Overall Ranking

Figure 4 displays the overall ranking produced by multiplying the local weights of the sub-criteria by the weights of their parent main criteria. The results show that the environmental dimension's three most significant aspects are carbon footprint reduction (C4; 0.088), energy production pollution (C2; 0.077), and raw material production pollution (C1; 0.067). Notably, the legal dimension's sub-criteria rank in the middle of the overall list, despite the legal dimension having the most weight at the main-criterion level. This is because the environmental dimension only has four sub-criteria, which causes the relevant elements to concentrate at the top of the ranking, whereas the legal dimension has seven sub-criteria, which lowers the local weight of each particular sub-criterion. Raw material price volatility is ranked as the least important factor (C9; 0.028).

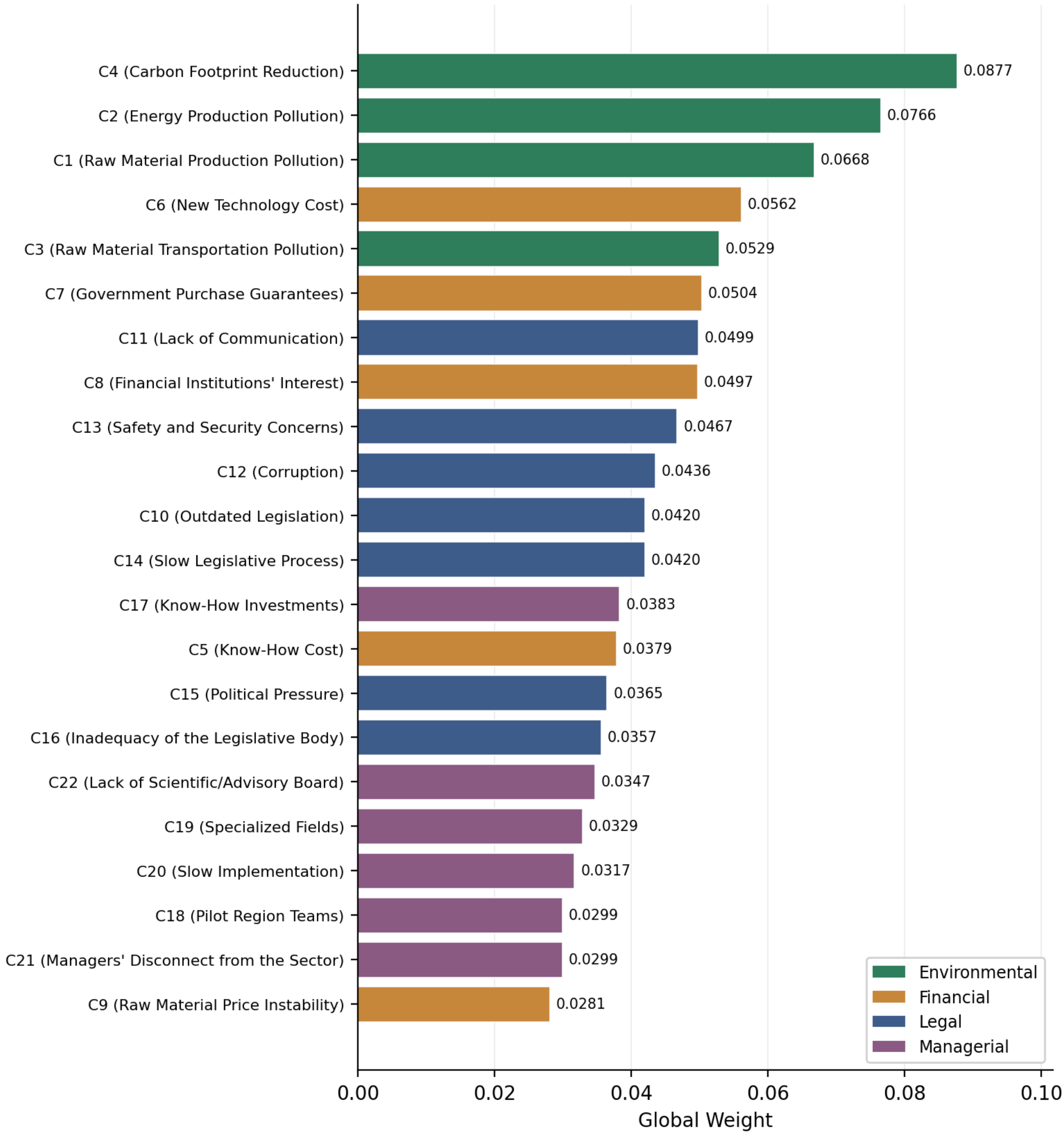

Fig. 4. Ranking of the sub-criteria by global weight

3.4 Sensitivity Analysis

The stability of the final ranking was tested using a sensitivity analysis. The environmental main criterion, to which the top-ranked factors belong, had its weight varied between 0.5 and 1.5 times its baseline value within this scope. The global weights of the top five factors were tracked, and the remaining main-criterion weights were renormalized proportionately in each scenario (Figure 5). The findings demonstrate that, despite significant fluctuations in the environmental dimension's weight, the relative positions of the leading variables are essentially maintained, demonstrating the stability and dependability of the resulting prioritization.

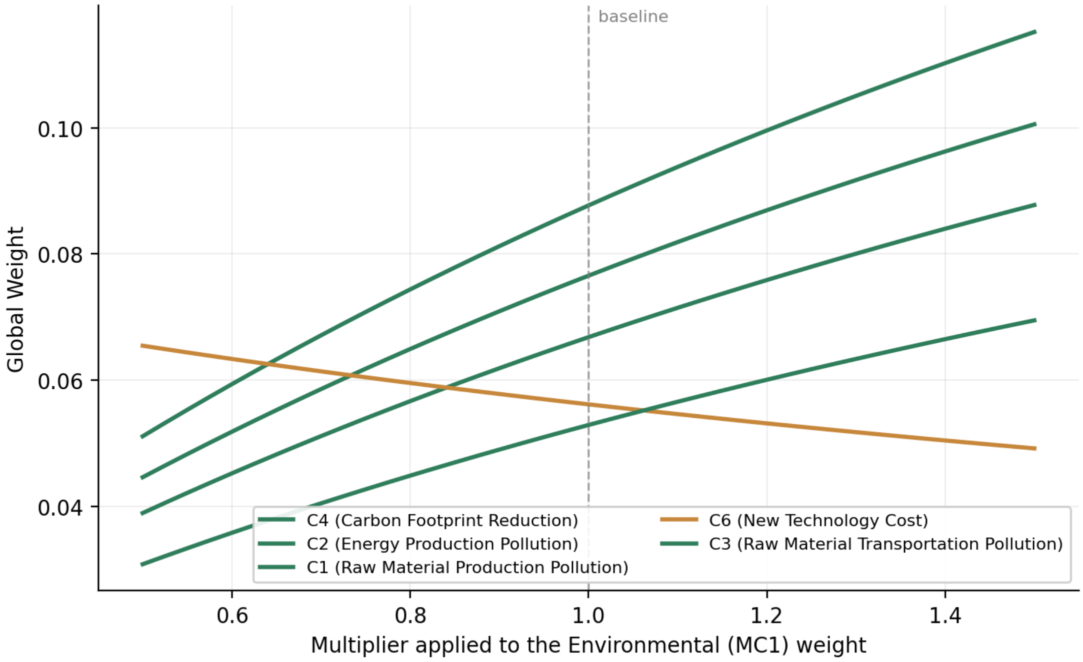

Fig. 5. Sensitivity of the global weights of the top five factors with respect to the environmental main-criterion weight

3.5 Discussion

Environmental factors were the main concern about the energy requirements of the ITS platforms examined in this study, based on the research and interviews conducted as well as the opinions of experts. While technological developments during the last 15 to 20 years have given humanity new opportunities, they have also created some direct or indirect problems for the planet [21]. According to this viewpoint, the experts' opinions have been heavily influenced by environmental variables and the obvious effects of the climate crisis [10]. The issues addressed in the survey — carbon footprint reduction, energy production pollution, and raw material production pollution — have become the primary focus for decision-makers regarding SMR.

Some of the most valuable information in this study came from the questions about the legal aspects. Even while the survey findings indicate that legal criteria appear to be relevant, especially at the main criterion level, this impact is not shown in the distribution of the sub-criteria. These findings demonstrate that while legal criteria seem important when considered together, none of them are dominant when considered separately. The analytic hierarchy technique is especially well-suited to uncover this structural pattern [39]. Therefore, even if legal requirements are addressed and resolved independently, they will not yield definitive results. A comprehensive legal framework for the SMR–data center–ITS connection would be more effective. The same structural pattern is expected in nations with nuclear regulations that were created without taking into account small modular reactors [13], where rapid urbanisation is driving investment in intelligent transportation systems [32], and where data centre capacity is still expanding [11].

The possible environmental damage that nuclear energy may create is another concern. Even while renewable energy plants have relatively little negative environmental impact [16], the amount of energy they generate is still much below what is needed for national infrastructure [8,15]. While these concepts offer attractive alternatives for countries in terms of energy production, they are less efficient than nuclear power plants [14,19]. The situation of the economy and the challenge of overcoming it are the main barriers to SMR technology, as mentioned in the literature [18]. According to the conversations held for this study, however, experts studying intelligent transportation systems in Türkiye are primarily concerned with the legal framework and environmental validity. This viewpoint is crucial because it emphasizes how important environmental legitimacy and the legal framework will be during the operational and implementation phases, even though the investment economy has a substantial impact on the decision-making process.

SMR–data center projects stand out as a means of expanding and ensuring the sustainability of the ITS infrastructure employed in urban infrastructure management and coordination [32]. Among the most important concerns raised by professionals about these projects are environmental reporting and carbon justification. However, these technological initiatives face substantial obstacles due to fragmented legal restrictions. Establishing a thorough regulatory framework is essential in this situation to guarantee that environmental reporting for these projects is carried out in compliance with established protocols and to remove these disjointed legal obstacles. It becomes clear that these two problems need to be handled together when looking at the National ITS Strategy Document [30] in conjunction with the environmental objectives of the country.

4. Conclusions

The purpose of this study is to assess small modular reactors as a possible energy infrastructure option to fulfill the growing power demand brought on by the rapid development of Intelligent Transportation Systems and the data centers that go along with them. In order to do this, a three-level Analytic Hierarchy Process model comprising one aim, four primary criteria, and twenty-two sub-criteria was used to outline the aspects determining the applicability of SMRs in this particular context. The relative significance of these elements was then ascertained using importance evaluations gathered from a specially constructed panel of eight professionals chosen from the public and private sectors in the domains of ITS, academia, and transportation.

Reducing the carbon footprint, pollution from energy production, and pollution from raw material manufacturing emerged as the three most influential aspects, according to the analysis, which showed that environmental criteria generally carried the largest weight among the four dimensions analyzed. The legal dimension was given the highest weight at the primary criterion level, but its sub-criteria were dispersed across the middle of the total ranking rather than taking center stage. This implies that whereas legal obstacles are significant when taken as a whole, they are viewed as dispersed when taken separately. When taken together, these results show that environmental legitimacy and the creation of a thorough legal framework are just as important as economic factors when it comes to the adoption of SMRs in the context of ITS–data centers.

The primary contribution of this study is that it offers one of the first systematic evaluations of the connection between ITS, data centers, and SMR in the Turkish context and uses the AHP technique to organize expert viewpoints into a list of priorities. These findings suggest that environmental reporting and carbon justification should be the primary methods used by decision-makers and policymakers to approach SMR–data center projects, and that a single, comprehensive regulatory framework, rather than piecemeal changes, should be used to address the various legal obstacles associated with these projects.

There are a number of limitations that should be noted. First, the panel was relatively small and concentrated in the transportation and ITS domain, so the perspective of nuclear-engineering specialists was only indirectly represented, even though eight experts make up an adequate panel for the analytic hierarchy process, which depends on the depth of domain expertise rather than on a statistically representative sample. Second, the resulting matrices are nearly perfectly consistent by construction because the pairwise comparison values were derived as the ratios of the experts' mean importance scores rather than from direct pairwise judgments; therefore, the extremely low consistency ratios reported here should be interpreted as a mathematical feature of this aggregation approach rather than as proof of exceptionally high agreement among the experts [40]. Third, the findings reflect the specific institutional and regulatory context of Türkiye, which limits their direct generalizability. Future research could address these limitations by employing a larger and more multidisciplinary expert panel, by comparing alternative judgment-elicitation and aggregation techniques, and by extending the sensitivity analysis to a wider range of scenarios.

Funding
This research received no external funding.

Declaration of Prior Dissemination
This article is derived from the M.S. thesis of the first author, entitled “Evaluation of Small Modular Reactors as an Energy Infrastructure Response to the Electricity Demand of Intelligent Transportation Systems and Data Centers”, submitted to the Institute for Graduate Studies in Science and Engineering, Boğaziçi University, in 2026 under the supervision of the second author. The thesis is publicly accessible through the Turkish Council of Higher Education (YÖK) National Thesis Centre. The present article reports the same study in condensed form and has not been published elsewhere, nor is it under consideration by another journal.

Conflicts of Interest
The authors declare no conflict of interest.

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