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Investigating Strategies for Implementing Resilience Based on Industry 4.0 in the Electricity Supply Chain: A Combination of Soft and Hard Operational Research

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ABSTRACT

Resilience is one of the most crucial parameters in the electricity supply chain, and the absence of this concept can lead to various issues in service provision. One perspective that can greatly contribute to resilience is utilizing the Industry 4.0 approach. This study examines the challenges and strategies for the flexibility of the electricity supply chain in the Industry 4.0 era. A descriptive-analytical method employing library research and field studies has been employed. Subsequently, using the factors and criteria obtained from Value-Focused Thinking (VFT) from Soft Operational Research and verification by literature, a fuzzy IVIF-WASPAS-based analysis was conducted. The decision-making team comprised internal experts in the electricity supply chain in Iran, focusing on the principles of resilience in the Industry 4.0 era to analyze key issues. A case study was also conducted within the electricity supply chain, incorporating insights from academic experts and the team's experiences. Strategies like smart network systems, blockchain technology, cybersecurity, and education are fundamental to enhancing the supply chain's flexibility. This study's findings indicate a long journey in developing Industry 4.0 in Iran's electricity supply chain. However, relying on the proposed strategies can minimize existing issues and propel the system toward growth.

Keywords

Keywords: Electricity supply chain, Industry 4.0, Fuzzy IVIF-WASPAS, Value-Focused thinking, Soft operational research.

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1. Introduction

Considering incomplete information about future events, there is always a presence of risk and uncertainty. In other words, uncertainty about the future creates risks (Alamerew and Brissaud, 2020). This risk in the supply chain involves the potential occurrence of events that hinder the flow of materials and information, leading to disruptions in its performance (Borazon et al., 2022). In this regard, one of the current challenges for businesses is the management and reduction of risks arising from resilient supply chain design. Resilience has gained attention as a distinctive capability by organizations to maintain sustainability and continuity in a turbulent economic environment. From a supply chain resilience perspective, it refers to its ability to confront disturbances, provide responses, improve, and grow without interrupting customer service (Hosseini et al., 2019).

Resilience is a significant and interdisciplinary concept addressed in various fields, such as ecology, engineering, and beyond. Multiple definitions and quantitative methods for assessing resilience have been proposed, drawing much attention to this concept (Mishra et al., 2019). Facing complexities and unpredictabilities in supply chain management within disruption-prone business environments, achieving resilience capabilities to cope with or prevent disruptions is inevitable (Wang et al., 2019). Based on supply chain resilience studies, emphasis has been placed on identifying and analyzing supply chain vulnerabilities against potential disruptions and enhancing resilience capabilities to counter these vulnerabilities (Wangsa and Wee, 2019). Resilience in the electrical industry is crucial because it ensures the continuous delivery of electricity despite disruptions, whether from natural disasters, cyber-attacks, or equipment failures. This ability to anticipate, respond to, and recover from such disturbances is essential for maintaining energy security and supporting economic stability and public safety.

In 2021, the average Iranian consumed 3,160 kWh of electricity per year. It is slightly higher than the world average of 2,800 kWh per year. Iran's average electricity consumption per capita is slightly higher than the world average (Figure 1), which indicates a significant reliance on electricity for daily activities. Ranked 37th in the world for electricity consumption per capita, Iran's electricity needs are influenced by its climatic conditions, particularly the hot climate that necessitates increased energy consumption for air conditioning and cooling. Additionally, rapid urbanization has resulted in more households using energy-intensive appliances. Moreover, the government's subsidizing electricity prices has made electricity affordable for the population, further driving demand.

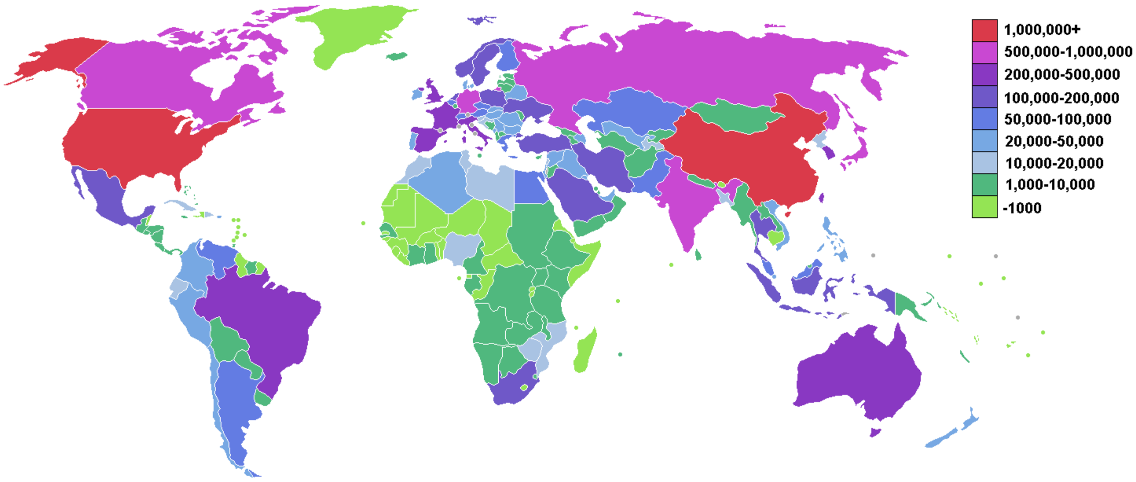

Figure 1. Average electricity consumption by countries in million kWh (CIA Factbook).

Despite being a net exporter of electricity, Iran's large installed capacity for electricity generation mainly depends on fossil fuels (Saghaei et al., 2020). It underscores the need for a robust and resilient electricity supply chain to ensure consistent power availability and stability, especially given the country's reliance on electricity for various sectors and the potential environmental impacts of fossil fuel-based generation (Hosseini et al., 2019). Ensuring the resilience of the electricity supply chain is crucial to maintaining economic activities, public services, and the overall well-being of the population, highlighting its vital significance in Iran's energy landscape (Wangsa and Wee, 2019).

With the rapid advancement toward Industry 4.0, there is a fundamental need to enhance and align the supply chain with these transformations (Mastos et al., 2021). The necessary resilience capabilities to address disruptions arising from the Fourth Industrial Revolution and ensure non-interruption of organizational activities have become essential (Lasi et al., 2014). The need to analyze supply chain vulnerabilities and strengthen resilience capabilities against them holds greater significance in supply chain management, especially in today's complex and dynamic environment (Tsaramirsis et al., 2022). Considering the significance of the electricity industry as a vital foundation for other industries and services, economic development and societal well-being are heavily dependent on a consistent power supply. Hence, ensuring a sustainable and resilient electricity supply chain has become a critical national concern (Hosseini et al., 2019; Vafadarnikjoo et al., 2022). As energy demands increase in the modern world, dependence on electricity as a primary energy source grows, and ensuring its sustainable supply becomes imperative for every country's society and economy (Richter et al., 2022; Queiroz et al., 2020). Consequently, disruptions in the electricity supply chain can lead to serious economic and societal consequences. For example, summer electricity crises can impact the production and distribution of goods and services, causing extensive economic and social damage (Paoli and Gül, 2022; Mishra et al., 2019; Chen et al., 2023).

Therefore, the concept of electricity supply chain resilience, as the ability to confront disruptions, provide rapid responses and continuously improve in today's highly risky environment, holds a significant position (Ahmad et al., 2022; Robert et al., 2022; Tsaramirsis et al., 2022; Lahtinen et al., 2017). Ultimately, the importance of electricity supply as a fundamental factor for economic development and societal welfare, coupled with the need to seriously address electricity supply chain resilience in the face of future challenges and transformations, is paramount (Hosseini et al., 2019). In this regard, research and planning efforts to ensure sustainable performance and responsiveness to disruptions in the electricity supply chain are highly crucial to providing energy services to society and industries sustainably and reliably.

In conclusion, this study makes significant contributions to the understanding and enhancement of the electricity supply chain's resilience through the lens of Industry 4.0. By investigating the challenges and strategies related to flexibility in the Industry 4.0 era (Lasi et al., 2014; Oliveira-Pinto et al., 2019; Gao et al., 2017). This study fills a critical gap in the literature surrounding the application of advanced technological paradigms in the electricity supply chain. Utilizing a descriptive-analytical approach that combines library research, field studies, and a comprehensive fuzzy IVIF-WASPAS-based analysis underscores this research's rigor and multidimensional nature. To clarify the innovative content and methodology articulated in the problem statement, this paper introduces the Variable Flexibility Threshold (VFT) model as a novel approach to managing uncertainty and enhancing adaptability in the electricity supply chain. The VFT model leverages real-time data and adaptive decision-making processes to adjust flexibility thresholds based on prevailing market conditions and supply chain disruptions. This approach not only underpins the theoretical contributions of our study but also provides a practical framework for implementing Industry 4.0 technologies effectively. By integrating the VFT model, we offer a unique perspective on resilience and flexibility, addressing both theoretical gaps and practical challenges in the current landscape of the electricity supply chain.

Moreover, the involvement of internal experts from Iran's electricity supply chain and the integration of academic insights through a real case study further validate the practical implications of the findings. Ultimately, this research is a valuable guide for stakeholders and decision-makers in navigating the complexities of Industry 4.0 integration within the electricity supply chain, fostering resilience and sustainable development.

2. *Literature review*

The integration of Industry 4.0 concepts in the electric supply chain is a critical aspect of the fourth industrial revolution, offering the transformative potential for enhanced efficiency, innovation, and cost reduction (Mastos et al., 2021; Bressanelli et al., 2021; Alamerew and Brissaud, 2020). This integration involves advanced technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), big data, and robotics, which enable improved processes and intelligent communication within the electricity supply chain (Zhao et al., 2021; Mishra et al., 2019; Chen and Fan, 2023). The literature highlights the considerable benefits of Industry 4.0 adoption in the electricity supply chain, including increased efficiency, cost reduction, heightened security, and innovation (Wang et al., 2019; Pamucar et al., 2022).

An essential focus in this domain is the interconnectedness and communication among equipment and devices within the electricity supply chain. Industry 4.0 facilitates data exchange between producers, distributors, and consumers using sensors and smart devices. At the same time, the IoT supports data collection related to electricity production, distribution, and consumption, contributing to efficiency enhancement and energy optimization (Paoli and Gül, 2022; Pamucar et al., 2022; Ahmad et al., 2022). Moreover, AI can address load fluctuations, workforce estimation, and energy optimization, further exemplifying the potential of Industry 4.0 in improving the electricity supply chain (Hosseini et al., 2019).

Saghaei et al. (2020) highlighted essential supply chain management concepts within the electricity sector, including collaboration, flexibility, and knowledge sharing. The principles of supply chain management in electricity, encompassing risk management, innovation, and supplier evaluation, were outlined. Hosseini-Motlagh et al. (2020) addressed uncertainty in designing a reliable and sustainable electricity supply chain network, introducing a multi-objective optimization model incorporating reliability measures and corporate social responsibility aspects. Richter et al. (2022) underscored the significance of the electricity supply chain in enhancing production, transportation, and consumption processes.

Moreover, the literature also examines specific risk and security aspects of power supply chains. Vafadarnikjoo et al. (2022) introduced a vulnerability assessment framework for evaluating risks associated with the electric power supply chain in the United Kingdom, highlighting the relationship among these risks and presenting a novel hesitant expert selection model. Lotfi et al. (2022) studied resilience and sustainable healthcare supply chains using a hybrid fuzzy and data-driven robust optimization approach. The findings of this study shed light on the importance of robust optimization techniques in enhancing the resilience of the healthcare supply chain. Dubey et al. (2023) explored the role of dynamic digital capabilities in enhancing supply chain resilience. Their study emphasized the significance of government effectiveness in facilitating digital capabilities that contribute to the supply chain's resilience.

Zhao et al. (2023) examined the impact of supply chain digitalization on resilience and performance. They proposed a multi-mediation model highlighting the complex interplay between digitalization, resilience, and supply chain performance. Zamani et al. (2023) conducted a systematic literature review on applying artificial intelligence and big data analytics to enhance supply chain resilience. The findings of this review underscored the potential of advanced technologies in strengthening the resilience of supply chains. Aityassine et al. (2022) investigated the effect of supply chain resilience on the performance of chemical industrial companies. Their study provided insights into the positive impact of resilience on supply chain performance.

Although the reviewed literature has provided valuable insights into Industry 4.0 integration in the electricity supply chain, a notable gap exists in understanding and addressing the specific challenges of implementing Industry 4.0 in Iran's electric supply chain. While the literature emphasizes the potential benefits and methodologies for analysis, a comprehensive investigation into the practical challenges, barriers, and strategies to overcome them within the Iranian context is lacking. Thus, a potential research direction would be to conduct a comprehensive empirical study focusing on the Iranian electricity supply chain and its readiness for Industry 4.0 integration. This research could involve qualitative and quantitative data collection to identify the unique challenges that Iranian organizations face in adopting Industry 4.0 technologies. Additionally, the study could explore potential strategies, policies, and best practices to overcome these challenges and facilitate the successful implementation of Industry 4.0 concepts in the Iranian electric supply chain. By addressing this gap, researchers can provide practical insights to policymakers, industry leaders, and practitioners to drive the effective integration of Industry 4.0 in the Iranian electricity supply chain, contributing to sustainable development and improved efficiency in the sector.

2.1. Criteria, sub-criteria, and extracted strategies from literature

In order to conduct further analyses in the methodology section, criteria and strategies for addressing the challenges of implementing a resilient electricity supply chain in the Industry 4.0 context need to be identified. Accordingly, three overarching criteria of intelligent performance, resilience performance, and environmental performance have been considered for the system, accompanied by the specified criteria, sub-criteria, and sources as presented in Table 1:

Table 1. Performance indicators of the electricity supply chain

Criteria	Sub-Criteria	Sub criteria description	References
Intelligent performance (IP)	Automation and intelligent control (IP-1)	Automating electricity supply chain processes with intelligent systems, including automatic execution of production, transmission, and distribution tasks, and adjusting parameters in response to network changes.	Richter et al., (2022), Queiroz et al., (2020), Hosseini-Motlagh et al., (2020)
	Advanced Forecasting and Analysis (IP-2)	Utilizing data analysis and AI to predict electricity supply chain events and disruptions, identifying issues through historical data and forecasts, and implementing preventive measures for performance optimization.	Richter et al., (2022), Queiroz et al., (2020), Mastos et al., (2021), Ahmad et al., (2022)
	Interaction and intelligent communication (IP-3)	Enabling communication between electricity supply chain components through smart technologies, facilitating real-time interaction among equipment, sensors, systems, and managers to enhance decision-making and manage disruptions.	Richter et al., (2022)
	Flexibility and quick response (IP-4)	Swiftly adapting the electricity supply chain to sudden changes, customer demands, and environmental shifts using smart technologies and available data to adjust electricity production, distribution, and consumption as needed.	Zhao et al., (2021), Bas, (2013), Oliveira-Pinto et al., (2019)
Resilience performance (RP)	Identification and prediction of risks (RP-1)	Detecting and analyzing advanced risks and threats in the electricity supply chain through data analysis, predictive models, and AI, allowing for early identification and application of preventive measures.	Chen et al., (2023), Chen and Fan, (2023)
	Specialized management and coordination of supply chain components (RP-2)	Integrating and coordinating electricity supply chain components during disruptions using smart technologies and connected systems to foster participation, cooperation, and specialized decision-making.	Zhao et al., (2021), Vafadarnikjoo et al., (2022)
	Preventive and Corrective Strategies (RP-3)	Developing and implementing preventive and corrective strategies for managing disturbances in the electricity supply chain, leveraging data, analytics, and predictive models for proactive actions and responsive improvements.	Chen and Fan, (2023), Urciuoli et al., (2014)
Environmental performance (EP)	Sustainable Resource Management (EP-1)	Sustainably and optimally managing electricity production resources over time using smart technologies, accurately monitoring resource consumption, and enhancing overall productivity.	Zhao et al., (2021), Gao et al., (2017), Lahtinen et al., (2017)

3. Research methodology

The present study investigates the challenges and strategies of flexibility in the electricity supply chain in the Industry 4.0 era. This study adopts a descriptive-analytical approach to examine the fundamental problems in this domain. To this end, a literature review method has been utilized to gather information and identify performance indicators of the electricity supply chain from various sources. Additionally, through field study methodology, questionnaires were distributed to industry experts and professionals, and performance indicators and strategies were evaluated. A purposive judgmental sampling technique was also employed to select the experts. VFT, as a soft operational research approach, has been incorporated as a cognitive method for a comprehensive exploration and definition of strategies, leveraging expert interviews to gather opinions and insights. This approach allows for a deep understanding of the challenges and complexities within the electricity supply chain.

Furthermore, a decision-making team of experts from within the Tehran Electric Company's supply chain has been formed, emphasizing the importance of adapting to existing challenges and variables. The insights of academic experts, including three professors and researchers, and the experiences of team members, including power system engineers, energy analysts, load dispatchers, and grid managers, have played a crucial role in enhancing the performance of the supply chain. To analyze and refine the identified strategies, the study employs Fuzzy WASPAS-IVIF, providing a robust framework for evaluating and prioritizing strategies in the dynamic landscape of the electricity supply chain.

3.1. Value-Focused thinking (VFT)

VFT, as developed by Keeney in 1992, integrates concepts from problem structuring methods and soft Operational Research (OR), serving as a pragmatic tool in operational research practices tailored to address client needs, problem owners, and stakeholders. OR involves creating simplified mathematical models of complex real-world systems, focusing on defining useful variables and relationships that guide real-world actions efficiently. This process is underpinned by problem structuring, which is essential for transforming unstructured real-world issues into manageable problems with solvable mathematical models. VFT specifically aids in mapping out stakeholders' concerns into a structured and measurable set of variables, preparing the ground for constructing formal utility models that can guide decision-making processes (Figure 2).

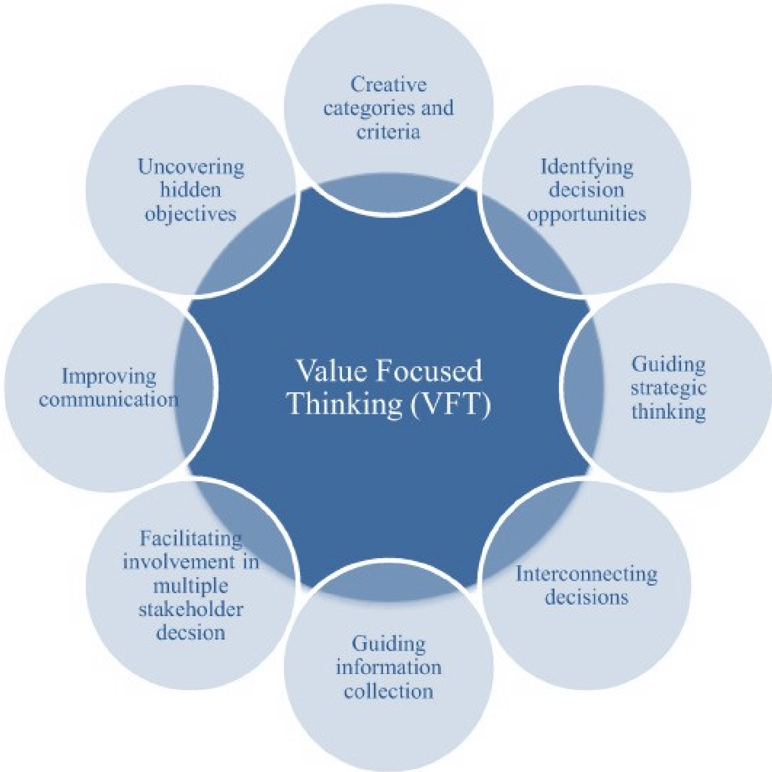

Figure 2. Value-Focused thinking process and elements

In the realm of soft OR, which uses elements of OR modeling to facilitate decision-making without necessarily arriving at a detailed formal solution, VFT plays a crucial role. It simplifies the formal OR methods to adapt to the dynamics of group and organizational processes, often culminating in qualitative decision-making by stakeholders. This approach is particularly effective in decision conferencing contexts, where VFT can be seamlessly integrated with decision analysis models to foster group interactions and facilitate consensus-building. By bridging problem structuring and decision analysis, VFT helps clarify and prioritize values and objectives within organizational processes and generates and evaluates strategic alternatives, making it a versatile tool in both structured decision analysis and broader soft OR applications.VFT application in this research

VFT represents a key application of soft operational research and systems thinking methodologies tailored to address strategic decision-making within the electricity supply chain amidst the complexities of Industry 4.0. This structured decision-making approach aligns supply chain strategies with the core organization's values and long-term objectives. Initially, the process involves identifying key stakeholders—experts, decision-makers, and other relevant parties within the electricity supply chain. A diverse team of eight experts is assembled to bring a broad range of perspectives and deep industry insights. During structured meetings, these experts engage in systems thinking to map out the interdependencies and potential impacts within the supply chain. They collaboratively work to define and prioritize the core values and strategic objectives, ensuring that the identified strategies are feasible but also integrative and systemic.

The application of VFT within this framework facilitates a holistic approach to decision-making. It emphasizes the importance of comprehensive engagement and collective intelligence, fostering a dynamic exchange of ideas underpinning robust, adaptable strategies. It is particularly crucial in navigating the rapidly evolving technological landscape of Industry 4.0, where the ability to anticipate and react to changes can significantly influence organizational resilience and adaptability. Furthermore, VFT supports operationalizing these strategies by ensuring they resonate with the organization's foundational principles and respond effectively to the current and anticipated challenges. This methodological approach not only underscores the technical feasibility of the strategies but also enhances their sustainability and relevance in the face of future developments. In summary, integrating VFT as a soft and systemic tool within the quantitative approaches provides a strategic, value-aligned approach to managing the complexities of the electricity supply chain in the era of Industry 4.0. By focusing on core values and the systemic impact of decisions, VFT helps to forge strategies that are effective in the short term and sustainable and adaptive over the long haul, thus aligning with the overarching goals and values of the electricity supply chain.

3.2. Basic concepts of intuitive fuzzy sets with interval values

Intuitive fuzzy sets are described by three functions: degree of membership, degree of non-membership, and degree of uncertainty. An intuitionistic fuzzy set A of the reference set X is defined as follows (Equation1);

$$A = \{\langle x, \mu_A(x), v_A(x)\rangle | x \epsilon X, \} \tag{1}$$

According to this definition, the degree of membership and the degree of non-membership are defined as follows (Equation 2 and 3):

$$\mu_A : X \rightarrow [0\,,1] \tag{2}$$

$$v_A : X \rightarrow [0\,,1] \tag{3}$$

And the following equation always holds (Equation 4):

$$0 \le \mu_A(X) + v_A(X) \le 1 \tag{4}$$

For each $x \epsilon X$ ، $\mu_{\tilde{A}}(x)$and $v_{\tilde{A}}(x)$are the interval values that $\mu_{AU}(x)$ ،$\mu_{AL}(x)$ ، $v_{AL}(x)$ ،$v_{AU}(x)$ form the upper limit and lower limit of this interval, respectively. The IVIF set is defined as follows in Equation. 5 and 6 (Zavadskas et al., 2014):

$$A = \{\langle x, [\mu_{AL}(x), \mu_{AU}(x)], [v_{AL}(x), v_{AU}(x)]\rangle | x \epsilon X, \} \tag{5}$$

$$0 \leq \mu_{AU}(X) + v_{AU}(X) \leq 1, \qquad 0 \leq \mu_{AL}(X) + v_{AU}(X) \leq 1 \tag{۶}$$

The interval intuitionistic fuzzy set is represented as $\tilde{A} = ([a, b], [c, d])$. If $\widetilde{A_1} = ([a_1, b_1], [c_1, d_1])$ and $\widetilde{A_2} = ([a_2, b_2], [c_2, d_2])$ are two IVIF numbers, the intuitive interval fuzzy operators are as defined below becomes (Equation 7-11):

$$\tilde{A}_1 + \tilde{A}_2 = ([a_1 + a_2 - a_1 a_2, b_1 + b_2 - b_1 b_2], [c_1 c_2, d_1 d_2]) \tag{7}$$

$$\tilde{A}_1 . \tilde{A}_2 = ([a_1, a_2, b_1 b_2], [c_1 + c_2 - c_1 c_2, d_1 + d_2 - d_1 d_2]) \tag{8}$$

$$\lambda \tilde{A} = ([1 - (1 - a_1)^{\lambda}, 1 - (1 - b_1)^{\lambda}], [c_1^{\lambda}, d_1^{\lambda}]) \qquad \lambda > 0 \tag{9}$$

$$\tilde{A}_1^{\lambda} = ([a_1^{\lambda}, b_1^{\lambda}], [1 - (1 - c_1)^{\lambda}, 1 - (1 - d_1)^{\lambda}]) \qquad \lambda > 0 \tag{10}$$

$$\frac{\tilde{A}_1}{\tilde{A}_2} = ([\min(a_1, a_2), \min(b_1, b_2)], [\max(c_1, c_2), \max(d_1, d_2)]) \tag{11}$$

To compare two IVIF numbers, the score function, $s(\tilde{A})$ is defined (Equation 12):

$$s(\tilde{A}) = \frac{1}{2}(a - c + b - d) \tag{12}$$

If $s(\tilde{A}) \in [-1,1]$, the accuracy function $h(\tilde{A})$ is used (Equation 13):

$$h(\tilde{A}) = \frac{1}{2}(a + c + b + d) \tag{13}$$

If $s(\tilde{A}_1) < s(\tilde{A}_2)$ we can conclude $(\tilde{A}_1) < (\tilde{A}_2)$؛

If $s(\tilde{A}_1) = s(\tilde{A}_2)$, then:

If $h(\tilde{A}_1) = h(\tilde{A}_2)$ we can conclude $(\tilde{A}_1) = (\tilde{A}_2)$؛

If $h(\tilde{A}_1) < h(\tilde{A}_2)$ we can conclude $(\tilde{A}_1) < (\tilde{A}_2)$.

3.3. Intuitive fuzzy WASPAS with interval values

WASPAS is one of the new decision-making techniques (Pamucar et al., 2022) and is categorized as multi-criteria decision-making methods (Khazaei et al., 2023; Zare et al., 2015; Wang et al., 2022). This method is a combination of the weighted sum model (WSM) and the

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weighted product model (WPM) (Putra et al., 2016; Taghipour et al., 2023). This model is highly effective in complex decision-making problems, and its results are highly accurate.

In this research, an expanded version of the WASPAS method (Zavadskas et al., 2014), namely WASPAS-IVIF, is presented (Zavadskas et al., 2014; Ilbahar, 2022), which can be applied in the environment of ambiguous decision making and uncertainty. Suppose the decision problem is a set of m number of options including $\tilde{A}_m, \ldots \tilde{A}_2, \tilde{A}_1$ and n number of criteria including $\tilde{c}_n, \ldots \tilde{c}_2, \tilde{c}_1$. Performance review and ranking of each option i in criterion j is done based on IVIF numbers. Also, k determines the number in relation to the importance of weight. w_j^k is k's expert's judgment about the importance of j's criterion. Table 2 decision-making variables will participate in the decision-making process. The decision maker expresses his opinions and evaluations in the language that is used to determine the weight of the criteria:

Table 2. Linguistic variable to determine the relative importance of criteria

Linguistic variable	IVIF Numbers
Very important (VI)	([0.9,0.9], [0.1,0.1])
Important (I)	([0.4,0.7625], [0 ,0.2115])
Medium (M)	([0.15,0.5125], [0.25,0.4625])
Unimportant (U)	([0 ,0.3625], [0.4,0.6125])
Very Unimportant (VU)	([0.1,0.1], [0.9,0.9])

The following formula is used to summarize the opinion of decision makers in a matrix (Equation 14):

$$w_i = \frac{1}{k}\left[\sum_{\rho=1}^{k} \tilde{w}_i^{\rho}\right], \qquad i = 1,2,3, \ldots, m \tag{14}$$

ρ represents the number of decision makers. Another element that must be calculated at this stage is the evaluation of options against the criteria according to the following matrix:

$$\tilde{X}^k = \begin{bmatrix} \tilde{x}_{11}^k & \tilde{x}_{12}^k & \cdots & \tilde{x}_{1n}^k \\ \tilde{x}_{21}^k & \tilde{x}_{22}^k & \cdots & \tilde{x}_{2n}^k \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{m1}^k & \tilde{x}_{m2}^k & \cdots & \tilde{x}_{mn}^k \end{bmatrix}$$

$$\tilde{x}_{ij}^k = \left(\left[\mu_{Lij}^k, \mu_{Uij}^k\right], \left[v_{Lij}^k, v_{Uij}^k\right]\right)$$

IVIF numbers, as specified in Table 3, are used to replace linguistic information to evaluate options against criteria:

Table 3. IVIFN scale for evaluating options against criteria

Linguistic variable	IVIF Numbers
Extremely Good (EG)	([1,1], [0,0])
Perfectly good (PG)	([0.9,0.9], [0.1,0.1])
Very Good (VG)	([0.7333,0.825], [0,0.125])
Good (G)	([0.6333,0.725], [0.1,0.225])
Medium Good (MG)	([0.5333,0.625], [0.2,0.325])
Medium (M)	([0.4333,0.525], [0.3,0.425])
Medium bad (MB)	([0.3333,0.425], [0.4,0.525])
Bad (B)	([0.15,0.2875], [0.42,0.6375])
Very bad (VB)	([0,0.1375], [0.6,0.7875])
Extremely Bad (EB)	([0.1,0.1], [0.9,0.9])

The next step (Equation 15) is to summarize the opinion in a matrix, meaning equation 16 is used (Putra et al., 2016, Ilbahar, 2022):

$$\tilde{x}_{ij} = \frac{1}{k}\left[\sum_{\rho=1}^{k} \tilde{x}_{ij}^{\rho}\right], \qquad j = 1,2,3,\ldots,n; \qquad 1 \leq \rho \leq k \tag{15}$$

As a result, the decision matrix with n options and m criteria is formed as follows:

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix}$$

$$\tilde{x}_{ij} = \left(\left[\mu_{Lij}, \mu_{Uij}\right], \left[v_{Lij}, v_{Uij}\right]\right)$$

The first step in the WASPAS-IVIF technique is the normalization of the X matrix. For this purpose, the criteria are divided into two categories: profit, B and cost, C (Pamucar et al., 2022). If $j \in B$, then (Equation 16-19):

$$\tilde{x}_{ij} = \frac{\tilde{x}_{ij}}{\max_i \tilde{x}_{ij}} \tag{16}$$

$$\max_i \tilde{x}_{ij} = \left(\left[\max_i \mu_{Lij}, \max_i \mu_{Uij}\right], \left[\min_i v_{Lij}, \min_i v_{Uij}\right]\right) \tag{17}$$

If $j \in C$ is

$$\tilde{x}_{ij} = \frac{\min_i \tilde{x}_{ij}}{{}_i\tilde{x}_{ij}} \tag{18}$$

$$\min_i \tilde{x}_{ij} = \left(\left[\min_i \mu_{Lij}, \min_i \mu_{Uij}\right], \left[\max_i v_{Lij}, \max_i v_{Uij}\right]\right) \tag{19}$$

According to the WASPAS-IVIF method, the total relative importance of the i-th criterion can be calculated as Equation 20:

$$Q_i^{(1)} = \sum_{j=1}^{n} \tilde{\tilde{x}}_{ij} w_j \tag{20}$$

Equations 7 and 8 are used to calculate $Q_i^{(1)}$. On the other hand, the relative importance of the entire i-th criterion can also be calculated using Equation. 21 and 22 (Zavadskas et al., 2014):

$$Q_i^{(2)} = \prod_{j=1}^{n} \tilde{\tilde{x}}_{ij}^{\tilde{w}_j} \tag{21}$$

$$(\tilde{\tilde{x}}_{ij})^{\tilde{w}_j} = \left(\left[min\left(\mu_{Lij}, \mu_{Lj}\right), min\left(\mu_{Uij}, \mu_{Uj}\right)\right], \left[max\left(v_{Lij}, v_{Lj}\right), max\left(v_{Uij}, v_{Uj}\right)\right]\right) \tag{22}$$

Finally, Eq. 23 is used to rank the criteria using the WASPAS method:

$$\tilde{Q}_i = 0.5Q_i^{(1)} + 0.5Q_i^{(2)} \tag{23}$$

Equations 9 and 7 are used to calculate $\tilde{Q}_i$.

4. Research findings

4.1. VFT analysis

In the initial stage of the research, a team of decision-makers comprising eight experts from diverse backgrounds, including managers, experts, and professors, was assembled as outlined in the research methodology. Various strategies were meticulously identified in the VFT process involving these expert participants to address challenges and enhance flexibility in the electricity supply chain within the Industry 4.0 era (Table 4). Implementing intelligent network systems (S1) emerged as a key approach among these strategies. By harnessing smart networks capable of collecting, analyzing, and transmitting real-time data, precise management of electricity production and consumption, both in terms of time and location, is facilitated.

Table 4. Strategies for Overcoming Challenges in Implementing a Resilient Electricity Supply Chain

Code	Strategy	Description	Reference
S1	Using intelligent network systems	Smart networks, with their ability to collect, analyze, and transmit accurate and up-to-date data, herald a new era in electricity production and consumption management, promising a future of unprecedented efficiency and control.	Zare et al., (2015), Wang et al., (2019)
S2	Anticipation and prevention of disorders	The proactive use of advanced technologies, such as the Internet of Things (IoT) and data analysis, to detect and predict malfunctions early on instills confidence in the resilience of our electricity supply chain.	Saghaei et al., (2020)), Richter et al., (2022)
S3	Use of renewable energy	By shifting our focus to energy production from renewable sources such as solar and wind, people are reducing their dependence on fossil fuels and paving the way for a more sustainable and stable supply chain.	Zhao et al., (2021), Saghaei et al., (2020)
S4	Use of energy storage	Energy storage technologies and systems can help increase stability in the face of fluctuations in production and consumption.	Wang et al., (2019)
S5	Use of microgrid networks.	Creating local and independent networks for producing and consuming electricity using renewable sources helps to balance demand and supply.	Queiroz et al., (2020)
S6	Using blockchain technology	Using blockchain technology to increase transparency, security, and accuracy in transactions and information transfer in the electricity supply chain can have a positive effect.	Queiroz et al., (2020)
S7	Using artificial intelligence and data analysis	Artificial intelligence and data analysis can effectively improve disruption prediction, optimize operations, and increase productivity in the electricity supply chain.	Queiroz et al., (2020)
S8	Development of advanced communication networks	Creating advanced and secure communication networks between different equipment and systems in the supply chain enables fast and accurate information exchange.	Wangsa and Wee, (2019)
S9	Strengthen cyber security	Increasing the security of networks and systems against cyber-attacks can be important to prevent disruptions and security threats.	Richter et al., (2022), Hosseini-Motlagh et al., (2020)
S10	Education and awareness	Creating awareness in society about the importance of electricity resilience and the role of Industry 4.0 technologies in improving it can help promote the required developments in the supply chain.	Vafadarnikjoo et al., (2022)

Furthermore, the strategies uncovered during the VFT sessions encompassed a comprehensive array, including the anticipation and prevention of disorders through advanced technologies like the Internet of Things (S2), the integration of renewable energy sources (S3) to enhance sustainability, the use of blockchain technology (S6) to bolster transparency and security, and the strengthening of cybersecurity measures (S9) to safeguard against potential disruptions. Additionally, a focus on education and awareness (S10) emerged as a crucial strategy, aiming to promote societal understanding of the significance of electricity resilience and the role of Industry 4.0 technologies in advancing improvements within the supply chain. These strategies collectively reflect a holistic and forward-looking approach toward fortifying the electricity supply chain in the era of Industry 4.0.

Moreover, the literature reviewfacilitated the recognition of linguistic variables, duly documented in Tables 2 and 3. Proceeding to the subsequent research stage, the relative significance of each index and sub-index was established through the expertise of the panel of experts, an essential step in the process, as depicted in Table 5.

Table 5. Relative importance of indicators and sub-indices

#	IP	RP	EP	IP-1	IP-2	IP-3	IP-4	RP-1	RP-2	RP-3
DM1	M	VI	U	VI	M	M	VU	I	U	VI
DM2	VI	M	VI	VI	VI	VI	VU	I	VI	VI
DM3	I	VU	I	M	I	VI	VU	VI	VI	VI
DM4	VI	I	VU	I	VI	U	VI	VI	M	VI
DM5	VI	I	M	I	VI	U	VI	VI	VI	VI
DM6	VI	VI	VI	M	M	VI	VI	VI	VI	VI
DM7	VI	VI	VI	VI	U	VI	VI	VI	VI	VI
DM8	VU	U	I	VI	VI	VU	VU	I	VU	VU

Step 5: In order to gather experts' opinions, the averaging method according to equation 14 was used. for example:

$$\widetilde{w}_1 = \frac{1}{8}\left[\sum_{\rho}^{8}([0.4,0.7625],[0,0.2115]) + ([0.9,0.9],[0.1,0.1]) + \cdots + ([0.9,0.9],[0.1,0.1])\right]$$

$$= ([0.99999985, 1],[\cdot,0.0000003642])$$

Step 6: By combining the opinions of experts and linguistic variables, the IVIF weights of indicators and sub-indices are as described in Tables 6:

Table 6. Aggregated weights of indicators

Criteria and Sub-Criteria	Locally aggregated weights
IP	[0.7485, 0.8225], [0, 0.17501]
RP	[0.6242, 0.70346], [0, 0.28890]
EP	[0.7532, 0.79405], [0, 0.19906]
IP-1	[0.276549, 0.53688], [0, 0.175019]
IP-2	[0.71514, 0.79520], [0, 0.19006]
IP-3	[0.6418578, 0.708395], [0.208707, 0.272394]
IP-4	[0.7, 0.7], [0.3, 0.3]
RP-1	[0.84202, 0.868354], [0, 0.143153]
RP-2	[0.7067167169, 0.7777392], [0.150129, 0.198]
RP-3	[0.89260, 0.86260], [0.1604, 0.1607]

Because the third index has only one sub-index, we consider its importance as one. Based on the rank order of the decision-making problem of the present research, the final weights of the sub-indices were obtained from the product of the local weights of the indicators in the local weights of the sub-indices of each of the indicators of the problem, which Table ۷ shows these weights:

Table 7. Final weights of sub-indices

Sub-Criteria	Final Weights
IP-1	[0.57511635, 0.66976334], [0, 0.32091634]
IP-2	[0.56128689, 0.64986296], [0, 0.34165628]
IP-3	[0.54483678, 0.61190355], [0.20870738, 0.38186085]
IP-4	[0.54940012, 0.57487816], [0.3, 0.42251270]
RP-1	[0.50055330, 0.60616453], [0, 0.38307443]
RP-2	[0.47968287, 0.56120632], [0.17550129, 0.43104936]
RP-3	[0.54050649, 0.61088411], [0.13160740, 0.38248840]
EP-1	[0.72532564, 0.79405263], [0, 0.19906558]

During Stage 3 of the research process, expert opinions were collected and aggregated using Equation 16. The resulting IVIF (Interval-valued intuitionistic fuzzy) decision matrix of expert opinions is presented in Appendix A1. This step facilitated the comprehensive synthesis of expert insights, contributing to the analytical framework's robustness and enriched decision-making process. Step 8: Using equations 16, 17, 18, and 19, the normalized IVIF decision matrix is calculated according to Appendix A2. Step 9: After calculating $Q_i^{(1)}$and $Q_i^{(2)}$ through equations 20 and 21, the values of $\tilde{Q}_i$ are determined according to Table 8.

Table 8. $\tilde{\mathbf{Q}}_{\mathbf{i}}$values

Strategies	$\tilde{Q}_i$
S1	[0.743349972, 0.817106485], [0.000000000, 0.217151760]
S2	[0.409193925, 0.535338164], [0.222354638, 0.209696697]
S3	[0.256828683, 0.405832631], [0.299830211, 0.168883582]
S4	[0.496928456, 0.627305665], [0.000000000, 0.242509585]
S5	[0.184903915, 0.276079113], [0.488400258, 0.147216919]
S6	[0.366258792, 0.492000017], [0.238890070, 0.189271880]
S7	[0.306473222, 0.455854733], [0.256295586, 0.182813609]
S8	[0.511336551, 0.638039114], [0.091083214, 0.213878104]
S9	[0.608131644, 0.714531781], [0.000000000, 0.220252736]
S10	[0.688267972, 0.776332034], [0.000000000, 0.225663948]

Step 10: Finally, each option's rank was calculated using the score function. Figure 3 shows the ranking of strategies.

Strategies	Score Function	Rank
S1	0.671652349	1
S2	0.256240377	6
S3	0.096973761	9
S4	0.440862268	4
S5	0.087317075	10
S6	0.21504843	7
S7	0.161609379	8
S8	0.422207174	5
S9	0.551205345	3
S10	0.603980263	2

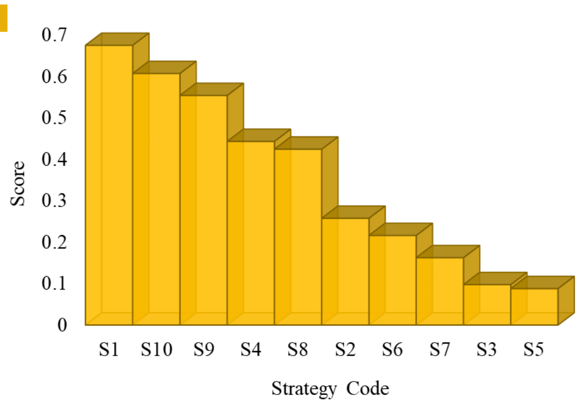

Figure 3. The final ranking of strategies

Considering the incoming strategies in facing the challenges and improving the flexibility in the electricity supply chain in the era of Industry 4.0, diverse strategies have been identified and evaluated to improve the abilities and deal with the obstacles. These strategies include using smart grid systems (S1) that improve the power grid's performance through automation and intelligent control. Also, predicting and preventing disruptions (S2) by using detailed data analysis and identifying disruption patterns so that they can be acted upon. Using renewable energy (S3) and using sustainable and environmental resources can help increase resilience and reduce environmental impacts.

According to the final calculation table, the ranking results can be evaluated. Based on the scoring function and ranking of the strategies, the strategy of using smart network systems (S1) and blockchain technology (S6) is ranked first and second, respectively. It shows that using blockchain in the electricity supply chain improves the security and transparency of transactions, reduces the possibility of errors, and increases the system's flexibility. Also, the strategy to strengthen cyber security (S9) and focus on education and awareness (S10) are among the top-rated strategies. As a result, the analysis of these tables shows that to increase flexibility and resilience in the electricity supply chain in the era of Industry 4.0, implementing smart technologies, using renewable resources, strengthening cyber security, and facilitating awareness and education can be among the key strategies.

5. Discussion and recommendations

This study highlights the essential role of Industry 4.0 technologies in enhancing the resilience of the electricity supply chain. By integrating advanced technologies such as smart grid systems, blockchain, and cybersecurity measures, the electricity supply chain can significantly improve flexibility and robustness against disruptions. The research findings suggest that these technologies facilitate better management and forecasting and ensure secure and transparent operations within the supply chain. The strategic use of these technologies is crucial, especially in a country like Iran, where energy demand is high, and the supply chain faces unique geopolitical and technical challenges.

- Electricity sector managers, like every energy systems, should actively pursue the integration of Industry 4.0 technologies (Ramezani et al., 2024). Implementing smart grid systems can enhance real-time data analysis and response capabilities, thus allowing for more efficient management of energy flows and immediate detection of faults or disruptions.
- As digital transformation escalates, cybersecurity becomes paramount. Managers need to ensure robust security protocols are in place to protect infrastructure from cyber threats (Kimani et al., 2019), which are becoming more sophisticated and frequent.

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- Blockchain technology offers immense potential beyond cryptocurrency. In the electricity supply chain, it can be used to improve the accuracy, transparency, and efficiency of transactions and data management. This technology also helps mitigate fraud and errors, thereby enhancing trust among stakeholders.
- Educational programs that can help stakeholders understand the importance of Industry 4.0 technologies in the electricity supply chain are needed (Taghipour et al., 2023b). Training employees on operating and maintaining new technologies will be crucial for smooth integration and operation.
- Policymakers should provide support through incentives, subsidies, and clear regulations that promote the adoption of Industry 4.0 technologies (Sharma et al., 2021). Such policies could accelerate technological adoption and ensure a standardized approach across the industry.
- Collaboration between academia, industry, and government can lead to innovative solutions and strategies that enhance resilience. These collaborations can also facilitate shared learning and leverage expertise from various fields (Wang et al., 2022).

6. Conclusion

This research investigated strategies for enhancing resilience in the electricity supply chain within the context of Industry 4.0. The challenges and opportunities surrounding resilience implementation were explored through a descriptive-analytical approach incorporating a literature review, field studies, VFT, and fuzzy IVIF-WASPAS analysis. The study found that intelligent network systems, blockchain technology, cybersecurity strengthening, and education promotion constitute the foremost strategies based on expert evaluations. Smart grid capabilities involving real-time data exchange and AI-enabled analytics allow precise management of electricity flows. Blockchain provides transparency, security, and accuracy in supply chain transactions and communications. Robust cybersecurity defenses are essential to safeguard against disruptions.

Additionally, societal education and awareness are key enablers for advancing improvements. These findings have significant managerial and policy implications. Organizations must actively embrace Industry 4.0 technologies like automation, IoT, and data analytics to predict and mitigate disturbances through agile responses. Developing renewable energy infrastructure and AI systems will be pivotal for long-term resilience. Effective cooperation and open communication among stakeholders should also be fostered. For policymakers, the research underscores the need for investments, incentives, and standards to facilitate nationwide Industry 4.0 integration, renewables expansion, and electricity infrastructure modernization.

However, certain limitations exist, including the context-specific focus on Iran's electricity landscape. Additionally, the qualitative nature of VFT and WASPAS analyses relies on subjective expert inputs. Quantitative modeling through optimization algorithms could be incorporated in future works. There are also opportunities for expanded criteria evaluation encompassing economic, social, and environmental dimensions. Larger expert panels with global representation may provide broader perspectives.

Nonetheless, this research delivers a rigorous analytical framework combining diverse resilience concepts, Industry 4.0 viewpoints, and multi-criteria decision-making tools. The findings help define a roadmap for Iranian electricity supply chain stakeholders to embark on the transition towards intelligence, sustainability, and resilience. With apt contextualization, the strategies can inform electricity resilience enhancement globally amidst the complex transformations of Industry 4.0.

In future research, exploring the sustainable electricity supply chain further by incorporating renewable energy sources such as solar, wind, and particularly hydrogen energy offers a promising avenue. Hydrogen, as a clean energy carrier, holds the potential to revolutionize energy systems by providing a high-density energy storage solution, which can significantly enhance the flexibility and resilience of electricity supply chains. Moreover, integrating critical systems thinking methods could yield deeper insights into the systemic interdependencies and complexities within the electricity supply chain. This approach would facilitate a more holistic understanding of the barriers and opportunities in transitioning toward sustainable energy practices. Additionally, employing other systems thinking methodologies, such as Soft Systems Methodology (SSM) or System Dynamics (SD), could provide a structured way to model and simulate the impacts of various strategies on the sustainability and efficiency of the supply chain. These methods would allow for a dynamic exploration of policy scenarios and technology integration, supporting decision-makers in crafting robust strategies to navigate the challenges of the evolving energy landscape.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendices

Appendix A1: Aggregated IVIF matrix of expert opinions (Expert 4 as an example).

Sub-Criteria	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
IP-1	PG	B	B	MG	EG	B	B	G	G	G
IP-2	PG	B	VB	M	VB	EB	B	B	VG	VG
IP-3	EG	MG	M	G	VB	MG	M	VG	VG	PG
IP-4	EG	B	M	G	EB	G	MG	MG	PG	EG
RP-1	EG	G	M	G	EB	MG	MB	MG	PG	EG
RP-2	EG	VG	VB	VG	EB	M	M	VG	PG	PG
RP-3	EG	MG	MB	MG	EB	M	M	PG	EG	EG
EP-1	EG	G	B	G	EB	G	B	G	PG	G

Appendix A2: Normalized IVIF decision matrix.

Sub-Criteria	S1	S2
IP-1	[0.15000, 0.28750], [0.45000, 0.63750]	[0.58631, 0.67887], [0.14142, 0.27042]
IP-2	[0.19200, 0.32271], [0.42776, 0.60599]	[0.47393, 0.57647], [0.22462, 0.36734]
IP-3	[0.11327, 0.12354], [0.85462, 0.88754]	[0.11327, 0.12354], [0.85462, 0.88754]
IP-4	[0.43209, 0.52898], [0.28517, 0.41809]	[0.66530, 0.73726], [0.00000, 0.22088]
RP-1	[0.08456, 0.11228], [0.88452, 0.88776]	[0.08456, 0.11228], [0.88452, 0.88776]
RP-2	[0.04987, 0.12537], [0.70386, 0.81345]	[0.04987, 0.12537], [0.70386, 0.81345]
RP-3	[0.00325, 0.00325], [0.98999, 0.98999]	[0.00325, 0.00325], [0.98999, 0.98999]
EP-1	[0.090142, 0.10236], [0.78631, 0.79986]	[0.090142, 0.10236], [0.78631, 0.79986]
Sub-Criteria	**S3**	**S4**
IP-1	[0.12360, 0.25482], [0.49394, 0.67353]	[0.51883, 0.61184], [0.00000, 0.33456]
IP-2	[0.14123, 0.27241], [0.47649, 0.65597]	[0.54145, 0.63523], [0.17955, 0.31310]
IP-3	[0.11327, 0.12354], [0.85462, 0.88754]	[0.11327, 0.12354], [0.85462, 0.88754]
IP-4	[0.30083, 0.39010], [0.43337, 0.56039]	[0.60095, 0.69392], [0.12510, 0.25508]
RP-1	[0.08456, 0.11228], [0.88452, 0.88776]	[0.08456, 0.11228], [0.88452, 0.88776]
RP-2	[0.04987, 0.12537], [0.70386, 0.81345]	[0.04987, 0.12537], [0.70386, 0.81345]
RP-3	[0.00325, 0.00325], [0.98999, 0.98999]	[0.00325, 0.00325], [0.98999, 0.98999]
EP-1	[0.090142, 0.10236], [0.78631, 0.79986]	[0.090142, 0.10236], [0.78631, 0.79986]
Sub-Criteria	**S5**	**S6**
IP-1	[0.07598, 0.10953], [0.81324, 0.87045]	[0.21821, 0.30952], [0.48356, 0.63695]
IP-2	[0.07598, 0.10953], [0.81324, 0.87045]	[0.23410, 0.31770], [0.50126, 0.63395]
IP-3	[0.11327, 0.12354], [0.85462, 0.88754]	[0.11327, 0.12354], [0.85462, 0.88754]
IP-4	[0.11277, 0.15106], [0.75681, 0.82566]	[0.57615, 0.66924], [0.14877, 0.27964]
RP-1	[0.08456, 0.11228], [0.88452, 0.88776]	[0.08456, 0.11228], [0.88452, 0.88776]
RP-2	[0.04987, 0.12537], [0.70386, 0.81345]	[0.04987, 0.12537], [0.70386, 0.81345]
RP-3	[0.00325, 0.00325], [0.98999, 0.98999]	[0.00325, 0.00325], [0.98999, 0.98999]
EP-1	[0.090142, 0.10236], [0.78631, 0.79986]	[0.090142, 0.10236], [0.78631, 0.79986]
Sub-Criteria	**S7**	**S8**
IP-1	[0.98987, 0.98987], [0.00000, 0.00000]	[0.22400, 0.34255], [0.43056, 0.59273]
IP-2	[1.00000, 1.00000], [0.00000, 0.00000]	[0.31142, 0.42480], [0.35676, 0.51316]
IP-3	[0.11327, 0.12354], [0.85462, 0.88754]	[0.11327, 0.12354], [0.85462, 0.88754]
IP-4	[0.83721, 0.85387], [0.10000, 0.13554]	[0.67779, 0.72980], [0.15651, 0.24019]
RP-1	[0.08456, 0.11228], [0.88452, 0.88776]	[0.08456, 0.11228], [0.88452, 0.88776]
RP-2	[0.04987, 0.12537], [0.70386, 0.81345]	[0.04987, 0.12537], [0.70386, 0.81345]
RP-3	[0.00325, 0.00325], [0.98999, 0.98999]	[0.00325, 0.00325], [0.98999, 0.98999]
EP-1	[0.090142, 0.10236], [0.78631, 0.79986]	[0.090142, 0.10236], [0.78631, 0.79986]
Sub-Criteria	**S9**	**S10**
IP-1	[0.66378, 0.75956], [0.00000, 0.18531]	[0.66136, 0.75438], [0.00000, 0.19425]
IP-2	[0.65013, 0.74558], [0.00000, 0.19944]	[0.98987, 0.98987], [0.00000, 0.00000]
IP-3	[0.11327, 0.12354], [0.85462, 0.88754]	[0.11327, 0.12354], [0.85462, 0.88754]
IP-4	[0.90000, 0.90000], [0.10000, 0.10000]	[0.98987, 1.00000], [0.00000, 0.00000]
RP-1	[0.08456, 0.11228], [0.88452, 0.88776]	[0.08456, 0.11228], [0.88452, 0.88776]
RP-2	[0.04987, 0.12537], [0.70386, 0.81345]	[0.04987, 0.12537], [0.70386, 0.81345]
RP-3	[0.00325, 0.00325], [0.98999, 0.98999]	[0.00325, 0.00325], [0.98999, 0.98999]
EP-1	[0.090142, 0.10236], [0.78631, 0.79986]	[0.090142, 0.10236], [0.78631, 0.79986]