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Selection of optimum renewable energy sources under smart city environment for energy management and planning: An eclectic decision

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ABSTRACT

The purpose of this paper is to present a decision support framework, able to assess and optimize the energy use in smart cities. This paper has taken a sincere endeavour to develop an innovative integrated analytical framework as a benchmark to understand to what extent the energy has been consumed in smart city spectrum. Initially five sectors (construction, water management, transport, waste treatment and public services) of smart city and their corresponding sub-factors are identified based on industry, academia partnership. Once the data were gathered, those were analysed using various statistical tools. This research is useful for the policymakers, executive people, especially those are working or involved in smart city development projects. The developed framework helps to identify the significant energy consumption sector and also suggest the suitable green energy alternatives for developing a cleaner and sustainable future. As this study discusses the various parameters related to smart city energy consumption sector in western India, it will have a huge practical potential on the proposed operational smart cities in India. Literature has witnessed minimum number of studies have been carried out on this proposed framework and that could improve the wellbeing of the people living in the cities.

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1. Introduction

The smart city is a moderately recent notion that has been utilized by a number of literature and institutes (Calvillo et al., 2016). Eloquently the smart city aims to address or minimise challenges caused by fast urbanisation and population expansion, such as energy supply, waste management, and mobility, by maximising efficiency and resource optimization. Literature witnessed variety of arrangement of smart-city interventions are there as in (Calvillo et al., 2016; Bhowmik et al., 2020). The main limitation of those orderings is that, they have written off as energy primarily based on smart grid, building, water, transport, services, and other facilities.

Cities have a diverse and abundant energy demand. As a result, modern cities should upgrade existing systems and deploy new solutions in a coordinated and optimal manner, taking use of the synergies between all of these energy solutions (Giffnger et al., 2007). The increasing demand of energy consumption at different sectors likely; building management, water management, transport, waste management and public service are better addressed as a whole rather than separately, as is usually the case (Giffnger et al., 2007; Ibrahim et al., 2018; Bibri, 2018; Beştepe and Yildirim, 2022). Many countries around the world have been actively involved in transitioning their energy systems. These efforts have been ongoing for several decades, indicating a long-term commitment to addressing the challenges posed by traditional energy sources and their impact on the environment (Badi et al., 2023a).

To help stakeholders comprehend urban dynamics and assess the effects of potential energy policy changes, simulation models have been developed. These initiatives frequently focus on different energy-related sectors, however, lacking the "whole picture" and leading to less-than-ideal results (Wüstenhagen et al., 2007; Yigitcanlar et al., 2019). In order to successfully satisfy the growing energy demands of current and future cities, a complete smart-city model that takes into account all energy-related activities while retaining the magnitude and complexity of the model feasible is highly desirable (Wu, 2012; Beştepe and Ozkan, 2019).

The five key sectors related to smart cities considered in this study are interconnected. While they are linked to each other, each sector makes a distinct contribution to the energy system. Therefore, diverse approaches are anticipated. The consumption areas are the key focus of attention in this research (Zeba, 2022).

Energy is a critical aspect for long-term growth, and determining the optimum green energy sources remains a big challenge for both emerging and established countries (Iddrisu and Bhattacharyya, 2015; Allen et al., 2016; Nikolaou and Kazantzidis 2016; Al Garni et al., 2016). An energy source is a critical input from both an economic and human well-being standpoint when constructing a generalised framework of sustainability for a cleaner future (Bhowmik et al., 2019). In modern cultures, technology also plays an important part in the choosing of energy sources. Technology, as it develops new capabilities, introduces new threats to the surrounding environment, depending on the mode of contact (Yi et al., 2011). According to the past, selecting the best sources is critical to steering the globe in a socially and environmentally sustainable direction (Janeiro and Patel, 2015). Dimensions of Energy Sustainability Since the Brundtland Report in 1987, motivation has been promoted. Following that, several efforts were made to capture various aspects of energy sustainability by merging renewable and conventional sources in order to revolutionize the future (Pinter et al., 2005; Patlitzianas et al., 2008; Singh et al., 2012; Petrillo et al., 2016;). Renewable energy sources, including solar, wind, hydro, geothermal, and biomass, play a pivotal role in addressing climate change by emitting minimal to no greenhouse gases, a primary driver of environmental shifts. By diminishing our dependency on fossil fuels and embracing these sustainable alternatives, we can effectively curb the repercussions of climate change, safeguarding the integrity of our planet's invaluable resources (Badi et al., 2023b).

Several studies have been established to address energy sustainability challenges (Zhang et al., 2016) for a cleaner future, using a variety of models and frameworks. Analytic Network Process (ANP) technique was used in three steps (Cannemi et al., 2014): problem analysis, synthesis using expert judgements, and evaluation of public administration. For the sake of sustainability, capital-risk investors in Italy have shown a preference for various types of biomass-fueled power plants. To create policy interventions for transitioning to a sustainable and secure energy future, a multidimensional, quantitative, modular, systematic, and flexible analytical framework was proposed (Narula and Reddy, 2016). The framework was able to provide information on the extraction of energy sources, and the provision of final enegy to various sectors of the economy by tansitioning the energy sources from primary to secondary. Optimal energy policy in Turkey using a fuzzy multi-criteria decision-making methodology based on the analytical hierarchy process (AHP) was investigated by Kahraman and Kaya (2010). In the sphere of energy source selection, the proposed decision-making process allowed experts to be flexible and leverage a vast evaluation pool. To derive sustainability (Erol and Klkş, 2012) for facilitating energy resource planning activities in the district of Aydin, Turkey, an AHP based technique was created. Väisänen et al., (2016) used two separate approaches, life cycle assessment (LCA) and the AHP, to evaluate the sustainability of Distributed energy systems (DESY) in numerous households as an alternative to traditional centralised energy generation. AHP and VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) have also been used to select sustainable renewable energy sources (Amar and Daim, 2011; Quijano et al., 2012; Ahmad and Tahar, 2014).

The methodologies outlined above can cope with distinct and specific competing criteria for strategy selection. A generalised new framework is required to facilitate the phrase "energy for smart city sustainability" of society. As a result, this study advances from the existing literature on green energy source selection by advocating for a practical and novel integrative approach. To identify and benchmark a solid generalised framework for optimum green energy source selection, an analytical approach with expert judgement levels (both strategic and tactic) is required to link and balance all other referral elements contributing to the selection strategy. Expert judgements are used to establish the relative importance of numerous criteria and subcriteria of the energy source selection problem, and green energy sources options are rated for optimal selection.

The primary goal of this research is to assess developments and trends and examine the synergies between various intervention areas in order to get insight into the complexity of energy-related operations in a smart city setting (keeping in mind the stakeholders and policymakers vision for energy solutions for smart cities). To this end, methodologies for efficient modelling and management of energy systems are provided, and existing initiatives and software tools are reviewed. The most pertinent components and common sources of knowledge needed for their mathematical modelling are included in these strategies.

2. Research design

The proposed creative integrated framework in this study is structured across building management, water management, transport management, waste management and public service. This study uses both primary and secondary methods of data collection to help the voice of the ordinary people for a cleaner future under smart city environment. Data processing plays a pivotal role in any kind of decision problem to improve the performance and productivity (Baranovski, 2022). Primary data in this study refers to information gathered by the researcher through in-person interviews with the expert team. The secondary data, however, represent other criteria and sub-criteria characteristics that were found in the literature and the aforementioned sectors are given in Table 1. Following that, a hierarchy for the smart city with the highest energy usage is created by merging all the structures. Different specialists were then approached for their opinions on the suggested hierarchical smart city framework. Each expert was required to respond to specific questions about the smart city concept and to give their assessment in pairs using a nine-point scale. With the aid of professionals, consistency ratio of the pairwise comparison was computed. Based on the AHP principles, the analogy used in this study is that "if the consistency ratio is below 10%, then the pairwise comparison is satisfactory." The proposed framework takes into account their observations. Six eco-friendly energy sources are chosen to demonstrate the effectiveness of the suggested structure. Finally, the suggested integrated, generalised framework is benchmarked using AHP. There are varieties of techniques available in literature but AHP is utilised in this study instead of other multi-criteria decision-making (MCDM) models as Interpretive Structural Modeling (ISM), Elimination Et Choix Traduisant la Realité (ELECTRE), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and ANP due to its convenience. MCDM refers to a field of study and a set of methodologies that are used to make decisions involving multiple criteria or factors (Sahoo & Goswami, 2023). MCDM methods help decision-makers evaluate and select the best alternative among a set of options based on various criteria, which may have different levels of importance or preference. Saaty (1980) proposed the AHP, which offers adaptable assistance to decision-makers in investigating opposing scenarios of selection strategy. Using this strategy, decision-making can take into account both concrete and intangible factors. Decomposition, comparative analysis, and priority synthesis are the three guiding concepts for the methodical processes of the AHP. It also offers a structured and transparent approach to decision-making, breaking down complex problems into a hierarchy for systematic evaluation (Alossta et al., 2021; Badi & Abdulshahed, 2021). By allowing for the comparison of multiple factors and the assignment of weights based on their relative importance, AHP enables rational and well-informed prioritization. The incorporation of a consistency check ensures the reliability of the decision-making process, while its adaptability to various scenarios, sensitivity analysis capabilities, and potential for group consensus make it a versatile tool for achieving inclusive and robust decisions. The following lists the pertinent stages for the associated principles:

Phase 1: The decision-making issue is initially located. The detected problem is then ranked in a hierarchy that is built using the works gathered. The top level of the hierarchy is covered by the objective, and the succeeding levels below it are listed as criteria, sub-criteria, and alternatives for appropriate GESS.

Phase 2: involves performing data collection and evaluating analogy matrices using expert opinions. According to a nine-point scale proposed by (Saaty, 1980), the respondents/experts are requested to assess the relative strength of each criterion in relation to other criterion locations in the hierarchy and assign relative scales in a paired manner (see Table 2).

Phase-3: All criteria, sub criteria, and alternatives have their normalised weights calculated after the creation of decision matrices. The normalised eigenvector approach is recommended for determining relative weight for the consistent dataset. The greatest eigenvalue λmax for each matrix is then calculated, along with the global weight (relative relevance of each element on the goal). By multiplying the normalised priority weights from the levels above, it is possible to determine the overall weights for each hierarchy level. The consistency ratio (CR) of the calculated eigenvector is estimated using the λ_max value, which is regarded as a reliable factor. Additionally, it verifies the pair-wise comparison matrix for consistency. The following formula can be used to get the CR;

$$CR = \frac{\lambda_{max} - n}{(n-1)(RI)} \quad (1)$$

where RI is the random index and n is the matrix order. As a result, Table 3 provides RI values for matrices of various orders (n = 1–7). For a third-order matrix, an acceptable range of CR values is from 0.0 to 0.05; for a fourth-order matrix, it is from 0.0 to 0.08; and for higher order matrices, it is from 0.0 to 0.1.40 a CR number that falls within the advised pair-wise comparisons must meet a certain standard of consistency, according to series.

Table 1. List of criteria and sub criteria.

Sl. No.	Criteria	Sub-criteria
1	Building management (BM)	Connection to the smart grid (BM1) Improve conditioning system (BM2) Improve lighting systems & controls (BM3) Improve heat recovery & storage (BM4) Hybrid ventilation systems (BM5) Adaptive façade systems (BM6) High efficiency generators (BM7) Solar active solution (BM8)
2	Water management (WTM)	Real-time data acquisition & monitoring (WTM1) Smart metering (WTM2) Leak detection (WTM3) Efficient pumping systems (WTM4) Integrated Operation System (WTM5) Power, control & security systems integration (WTM6) Water treatment & reuse facilities (WTM7) Storm water & urban flooding management (WTM8)
3	Transport management (TM)	EV charging infrastructure & supervision services (TM1) Shift vehicle technology - EVs & HEVs (TM2) Intelligent traffic management systems (TM3) Tolling & congestion charging (TM4) Integrated mobility, multi-modal & shared transport (TM5) Improve public transportation (TM6) Improve transportation infrastructure (TM7)
4	Waste management (WSM)	Waste-to-energy conversion (WSM1) Intelligent monitoring of general waste (WSM2) Smart Waste bins (WSM3) Dynamic management and routing (WSM4) Smart recycling facilities (WSM5) Biological & advanced thermal treatment (WSM6) Industrial heat recovery (WSM7) Solar integration (WSM8)
5	Public service (PS)	Smart sensors (PS1) Public safety (PS2) Video surveillance (PS3) Digital city services (PS4) Public street lighting management (PS5) Smart District Heating & Cooling (PS6) Automated distributed control (PS7) Renewable and distributed energy generators (PS8) Electrical & thermal energy storage (PS9)

Table 2. Saaty's scale of relative relevance for pair-wise comparisons (Saaty, 1980; Bhowmik et al., 2019).

Scale of relevance for intensity	Definition
1	Equally important
3	Moderately important
5	Much more important
7	Very much important
9	Strongly important
2, 4, 6 and 8	Intermediate important

Table 3. A random index of the several options that Saaty considered (Saaty, 1980; Bhowmik et al., 2019).

Variety of options (n)	1	2	3	4	5	6	7
Random index (RI)	0.00	0.00	0.58	0.90	1.12	1.24	1.32

3. The suggested sustainability framework for SEMP pertinent to smart city

It becomes clear that in the modern world, smart city energy management and planning (SCEMP) for buildings rely on organised, recorded, regular, and objective procedures as advised by some academics and by legislation. Whatever the methods employed, the SCEMP concept integrates the aforementioned elements with other pertinent constructs, such as building management (BM), water management (WTM), transport management (TM), waste management (WSM) and public service (PS) to create a novel generalised framework. Finding a potential sustainable solution is a difficult task. The current study shows a framework to incorporate those dimensions for an ideal SCEMP problem that requires ongoing contemplation on sustainability, viewing its complexity as a good aspect of the research.

Four tiers make up the recommended structure (Figure 1). Goals (such as SCEMP for sustainability) are at the top of the hierarchy, followed by criteria at the second level, sub criteria at the third level, and finally alternative renewable energy sources at the bottom. The following procedures can be used to choose the optimum renewable energy source in the proposed context.

Determine the sustainability metrics for SCEMP measurement and benchmarking in step 1.

Step 2: Conduct importance measurement with a team of energy industry professionals.

Step 3: Create a SCEMP framework.

Step 4: Using the AHP and the input of the subject-matter experts, evaluate the priority importance.

To determine the relevance of the criteria using the verbal scale as stated in Table 2, the aforementioned stages are taken into account through pairwise comparison at the criteria level. The importance of each sub criteria is then determined by doing a pairwise comparison at the level of the sub criteria. Thirdly, in order to identify the optimum renewable energy source, all alternative energy sources are compared side by side on each sub-criterion. Finally, the findings are combined throughout the hierarchy to demonstrate the significance of each green energy option overall for achieving sustainability.

Step 5: Make some suggestions for improvement in light of the outcomes.

4. Result and discussion

The suggested approach might be extremely useful to any government or non-government organisation working on smart city energy management for sustainability, as well as to policymakers. Due to their widespread use around the world, the six green energy choices of solar, wind, hydro, biogas, geothermal, and biomass should be given serious consideration. However, there is yet no widely accepted methodology for choosing the best green energy source for sustainability in the context of smart cities. As a result, the framework is created with the goal of achieving sustainable development while achieving a cleaner future. As part of an analytical approach within a strict governance structure and in accordance with the building management, water management, waste management, transport management, and public service objectives for sustainable communities, this research acknowledges the fundamental framework to pro-actively manage its contribution towards a more sustainable future. Each phase of the application is explained in the following sections.

Step 1: Recognise and evaluate the SCEMP framework for sustainability.

In order to choose the best SCEMP, six entirely different renewable energy sources are discovered. The selection of several materials was made in order to comprehend various diving and motivational techniques.

Step 2: Expert advice to continue the benchmarking exercise

To conduct the benchmarking exercise, a group of 15 researchers is assembled, each of whom represents a certain institution and energy resource centre in India. The group's members each have more than five years of expertise integrating renewable energy with smart cities for sustainability.

Step 3: Create a SCEMP framework

According to the participants, Figure 1 depicts the SCEMP importance framework for any of the organizations included. Each of the criteria and sub criteria are displayed in Tables 2 and 3, respectively.

Step 4: Evaluating the Priority Importance Using AHP Methodology with the Help of the field experts:

Building management, water management, waste management, transportation management, and public service are compared pairwise using a verbal scale as indicated in Table 2, in order to assess the relevance of the criteria as shown in Table 4. This study is conducted from the viewpoint of an expert's judgement. As a result, the primary focus of this research is on sustainable energy management in smart cities. Building is given greater consideration than the other aforementioned criteria. Each sub criteria are compared pairwise under each criterion in the case of sub criteria level. Table 5 (a-e) depicted the pairwise comparison with their relative weights. The expert panel gave particular sub-criteria under each of the main criteria the highest priority. The most significance was given to connection to the smart grid in under building management factor. Smart metering criteria is chosen as the most important sub-criteria for the water management category, whereas EV charging infrastructure and supervision services, waste to energy conversion, and public safety were chosen as the most important sub-criteria for the transport, waste management, respectively. Lastly, public safety has been given highest priority under public service category.

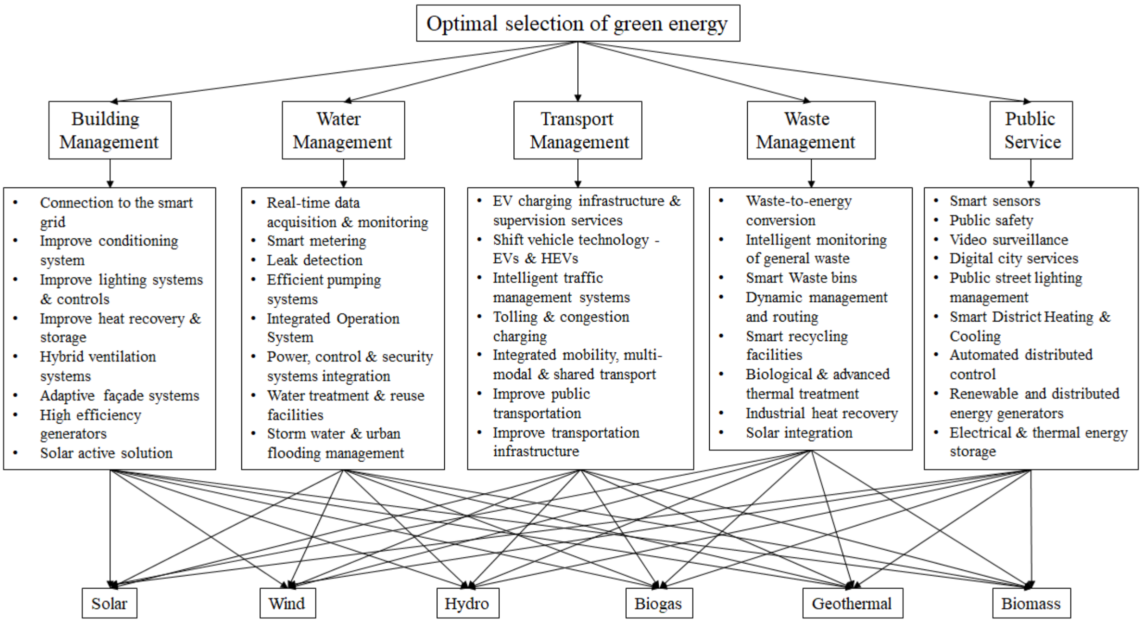

Figure 1. Proposed hierarchy

Table 4. Pair wise comparison between criteria level.

	BM	WTM	TM	WSM	PS	Importance (%)
BM	1	3	2	2	5	36.8
WTM	0.33	1	0.33	3	2	16.6
TM	0.5	3	1	2	4	26.6
WSM	0.5	0.33	0.5	1	3	13.6
PS	0.2	0.5	0.25	0.33	1	6.2

Table 5. Pair wise comparison under sub criteria level.

(a) Comparison among the sub criteria under building management

	BM1	BM2	BM3	BM4	BM5	BM6	BM7	BM8	Importance (%)
BM1	1	3	5	7	9	7	9	9	40.1
BM2	0.33	1	3	5	7	9	7.	9	25.4
BM3	0.20	0.33	1	3	3	5	7	9	13.5
BM4	0.14	0.20	0.33	1	1	2	3	3	5.4
BM5	0.11	0.14	0.33	1	1	5	7	9	8.4
BM6	0.14	0.11	0.20	0.50	0.20	1	2	2	3.1
BM7	0.11	0.14	0.14	0.33	0.14	0.50	1	3	2.5
BM8	0.11	0.11	0.11	0.33	0.11	0.50	0.33	1	1.8

(b) Comparison among the sub criteria under water management

	WTM1	WTM2	WTM3	WTM4	WTM5	WTM6	WTM7	WTM8	Importance (%)
WTM1	1	1	2	3	4	5	6	7	24.6
WTM2	1	1	8	3	8	7	6	9	35.1
WTM3	0.5	0.12	1	1	1	2	1	2	7.4
WTM4	0.33	0.33	1	1	3	4	5	6	13.7
WTM5	0.25	0.12	1	0.33	1	2	2	9	8.0
WTM6	0.2	0.14	0.5	0.25	0.5	1	2	3	4.7
WTM7	0.16	0.16	1	0.2	0.5	0.5	1	2	4.1
WTM8	0.14	0.11	0.5	0.16	0.11	0.33	0.5	1	2.3

(c) Comparison among the sub criteria under transport management

	TM1	TM2	TM3	TM4	TM5	TM6	TM7	Importance (%)
TM1	1	9	3	7	6	9	9	46.7
TM2	0.11	1	1	2	1	2	3	9.8
TM3	0.33	1	1	4	5	6	7	20.6
TM4	0.14	0.5	0.25	1	2	3	8	9.1
TM5	0.16	1	0.2	0.5	1	2	6	7.1
TM6	0.11	0.5	0.16	0.33	0.5	1	5	4.6
TM7	0.11	0.33	0.14	0.12	0.16	0.2	1	2.2

(d) Comparison among the sub criteria under waste management

	WSM1	WSM2	WSM3	WSM4	WSM5	WSM6	WSM7	WSM8	Importance (%)
WSM1	1	2	4	6	8	1	9	8	30.3
WSM2	0.5	1	7	6	5	4	9	8	30.2
WSM3	0.25	0.14	1	1	3	1	7	3	9.2
WSM4	0.16	0.16	1	1	1	1	3	1	6.0
WSM5	0.12	0.2	0.33	1	1	1	4	6	7.0
WSM6	1	0.25	1	1	1	1	8	9	12.6
WSM7	0.11	0.11	0.14	0.33	0.25	0.12	1	1	2.0
WSM8	0.12	0.12	0.33	1	0.16	0.11	1	1	2.7

(e) Comparison among the sub criteria under public service										
	PS1	PS2	PS3	PS4	PS5	PS6	PS7	PS8	PS9	Importance (%)
PS1	1	1	1	6	4	3	4	9	8	20.4
PS2	1	1	2	8	9	7	6	5	9	30.1
PS3	1	0.5	1	6	7	3	8	7	6	21.3
PS4	0.16	0.12	0.16	1	1	1	3	2	1	4.7
PS5	0.25	0.11	0.14	1	1	2	3	4	5	7.0
PS6	0.33	0.14	0.33	1	0.5	1	6	7	8	8.7
PS7	0.25	0.16	0.12	0.33	0.33	0.16	1	2	2	3.0
PS8	0.11	0.2	0.14	0.5	0.25	0.14	0.5	1	3	2.7
PS9	0.12	0.11	0.16	1	0.2	0.125	0.5	0.33	1	2.1

To determine the relative importance of each renewable energy source alternative, the alternatives are evaluated pairwise with regard to each sub-criterion. First, data for the six renewable energy sources shown in Table 1 are obtained against each sub criteria. Table 6 (a-z) and (aa-nn) displays typical pairwise comparison matrix along with the significance at various levels to help you understand the analysis.

Table 6. Pair wise comparison in alternative level.

(a) For sub criteria 'connection to the smart grid'							
	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	3	9	9	9	9	51.4
W	0.33	1	2	9	9	9	25.9
H	0.11	0.5	1	2	3	9	11.3
Bg	0.11	0.11	0.5	1	2	3	5.3
Gth	0.11	0.11	0.33	0.5	1	2	3.6
Bm	0.11	0.11	0.11	0.33	0.5	1	2.4

N.B: - S: Solar; W: Wind; H: Hydro; Bg: Biogas; Gth: Geothermal; Bm: Biomass

(b) For sub criteria 'improve conditioning system'							
	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	2	9	4	9	2	39.3
W	0.5	1	2	6	9	9	33.1
H	0.11	0.5	1	2	3	1	9.2
Bg	0.25	0.16	0.5	1	3	0.5	6.1
Gth	0.11	0.11	0.33	0.33	1	0.5	3.2
Bm	0.5	0.11	1	2	2	1	9.1

(c) For sub criteria 'improve lighting systems & controls'							
	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	3	5	7	7	5	43.9
W	0.33	1	7	6	9	3	29.7
H	0.2	0.14	1	2	2	1	7.5
Bg	0.14	0.16	0.5	1	3	0.25	5.2
Gth	0.14	0.11	0.5	0.33	1	0.5	3.7
Bm	0.2	0.33	1	4	2	1	10.0

(d) For sub criteria 'improve heat recovery & storage'							
	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	2	6	4	8	5	41.7
W	0.5	1	4	6	5	3	27.1
H	0.16	0.25	1	2	7	1	11.1
Bg	0.25	0.16	0.5	1	1	0.25	4.9
Gth	0.12	0.2	0.14	1	1	0.25	3.7
Bm	0.2	0.33	1	4	4	1	11.5

(e) For sub criteria 'hybrid ventilation systems'							
	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	2	1	3	6	5	31.3
W	0.5	1	1	6	9	3	26.4
H	1	1	1	2	7	2	21.9
Bg	0.33	0.16	0.5	1	1	0.5	6.5
Gth	0.16	0.11	0.14	1	1	0.25	3.8
Bm	0.2	0.33	0.5	2	4	1	10.1

(f) For sub criteria 'adaptive façade systems'							
	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	1	2	3	4	5	29.3
W	1	1	6	5	4	3	34.8
H	0.5	0.16	1	2	1	2	11.4
Bg	0.33	0.2	0.5	1	1	0.5	6.4
Gth	0.25	0.25	1	1	1	0.25	6.7
Bm	0.2	0.33	0.5	2	4	1	11.4

(g) For sub criteria 'high efficiency generators'							
	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	1	2	3	4	5	24.5
W	1	1	6	9	8	7	43.7
H	0.5	0.16	1	6	5	4	16.8
Bg	0.33	0.11	0.16	1	3	0.5	5.5
Gth	0.25	0.12	0.2	0.33	1	1	4.0
Bm	0.2	0.14	0.25	2	1	1	5.5

(h) For sub criteria 'solar active solution'							
	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	1	2	3	4	5	29.3
W	1	1	1	3	4	6	25.8
H	0.5	1	1	6	5	5	26.8
Bg	0.33	0.33	0.16	1	1	1	6.7
Gth	0.25	0.25	0.2	1	1	1	6.1
Bm	0.2	0.16	0.2	1	1	1	5.5

(i) For sub criteria 'real-time data acquisition & monitoring'							
	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	4	8	7	6	5	52.3
W	0.25	1	2	3	2	3	16.9
H	0.12	0.5	1	1	2	2	9.6
Bg	0.14	0.33	1	1	1	1	7.1
Gth	0.16	0.5	0.5	1	1	2	7.9
Bm	0.2	0.33	0.5	1	0.5	1	6.1

(j) For sub criteria 'smart metering'							
	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	3	8	3	6	5	47.1
W	0.33	1	2	3	2	3	18.6
H	0.12	0.5	1	1	2	3	11.0
Bg	0.33	0.33	1	1	1	1	8.9
Gth	0.16	0.5	0.5	1	1	2	8.2
Bm	0.2	0.33	0.33	1	0.5	1	6.1

(k) For sub criteria 'leak detection'							
	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	5	5	5	6	5	49.3
W	0.2	1	2	2	2	3	16.2
H	0.2	0.5	1	2	4	3	14.6
Bg	0.2	0.5	0.5	1	1	1	7.2
Gth	0.16	0.5	0.25	1	1	1	6.4
Bm	0.2	0.33	0.33	1	1	1	6.4

(l) For sub criteria 'efficient pumping systems'							
	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	2	1	9	6	5	36.2
W	0.5	1	2	2	2	2	19.4
H	1	0.5	1	2	4	9	24.7
Bg	0.11	0.5	0.5	1	1	2	7.9
Gth	0.16	0.5	0.25	1	1	1	6.4
Bm	0.2	0.5	0.11	0.5	1	1	5.4

(m) For sub criteria 'integrated operation system'							
	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	1	1	5	9	6	33.2
W	1	1	1	5	2	2	22.7
H	1	1	1	2	4	5	23.4
Bg	0.2	0.2	0.5	1	1	3	8.5
Gth	0.11	0.5	0.25	1	1	1	6.5
Bm	0.16	0.5	0.2	0.33	1	1	5.7

(n) For sub criteria 'power, control & security systems integration'							
	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	1	1	5	9	6	34.6
W	1	1	1	5	2	2	23.4
H	1	1	1	2	2	2	18.9
Bg	0.2	0.2	0.5	1	2	3	9.8
Gth	0.11	0.5	0.5	0.5	1	1	6.6
Bm	0.16	0.5	0.5	0.33	1	1	6.7

(o) For sub criteria 'water treatment & reuse facilities'

	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	2	2	7	7	5	41.1
W	0.5	1	2	2	5	2	21.0
H	0.5	0.5	1	2	3	2	15.3
Bg	0.14	0.5	0.5	1	3	3	11.1
Gth	0.14	0.2	0.33	0.33	1	1	4.8
Bm	0.2	0.5	0.5	0.33	1	1	6.6

(p) For sub criteria 'storm water & urban flooding management'

	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	4	2	7	9	5	45.8
W	0.25	1	1	2	5	2	15.9
H	0.5	1	1	2	5	2	17.8
Bg	0.14	0.5	0.5	1	3	2	9.5
Gth	0.11	0.2	0.2	0.33	1	1	4.2
Bm	0.2	0.5	0.5	0.5	1	1	6.7

(q) For sub criteria 'EV charging infrastructure & supervision services'

	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	5	5	5	5	5	48.1
W	0.2	1	3	3	3	3	19.7
H	0.2	0.33	1	1	1	2	8.3
Bg	0.2	0.33	1	1	1	5	10.6
Gth	0.2	0.33	1	1	1	2	8.3
Bm	0.2	0.33	0.5	0.2	0.5	1	4.9

(r) For sub criteria 'Shift vehicle technology - EVs & HEVs'

	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	7	5	3	3	5	47.3
W	0.14	1	3	4	2	3	19.4
H	0.2	0.33	1	1	2	2	9.5
Bg	0.33	0.25	1	1	2	2	10.2
Gth	0.33	0.5	0.5	0.5	1	2	8.2
Bm	0.2	0.33	0.5	0.5	0.5	1	5.3

(s) For sub criteria 'Intelligent traffic management systems'

	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	3	5	3	9	5	45.9
W	0.33	1	3	2	1	3	17.8
H	0.2	0.33	1	1	2	2	10.3
Bg	0.33	0.5	1	1	2	2	11.8
Gth	0.11	1	0.5	0.5	1	2	8.5
Bm	0.2	0.33	0.5	0.5	0.5	1	5.7

(t) For sub criteria 'tolling & congestion charging'

	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	1	2	3	2	3	25.5
W	1	1	3	3	5	6	34.5

H	0.5	0.33	1	1	3	2	13.9
Bg	0.33	0.33	1	1	2	2	11.9
Gth	0.5	0.2	0.33	0.5	1	2	8.1
Bm	0.33	0.16	0.5	0.5	0.5	1	6.0

(u) For sub criteria ‘integrated mobility, multi-modal & shared transport’

	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	3	4	5	4	3	41.6
W	0.33	1	3	1	1	1	13.8
H	0.25	0.33	1	1	0.33	1	7.9
Bg	0.2	1	1	1	2	2	14.0
Gth	0.25	1	3	0.5	1	2	13.6
Bm	0.33	1	1	0.5	0.5	1	9.1

(v) For sub criteria ‘improve public transportation’

	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	7	7	7	9	9	58.4
W	0.14	1	5	4	4	5	19.6
H	0.14	0.2	1	0.5	0.33	1	4.2
Bg	0.14	0.25	2	1	1	1	6.2
Gth	0.11	0.25	3	1	1	1	6.5
Bm	0.11	0.2	1	1	1	1	5.1

(w) For sub criteria ‘improve transportation infrastructure’

	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	3	3	3	3	3	36.1
W	0.33	1	2	1	2	2	16.6
H	0.33	0.5	1	1	1	1	10.7
Bg	0.33	1	1	1	2	5	18.5
Gth	0.33	0.5	1	0.5	1	2	10.5
Bm	0.33	0.5	1	0.2	0.5	1	7.6

(x) For sub criteria ‘waste-to-energy conversion’

	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	2	4	3	2	3	32.6
W	0.5	1	4	2	2	3	23.3
H	0.25	0.25	1	0.25	0.5	2	6.9
Bg	0.33	0.5	4	1	2	5	19.4
Gth	0.5	0.5	2	0.5	1	2	11.9
Bm	0.33	0.33	0.5	0.2	0.5	1	6.0

(y) For sub criteria ‘intelligent monitoring of general waste’

	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	7	5	3	4	6	47.6
W	0.14	1	8	2	2	3	19.3
H	0.2	0.125	1	0.25	0.5	2	5.1
Bg	0.33	0.5	4	1	2	5	15.1
Gth	0.25	0.5	2	0.5	1	2	8.6
Bm	0.16	0.33	0.5	0.2	0.5	1	4.3

(z) For sub criteria 'smart waste bins'

	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	3	5	3	4	6	41.2
W	0.33	1	2	2	1	4	17.4
H	0.2	0.5	1	0.25	0.33	2	6.6
Bg	0.33	0.5	4	1	1	5	16.3
Gth	0.25	1	3	1	1	2	13.8
Bm	0.16	0.25	0.5	0.2	0.5	1	4.7

(aa) For sub criteria 'dynamic management and routing'

	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	6	6	6	6	6	52.0
W	0.16	1	2	2	1	4	13.6
H	0.16	0.5	1	0.25	0.33	2	5.6
Bg	0.16	0.5	4	1	3	3	14.5
Gth	0.16	1	3	0.33	1	3	10.1
Bm	0.16	0.25	0.5	0.33	0.33	1	4.2

(bb) For sub criteria 'smart recycling facilities'

	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	6	6	6	6	6	52.8
W	0.16	1	1	1	1	1	8.8
H	0.16	1	1	0.5	0.5	2	7.7
Bg	0.16	1	2	1	3	3	15.0
Gth	0.16	1	2	0.33	1	3	10.2
Bm	0.16	1	0.5	0.33	0.33	1	5.6

(cc) For sub criteria 'biological & advanced thermal treatment'

	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	3	3	3	4	4	37.3
W	0.33	1	2	2	2	4	20.0
H	0.33	0.5	1	0.2	1	2	8.5
Bg	0.33	0.5	5	1	3	3	19.9
Gth	0.25	0.5	1	0.33	1	3	9.2
Bm	0.25	0.25	0.5	0.33	0.33	1	5.2

(dd) For sub criteria 'industrial heat recovery'

	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	5	6	5	6	5	48.6
W	0.2	1	6	2	2	4	19.0
H	0.16	0.16	1	0.2	1	2	5.5
Bg	0.2	0.5	5	1	3	3	14.9
Gth	0.16	0.5	1	0.33	1	3	7.5
Bm	0.2	0.25	0.5	0.33	0.33	1	4.5

(ee) For sub criteria 'solar integration'

	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	3	6	5	6	9	46.5
W	0.33	1	6	2	5	4	22.8
H	0.16	0.16	1	0.2	1	2	5.3
Bg	0.2	0.5	5	1	5	3	16.1
Gth	0.16	0.2	1	0.2	1	2	5.4
Bm	0.11	0.25	0.5	0.33	0.5	1	4.0

(ff) For sub criteria 'smart sensors'

	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	8	7	6	5	7	55.6
W	0.12	1	3	2	5	4	16.9
H	0.14	0.33	1	0.2	1	1	4.8
Bg	0.16	0.5	5	1	3	2	12.3
Gth	0.2	0.2	1	0.33	1	1	5.2
Bm	0.14	0.25	1	0.5	1	1	5.2

(gg) For sub criteria 'public safety'

	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	2	9	7	5	7	46.1
W	0.5	1	5	2	5	4	23.4
H	0.11	0.2	1	0.14	0.2	1	3.4
Bg	0.14	0.5	7	1	3	2	13.9
Gth	0.2	0.2	5	0.33	1	1	7.6
Bm	0.14	0.25	1	0.5	1	1	5.6

(hh) For sub criteria 'video surveillance'

	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	2	4	3	3	5	34.7
W	0.5	1	4	3	1	5	24.6
H	0.25	0.25	1	0.25	0.33	1	5.4
Bg	0.33	0.33	4	1	3	2	16.6
Gth	0.33	1	3	0.33	1	1	11.8
Bm	0.2	0.2	1	0.5	1	1	6.8

(ii) For sub criteria 'digital city services'

	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	2	9	3	4	8	40.7
W	0.5	1	3	4	5	7	29.6
H	0.11	0.33	1	0.5	0.5	1	5.5
Bg	0.33	0.25	2	1	3	2	12.0
Gth	0.25	0.2	2	0.33	1	1	6.9
Bm	0.12	0.14	1	0.5	1	1	5.3

(jj) For sub criteria 'public street lighting management'							
	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	2	4	3	4	8	36.9
W	0.5	1	6	3	5	7	30.9
H	0.25	0.16	1	0.2	0.33	1	4.7
Bg	0.33	0.33	5	1	3	2	14.8
Gth	0.25	0.2	3	0.33	1	1	7.4
Bm	0.12	0.14	1	0.5	1	1	5.3

(kk) For sub criteria 'smart district heating & cooling'							
	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	3	9	9	9	9	53.1
W	0.33	1	4	3	5	7	22.7
H	0.11	0.25	1	0.2	0.33	1	3.7
Bg	0.11	0.33	5	1	3	2	10.6
Gth	0.11	0.2	3	0.33	1	1	5.5
Bm	0.11	0.14	1	0.5	1	1	4.4

(ll) For sub criteria 'automated distributed control'							
	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	3	9	9	9	9	52.9
W	0.33	1	4	3	5	7	22.0
H	0.11	0.25	1	0.2	0.5	2	4.0
Bg	0.11	0.33	5	1	2	6	11.4
Gth	0.11	0.2	2	0.5	1	6	7.1
Bm	0.11	0.14	0.5	0.16	0.16	1	2.6

(mm) For sub criteria 'renewable and distributed energy generators'							
	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	5	5	5	5	5	47.2
W	0.2	1	4	4	4	4	23.0
H	0.2	0.25	1	0.5	0.5	2	6.0
Bg	0.2	0.25	2	1	3	3	11.5
Gth	0.2	0.25	2	0.33	1	3	7.9
Bm	0.2	0.25	0.5	0.33	0.33	1	4.4

(nn) For sub criteria 'electrical & thermal energy storage'							
	S	W	H	Bg	Gth	Bm	Importance (%)
S	1	1	4	3	4	5	28.8
W	1	1	6	7	8	9	44.2
H	0.25	0.16	1	0.5	1	2	6.8
Bg	0.33	0.14	2	1	1	2	8.9
Gth	0.25	0.12	1	1	1	1	6.5
Bm	0.2	0.11	0.5	0.5	1	1	4.9

To determine the relative importance of the renewable energy source choices, the data from each level of the hierarchy are then combined. Table 7 displays the results of the synthesised AHP and the relative relevance of the alternatives. The detailed calculation of synthesized AHP is shown in Table S1 of supplementary material for better understanding. It also demonstrates that, when taking into account building management, solar energy comes out on top, followed by the other renewable energy options. Similar to WTM, TM, WSM, and PS, solar power is the best option for producing cleaner electricity, while the remaining sources can be used to produce energy in the future. Utilizing solar energy more effectively requires increasing its environmental foresight through the use of a more aggressive strategy and the replacement of fossil fuels. In terms of economic and environmental planning, wind power performs better than hydro, yet hydro rules in terms of policy. Biomass receives a least grade when taking into account all the aspects.

Table 7. Synthesized AHP showing relative importance regarding each renewable energy sources.

Renewable energy alternative	Overall importance
Solar	0.439
Wind	0.232
Hydro	0.102
Biogas	0.096
Geothermal	0.067
Biomass	0.059

Step 5: Make suggestions for enhancements

This study provides an innovative architecture for the energy integration to address the issues that still exist in resource fragility as well as price fluctuation, which are highlighted by the above analysis as critical metrics. In the context of regional energy demand, integrating energy has frequently been the main thrust. For each region or nation where new opportunities for energy integration arise, the proposed framework is invaluable. The expert team also concurred that employing the SCEMP architecture need not come at a significant capital expense because they could analyze the data using Microsoft Office and MATLAB. However, some adjustments to practices and mindsets may be necessary to fully use the new selection framework.

Theoretically, this study suggests broad paradigms for SCEMP that address the network's consolidated sustainability while taking into account a variety of important and unexplored selection criteria. The components include building, water, transport, waste and public service aspects and are both spontaneous and impartial. This study recommended a framework for analysing the strategic, tactical, and operational levels of SCEMP relevance.

5. Sensitivity analysis

To assess the global applicability, sustainability, and resilience of the proposed optimal SCEMP framework, various dimensions are taken into account. Research clearly indicates a link between societal progress and sustainable energy access. These dimensions, along with their associated factors, serve as a solid foundation for sustainable planning since sustainability assessment is a complex task that cannot be easily quantified using straightforward criteria. In other words, these dimensions possess a somewhat nebulous nature and can be applied in diverse ways to measure energy sustainability. This study adopts the concept that a "dimension expression ratio ranging between zero (0) and one (1)" is suitable for evaluating sustainability. A value of 0 represents no sustainability, while a value of 1 indicates full sustainability. However, upon analyzing Figures 2(a) and 2(b), it becomes evident that all the dimensions and their corresponding factor along with the energy alternatives values fall within the permissible range considered in this study for sustainability measurement. The data (local importance) used to create the radar charts are derived from Table 7. The proposed structure will make SCEMP easily applicable and user-friendly for energy managers, policymakers, governmental and non-governmental organizations alike.

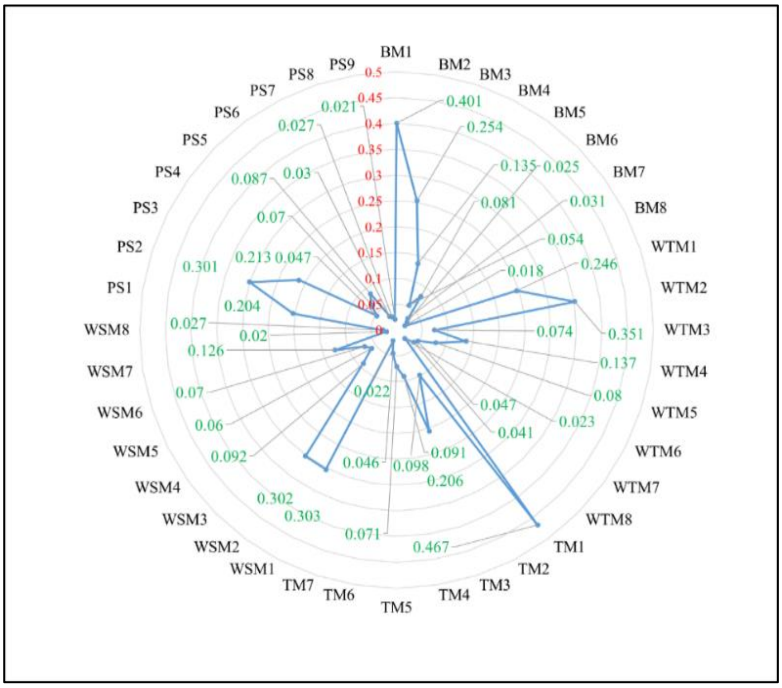

Figure 2. (a) Illustration of the factors sustainability for SCEMP

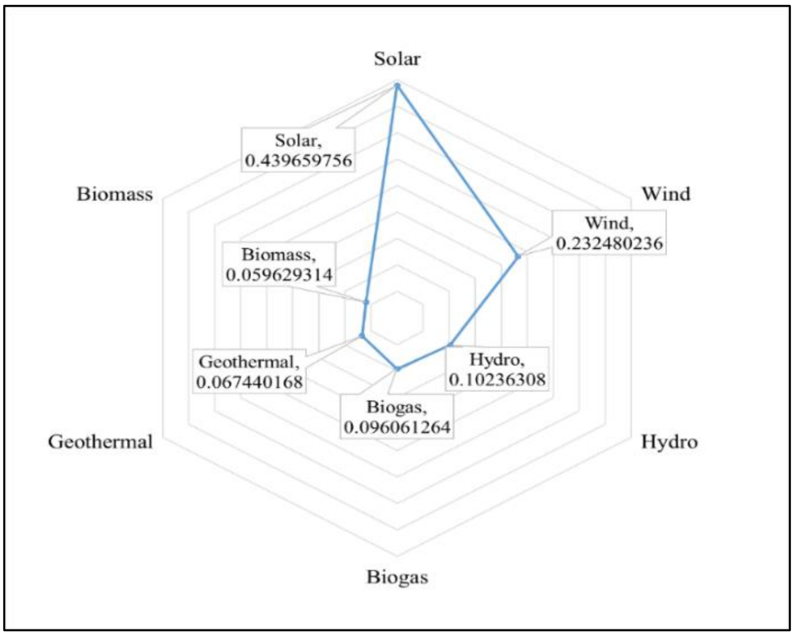

Figure 2. (b) Illustation of energy sources sustainability for SCEMP

5. Conclusions

The proposed SCEMP framework, which uses the AHP, aids managers of any region in determining the consequences and, consequently, in making thoughtful decisions that would improve the performance of renewable energy in the foreseeable future. The findings of this analysis are in agreement with the authors' use of this framework in practice for this study. This multidimensional framework, which incorporates five dimensions and their connected aspects, aids decision-makers in bridging the analytical gap (social acceptance) of green energy for sustainable development. Conceptually, this research can be expanded upon in the near future with the diversification of sustainable transition in the generation of renewable energy through many sources and their players (since social acceptance and practicality are key in transition). under the upcoming years, testing and investigating the ideas may be aided by the social acceptance and feasibility crises that is currently under progress. By including more elements into the suggested SCEMP structure, a more dependable and long-lasting method can be created.

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Conflict of interest

The authors declare no conflict of interests.

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