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# Analysis of Multi-Objective Decision-Making Indicators for Evaluating Smart Supply Chain Risks in the Electricity Industry Using the Attride-Stirling Method


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## ABSTRACT

This study analyzes multi-objective decision-making indicators for evaluating non-dominated solutions to smart supply chain risks in the electricity industry using the Attride-Stirling thematic analysis method. The research is applied in purpose and adopts a descriptive-analytical, qualitative survey design. The expert panel consisted of 18 electricity industry professionals and academic specialists with expertise in smart supply chains and decision-making, whose insights were employed to identify, refine, and validate the emerging themes.

Data were collected through an extensive review of the relevant literature and semi-structured expert interviews. Thematic analysis was conducted following Braun and Clarke's six-phase framework, including data familiarization, initial coding, theme generation, theme review, theme definition and naming, and report preparation. The analysis yielded 45 initial codes organized around the overarching theme of developing a multi-objective framework for evaluating non-dominated solutions to smart electricity supply chain risks. Three second-level organizing themes were identified: risk and reliability criteria, economic and cost criteria, and operational and resilience criteria. To ensure methodological rigor, Holsti's coefficient, Scott's pi, Cohen's kappa, and Krippendorff's alpha were employed to evaluate credibility and reliability, yielding values of 0.811, 0.835, 0.850, and 0.909, respectively, indicating substantial inter-coder agreement. The proposed framework provides a conceptually coherent and reliable basis for supporting multi-objective decision-making, selecting Pareto-efficient solutions, strengthening intelligent risk management, and enhancing digitally enabled supply chain resilience in the electricity industry.




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## Introduction

The smart electricity supply chain has evolved from a traditional procurement and logistics system into an intelligent, data-driven ecosystem in which suppliers, manufacturers, contractors, logistics providers, warehouses, operational units, and regulatory agencies continuously exchange information through digital technologies. The integration of the Internet of Things (IoT), artificial intelligence (AI), cloud computing, and real-time analytics has significantly improved supply chain visibility, responsiveness, and operational coordination. However, the infrastructure-intensive and capital-intensive nature of the electricity industry means that disruptions in this interconnected network can simultaneously affect operational efficiency, equipment availability, energy reliability, and national energy security. Consequently, smart supply chain risk management has become a strategic priority rather than merely an operational concern.

Managing these risks requires decision-makers to simultaneously consider multiple, often conflicting objectives. For example, minimizing procurement and logistics costs may reduce operational flexibility, while increasing redundancy, safety stock, or supplier diversification may improve resilience but substantially increase investment and maintenance costs. Similarly, strategies that maximize operational reliability may require longer implementation times or greater organizational resources. Because these objectives cannot be optimized simultaneously, supply chain managers must identify non-dominated (Pareto-efficient) solutions, where improvements in one objective inevitably require compromises in another. Accordingly, evaluating such solutions demands a multi-objective decision-making (MODM) perspective that simultaneously incorporates technical, economic, operational, resilience, sustainability, and implementation criteria rather than relying on a single performance indicator (Khoshal et al., 2025).

The complexity of this decision environment is further intensified by the diverse sources of supply chain risk within the electricity industry. In addition to operational and technical uncertainties, organizations face supplier disruptions, dependence on foreign vendors, exchange-rate volatility, geopolitical restrictions and sanctions, transportation failures, natural disasters, cyber vulnerabilities, and inconsistent supplier performance (Ebrahimpour et al., 2024). These interconnected risks differ not only in their probability of occurrence but also in their consequences, propagation speed, recovery time, and long-term operational impact. Therefore, evaluating non-dominated solutions requires a comprehensive assessment of their capability to reduce critical risks while maintaining acceptable levels of reliability, resilience, flexibility, economic efficiency, and regulatory compliance (Fuladvand et al., 2025).

Another important challenge lies in balancing economic efficiency with operational resilience. Risk mitigation strategies—including supplier diversification, strategic inventory, localization of critical equipment, and long-term partnerships with key suppliers—typically enhance supply continuity but increase investment and operational costs. Conversely, lean procurement strategies, supplier concentration, and extensive outsourcing may improve short-term financial performance while exposing the supply chain to greater vulnerability during disruptions. Consequently, non-dominated solutions represent different trade-offs between competing objectives, making their evaluation fundamentally a multi-objective decision problem rather than a purely financial or operational assessment (Fathi et al., 2023).

Moreover, decision-making is complicated by substantial uncertainty associated with delivery times, supplier capacity, transportation conditions, exchange-rate fluctuations, and the occurrence of extreme natural events (Ghasemi et al., 2023). Under these conditions, an alternative that performs well under normal operating circumstances may become ineffective during high-risk scenarios. Therefore, robust evaluation of non-dominated solutions requires considering multiple operational scenarios together with organizational readiness, implementation feasibility, and long-term sustainability. In practice, organizations frequently prefer solutions that provide balanced and implementable performance rather than theoretically optimal alternatives that are difficult to deploy (Ghobishi et al., 2022; Vamarzani et al., 2026; Sadri et al., 2024).

Despite the growing body of literature on supply chain risk management, multi-criteria decision analysis, and smart electricity systems, existing studies primarily focus on developing optimization models or prioritizing risks, while providing limited guidance on which decision indicators should be used to evaluate non-dominated solutions generated by multi-objective decision-making frameworks. Furthermore, there is no comprehensive thematic framework that systematically identifies, organizes, and explains these evaluation indicators within the context of smart electricity supply chains. This gap limits the practical applicability of multi-objective approaches because decision-makers often lack a structured basis for comparing Pareto-efficient alternatives.

To address this research gap, the present study applies the Attride-Stirling thematic network approach to identify and organize the key multi-objective decision-making indicators required for evaluating non-dominated solutions in smart electricity supply chain risk management. By extracting expert knowledge and developing a hierarchical thematic framework, the study provides a conceptual foundation for supporting intelligent decision-making under conflicting objectives. Accordingly, the main research question is: What multi-objective decision-making indicators should be used to evaluate non-dominated solutions in smart electricity supply chain risk management, and how can these indicators be organized into a coherent thematic framework?

## Literature Review

In the smart supply chain of the power industry, supply chain risk is no longer just a support or logistics issue, but has become a key factor in ensuring network stability, the continuity of development projects, and maintaining service reliability. In this chain, which is based on data integrity, information transparency, and real-time decision-making using technologies such as the Internet of Things, artificial intelligence, and predictive analytics, any disruption in the supply flow can quickly propagate throughout the network. The power industry’s dependence on specialized equipment, sensitive control technologies, imported components, and a network of contractors and suppliers has made it more exposed to supply chain vulnerabilities than many other industries. In such circumstances, delays in the supply of critical equipment—from cables and high-voltage switches to transformers and protection systems—can have consequences such as increased operating costs, project delays, and even disruption to network operation (Liang et al., 2024). Therefore, risk management in the smart supply chain of the power industry has become a strategic imperative to maintain the resilience of the energy infrastructure.

In this complex environment, organizations are faced with a set of managerial and technological solutions to reduce risk, none of which has absolute superiority. Some options increase economic efficiency by optimizing costs and using forecasting tools, but may reduce supply chain flexibility; in contrast, solutions such as diversifying suppliers or creating strategic inventory increase system resilience, but impose higher costs. Such conditions cause decision-making about risk management solutions to take on a multi-criteria nature and the concept of “non-dominated solutions” becomes important (Gong et al., 2025). A non-dominated solution refers to an option that is not weaker than other options in all criteria and has relative superiority in at least one or more performance dimensions. In the power industry supply chain, these criteria can include cost, reliability of supply, equipment quality, delivery time, flexibility, dependency risk, and level of technical support. Therefore, evaluating non-dominant solutions is essentially a process of comparing options that each offer a different balance between economic efficiency and operational resilience (Guo and Hu, 2025).

In this framework, the evaluation of options should not be focused solely on economic indicators, but should also measure the impact of each solution on technical and operational resilience. For example, complete reliance on a single external supplier may have appropriate cost and quality, but create high dependency; in contrast, using multiple suppliers simultaneously or creating strategic inventory can reduce the risk of supply disruption, although it may entail higher costs (Lee et al., 2025; Ezensi et al., 2025). Therefore, determining evaluation criteria plays a fundamental role in selecting appropriate options (Kumar et al., 2024). In addition, the evaluation of solutions should be dynamic and have the ability to adapt to changing environmental conditions and risk levels (Niranjan et al., 2025). The development of supply chain information systems and digital platforms can also guide the decision-making process towards a data-driven and predictive approach by increasing data transparency and real-time analytics (Lee et al., 2025).

On the other hand, in the evaluation of non-dominated solutions, a distinction should be made between everyday risks and critical risks, because focusing solely on the average performance of options may lead to the selection of solutions that are efficient under normal conditions but do not perform well in the face of severe shocks (Kulkarni et al., 2024). In such situations, solutions that have the ability to prevent widespread disruptions or network shutdowns—even if they are costlier in the short term—will have higher strategic value (Nieuw et al., 2025; McIver et al., 2025).

Also, feasibility is one of the determining factors in the selection of solutions. In many cases, an option that performs better in theoretical models is not feasible due to organizational or infrastructure constraints; while an option with moderate performance but high implementability can produce better practical results (Fru-Soto et al., 2024). In the power industry, the diversity of perspectives among different organizational units—from purchasing and logistics to operations and finance—also affects the evaluation of options and sometimes leads to different perceptions of the desirability of a solution (Huang et al., 2024). Therefore, in many cases, combining several complementary solutions—such as developing alternative suppliers, creating strategic inventories for critical items, and using smart monitoring systems—can create a better balance between cost, resilience, and operational sustainability in the power industry’s smart supply chain (Kitor and Agarwal, 2024).

The evolution of smart supply chains in the electricity industry is closely associated with the broader digital transformation of economic and financial ecosystems. Modern electricity supply chains increasingly rely on digital platforms, real-time data exchange, cloud computing, artificial intelligence, blockchain, and Internet of Things (IoT) technologies to support decentralized decision-making and autonomous operations. These digital infrastructures constitute essential components of the emerging digital economy, where operational decisions, resource allocation, and risk management are integrated with intelligent financial services such as digital transactions, automated contracting, smart payments, and blockchain-enabled traceability. Consequently, evaluating supply chain risks through multi-objective decision-making contributes not only to operational efficiency but also to the development of secure, transparent, and data-driven financial ecosystems that underpin smart industrial networks.

Furthermore, the rapid emergence of metaverse-enabled industrial environments has expanded the application of virtual platforms for monitoring, simulating, and optimizing complex supply chain operations. Digital twins, virtual collaboration spaces, immersive visualization technologies, and AI-driven simulation environments enable organizations to evaluate multiple risk scenarios and compare non-dominated solutions before implementing strategic decisions in physical systems. Within the electricity industry, these virtual environments facilitate more accurate risk assessment, enhance operational resilience, and improve the integration of smart financial services through real-time information sharing and automated decision support. Therefore, the analysis of multi-objective decision-making indicators for evaluating non-dominated solutions provides a theoretical bridge between smart supply chain risk management, the digital economy, virtual industrial ecosystems, and intelligent financial services, thereby strengthening the alignment of this study with the journal's interdisciplinary scope.

Studies conducted in the field of supply chain risk management in the energy industry show that this field has gradually moved from traditional approaches to the use of analytical tools and new technologies. In domestic research, the main focus has been on the use of analytical and modeling methods to improve risk management and supply chain performance. For example, Barzegar et al. (2025) used artificial intelligence algorithms to analyze risk in international energy trade supply chain financial services. The results of this study showed that the use of artificial intelligence-based models can improve the accuracy of assessing corporate creditworthiness, predicting environmental risks, and the quality of financial decision-making, and ultimately reduce operational and regulatory risks in supply chain financial services. In another study, Ghasemi-Barghi et al. (2023) designed an agent-based model for the supply chain and examined optimal risk management strategies. The results showed that in different scenarios, although the total cost of production and distribution did not differ significantly, reducing shortage costs increased profitability and improved customer satisfaction along the supply chain. These findings indicate that effective risk management can improve the economic performance of the supply chain in addition to reducing uncertainty.

At the international level, several studies have also examined risk in the energy supply chain. Mansouri et al. (2025) in a study on the sustainable bioethanol supply chain in Mexico showed that high initial investment in infrastructure and biomass conversion technologies is the most important risk to the development of this chain, and the lack of transparent policies was also identified as another important factor in increasing uncertainty. Betty Arousegbe et al. (2024) focused on global supply chains and presented a framework for identifying and reducing vulnerabilities in the field of transportation and logistics, emphasizing measures such as diversifying suppliers, developing inter-organizational collaborations, and using new technologies to increase supply chain resilience. Also, Hamuda et al. (2024) in a systematic review of the literature on sustainable supply chain management in energy production showed that existing research in this area is scattered and unbalanced, and some important dimensions such as inter-organizational coordination, stakeholder participation, and information integrity have received less attention. On the other hand, Axon and Darton (2023) showed in a study on energy security that even a decrease in energy demand has an independent supply chain that is exposed to a variety of operational and structural risks.

The increasing adoption of smart supply chain systems in the electricity industry has made multi-objective decision-making (MODM) an essential approach for evaluating and managing complex supply chain risks. Due to the dynamic nature of electricity supply chains, decision-makers must simultaneously optimize multiple conflicting objectives, including cost reduction, operational reliability, resilience, sustainability, service quality, and response speed. Traditional single-objective optimization techniques are insufficient for addressing these competing goals; therefore, multi-objective optimization methods generate a set of non-dominated (Pareto-optimal) solutions that represent different trade-offs among objectives. Evaluating these solutions requires robust decision-making indicators capable of identifying alternatives that achieve an appropriate balance between economic, technical, operational, and environmental performance while maintaining resilience against supply chain disruptions.

Recent studies have emphasized that the effectiveness of multi-objective optimization depends not only on generating Pareto-optimal solutions but also on employing comprehensive performance indicators to assess their quality. Indicators such as convergence, diversity, spread, hypervolume (HV), inverted generational distance (IGD), and epsilon (ε) provide quantitative measures for comparing non-dominated solution sets and evaluating the performance of optimization algorithms. In the context of smart electricity supply chains, where organizations face uncertainties arising from demand fluctuations, cyber threats, infrastructure failures, supplier disruptions, and energy market volatility, these evaluation indicators facilitate more reliable and data-driven decision-making. Consequently, the analysis of multi-objective decision-making indicators for evaluating non-dominated solutions provides a strong theoretical foundation for developing intelligent risk management models that enhance supply chain resilience, resource allocation efficiency, and long-term operational sustainability in the electricity industry.

The primary contribution of this study lies in developing the first comprehensive thematic framework that systematically identifies and organizes multi-objective decision-making indicators for evaluating non-dominated (Pareto-efficient) solutions in the context of smart electricity supply chain risk management. Unlike previous studies, which have mainly focused on optimization algorithms, risk prioritization, or multi-criteria decision-making techniques, this research concentrates on the evaluation criteria themselves by extracting expert knowledge through the Attride-Stirling thematic network approach. The study bridges the gap between theoretical concepts of multi-objective decision-making and practical supply chain risk management by integrating risk, reliability, economic, operational, and resilience indicators into a unified conceptual framework. This framework provides both a theoretical foundation for future multi-objective optimization research and a practical reference for decision-makers seeking to evaluate and select balanced Pareto-efficient solutions under complex and conflicting supply chain objectives in the electricity industry.

## Method

The present study is applied in terms of purpose and descriptive in terms of analytical nature and is classified as survey research. In this study, the application of Attride-Stirling content analysis in analyzing the indicators of the multi-objective model for evaluating non-dominant solutions to supply chain risks in the electricity industry has been addressed, and for this purpose, the content analysis method has been used. One of the simple and efficient methods of qualitative analysis is content analysis.

1. In your opinion, what are the most significant risks affecting smart supply chains in the electricity industry?
2. What factors have the greatest impact on the performance of smart supply chains in the electricity industry?
3. Which criteria should be considered simultaneously when evaluating smart supply chain risks?
4. What advantages does multi-objective decision-making offer over single-objective approaches in supply chain risk management?
5. What are the major conflicting objectives in managing smart supply chains within the electricity industry?
6. In your view, what characteristics should an effective non-dominated (Pareto-optimal) solution possess?
7. Which indicators do you consider most appropriate for evaluating the quality of non-dominated solutions?
8. How can organizations achieve a balance among cost, reliability, resilience, and sustainability in smart supply chain management?
9. How do smart technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), and Big Data Analytics contribute to reducing supply chain risks?
10. What factors enhance the resilience of electricity supply chains against internal and external disruptions?
11. Which performance indicators are essential for assessing the effectiveness of a multi-objective decision-making model?

12. What criteria should be used to prioritize decision alternatives under uncertainty?
13. How important is the use of real-time data in improving multi-objective decision-making for supply chain risk management?
14. What are the major challenges in implementing multi-objective decision-making models in the electricity industry?
15. What strategies would you recommend for improving the quality of non-dominated solutions in supply chain risk management?
16. How should the performance of multi-objective optimization algorithms be evaluated and compared?
17. To what extent are indicators such as Convergence, Diversity, Hypervolume (HV), Inverted Generational Distance (IGD), and Epsilon (ε) important for evaluating non-dominated solutions?
18. What organizational and managerial factors influence the successful implementation of multi-objective decision-making models?
19. What recommendations would you provide for improving the flexibility, resilience, and sustainability of smart supply chains in the electricity industry?
20. If you were to develop a comprehensive framework for evaluating non-dominated solutions to smart supply chain risks, what dimensions, indicators, and components would you include?

This study was conducted based on the views of 18 experts familiar with the electricity industry and academic professors related to the subject. In terms of gender, 12 are male and 6 are female. Finally, 14 people have less than 10 years of work experience and 4 people have more than 15 years of work experience, which is specified in Table 1 according to their frequency.

***Table 1.*** *Demographic characteristics of experts*

| Demographic characteristics | | Percentage | Frequency |
|---|---|---|---|
| Gender | Male | 69% | 12 |
| | Female | 31% | 6 |
| Work Experience | Under 10 years | 75% | 14 |
| | Over 11 years | 25% | 4 |
| | Total | 100% | 18 |

## Findings

Analysis and Research Findings:

The qualitative data were analyzed using the Attride-Stirling thematic network approach, which provides a systematic framework for organizing textual data into hierarchical thematic structures. This method consists of three main analytical stages.

***Stage 1: Coding and Theme Extraction***

The first stage involved familiarizing the researchers with the interview transcripts and identifying meaningful text segments related to the research objective. Each meaningful unit was assigned an initial code based on its conceptual meaning. Similar codes were subsequently grouped together to form Basic Themes, which represent the lowest level of abstraction and capture the explicit ideas expressed by participants. These basic themes were continuously refined through comparison and discussion until conceptual consistency was achieved.


***Figure 1.*** *Keywords in thematic network*

***Stage 2: Organizing Themes into Thematic Networks***

In the second stage, conceptually related Basic Themes were clustered to develop broader Organizing Themes. These themes represent higher-order conceptual categories that explain the relationships among multiple basic themes. The organizing themes were then integrated to construct an Overall (Global) Theme, which captures the central phenomenon of the study. This hierarchical structure (Basic Themes → Organizing Themes → Global Theme) formed the thematic network and provided a comprehensive representation of the experts' perspectives on multi-objective decision-making indicators for evaluating smart supply chain risks in the electricity industry.

***Stage 3: Interpretation and Network Description***

The final stage focused on interpreting the thematic network and explaining the relationships among the identified themes. The researchers examined how the organizing themes collectively contributed to the global theme and interpreted their theoretical and practical implications in the context of smart electricity supply chain risk management. To enhance the trustworthiness of the findings, the extracted themes were reviewed by the research team and validated through expert feedback. Furthermore, inter-coder agreement was assessed using Holsti's coefficient, Scott's pi, Cohen's kappa, and Krippendorff's alpha to ensure the reliability and consistency of the coding process.

***Table 2.*** *Identifying the overarching theme of presenting a multi-objective model for evaluating non-dominant solutions to supply chain risks in the electricity industry*

| **Overarching theme: Presenting a multi-objective model for evaluating non-dominant solutions to supply chain risks in the electricity industry** | | |
|---|---|---|
| Primary theme | Constructive Theme 1 | Constructive Theme 2 |
| Delays by suppliers in delivering equipment | Probability of supply disruption | Risk and reliability criteria |
| Probability of equipment failure in transit | | |
| Dependence on a single supplier | | |
| Political and sanction risks in importing equipment | | |
| Instability of the transportation and logistics network | | |
| Amount of energy not supplied during disruption | Severity of disruption impact | |
| Financial loss due to power generation shutdown | | |
| Number of subscribers affected by a definite outage | | |
| Duration of the network outage | | |
| Impact of disruption on the stability of the power network | | |
| Percentage of on-time delivery of equipment | Reliability of supply | |
| Success rate of supply contracts | | |
| Quality level of delivered equipment | | |
| Suppliers' performance history | | |
| Delivery compliance rate with the production schedule | | |
| Equipment purchase cost | Total supply chain cost | Economic and cost criteria |
| Transportation and logistics cost | | |
| Inventory maintenance cost | | |
| Warehousing and storage cost | | |
| Supply administrative and contractual costs | | |
| Equipment safety stock cost | Risk management cost | |
| Insurance and risk coverage cost | | |

| | | |
|---|---|---|
| Supply support contracts cost | | |
| Risk monitoring and management systems cost | | |
| Training and crisis management program cost | | |
| Ratio of supply cost to value of produced energy | Economic efficiency of supply | |
| Efficiency Investment in equipment supply | | |
| Ratio of operating cost to production output | | |
| Efficiency in use of supply resources | | |
| Cost savings resulting from supply optimization | | |
| Time to detect supply disruption | System recovery time | Operational and resilience criteria |
| Time to procure replacement equipment | | |
| Time to repair or replace damaged equipment | | |
| Time to return the network to a stable state | | |
| Speed of coordination between operating units | | |
| Number of alternative suppliers | Supply chain flexibility | |
| Ability to change transportation routes | | |
| Possibility of using replacement equipment | | |
| Level of strategic equipment inventory | | |
| Ability to quickly change supply plans | | |
| Ability to continue operations in crisis conditions | Supply chain resilience | |
| Capacity to respond to major disruptions | | |
| Level of preparedness of emergency plans | | |
| Amount of coordination between supply chain actors | | |
| Ability to learn and recover after a crisis | | |

The thematic network was developed following the Attride-Stirling (2001) approach through a systematic and iterative coding procedure. Initially, all interview transcripts were transcribed verbatim and reviewed several times to achieve a comprehensive understanding of the participants' perspectives regarding multi-objective decision-making indicators for evaluating smart supply chain risks in the electricity industry. During the open coding stage, meaningful statements and key expressions related to supply chain risk assessment, operational performance, reliability, economic efficiency, resilience, and decision-making were identified and assigned initial codes. This process resulted in 45 primary themes (initial codes) representing the explicit concepts expressed by the experts.

In the second stage, conceptually similar primary themes were compared and grouped into broader conceptual categories. Through continuous comparison and refinement, the initial codes were synthesized into nine first-level constructive themes, including *Probability of Supply Disruption*, *Severity of Disruption Impact*, *Supply Reliability*, *Total Supply Chain Cost*, *Risk Management Cost*, *Economic Efficiency of Supply*, *System Recovery Time*, *Supply Chain Flexibility*, and *Supply Chain Resilience*. These first-level themes were subsequently integrated into three second-level constructive themes, namely Risk and Reliability Criteria, Economic and Cost Criteria, and Operational and Resilience Criteria. Each second-level theme represents a major dimension of evaluating supply chain risks from a multi-objective decision-making perspective.

Finally, the relationships among the second-level themes were examined to identify the underlying concept that unified all dimensions of the analysis. This process led to the development of the overarching theme, "Presenting a Multi-Objective Model for Evaluating Non-Dominated Solutions to Supply Chain Risks in the Electricity Industry." The resulting hierarchical thematic network (Primary Themes → First-Level Constructive Themes → Second-Level Constructive Themes → Overarching Theme) provides a comprehensive conceptual framework that explains how operational, economic, reliability, and resilience indicators jointly contribute to evaluating Pareto-efficient (non-dominated) solutions for intelligent supply chain risk management in the electricity industry. The thematic structure was reviewed by the research team and validated by domain experts to ensure conceptual consistency, while coding reliability was confirmed using Holsti's coefficient, Scott's pi, Cohen's kappa, and Krippendorff's alpha.

Based on the above table, the research pattern consisted of 1 overarching theme and 3 level 2 organizing themes and 9 level 1 constructive themes. Finally, based on the final categories, the research model was presented:

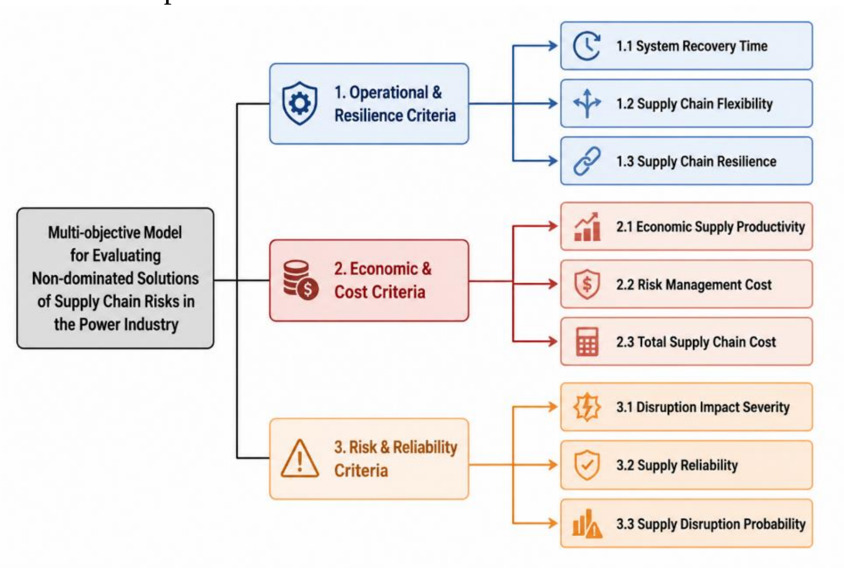


***Figure 2.*** *Design and explanation of the presentation of a multi-objective model for assessing non-dominant solutions to electricity industry supply chain risks*

Four quantitative criteria were used to examine the validity, transferability, verifiability, and reliability: Holstey coefficient, Scott's p-value, Cohen's kappa index, and Krappendorf's alpha.

The correlation of expert opinions by calculating the Holstey coefficient (PAO) or "percentage of observed agreement" was 0.811, which is a significant value. Considering the shortcomings of the Holstey method, the p-value was also calculated, which was 0.835. The fourth indicator of the validity of qualitative research is the Cohen's kappa index. The Cohen's kappa index in this study was 0.850. Finally, Krappendorf's alpha was used, and its value in this study was estimated to be 0.909.

## Discussion

The findings from the content analysis show that the design of a multi-objective model for evaluating non-dominated solutions to electricity industry supply chain risks is based on three main clusters of criteria, including “risk and reliability”, “cost and economic efficiency”, and “operation and resilience”. In the first cluster, criteria related to the probability and severity of supply disruption play a fundamental role in explaining structural risks of the supply chain. In this section, factors such as supplier delays, equipment breakdowns in the transportation route, dependence on a single supplier, and political-sanction risks have all been identified as the main drivers of disruption. This finding is consistent with recent studies in the field of energy supply chains, which emphasize that the fragility of global supply chains in the energy sector is primarily due to supply concentration and geopolitical shocks (Ivanov & Dolgui, 2024; Khan et al., 2025).

In addition to the probability of disruption, the severity of the disruption effect, as the second dimension of this cluster, is also of particular importance in the model. Indicators such as the amount of energy not supplied, financial losses due to the cessation of electricity production, the number of subscribers affected, and the duration of the outage show that risk in the electricity industry is not simply a probabilistic variable, but has broad social and economic consequences. These results are consistent with the findings of Strelzoff et al. (2024) who show that in critical infrastructure, the severity of consequences plays a more prominent role in resilient decision-making than the probability of occurrence. Also, the reliability of supply through indicators such as on-time delivery, equipment quality, and supplier performance history has been proposed as a key dimension in reducing uncertainty in the smart supply chain (Mohammadi et al, 2022; Salehi et al, 2022).

In the second cluster, economic and cost criteria, the findings show that decision-making in the power industry supply chain cannot be explained solely on the basis of the direct cost of purchasing equipment, but rather a set of hidden and direct costs must be considered simultaneously. The total cost of the supply chain, logistics costs, inventory holding and administrative costs, along with risk management costs such as insurance, safety stock and monitoring systems, form a complex cost structure. This result is consistent with recent research in the field of energy supply chain management, which emphasizes the need to move from “simple cost-oriented” to “developed cost-oriented” (Axon et al, 2023). The economic efficiency index also shows that the ratio of cost to the value of energy produced and the return on investment in equipment play a decisive role in choosing between non-dominant solutions.

In the third cluster, operational and resilience measures, the results show that system recovery time is one of the most critical indicators in evaluating the performance of the smart supply chain in the electricity industry. The time to detect a disruption, procure replacement equipment, repair or replace damaged equipment, and return the network to a stable state all indicate the system’s responsiveness capacity. These findings are consistent with recent studies in the field of energy infrastructure resilience, which emphasize that reducing recovery time is more important than reducing the probability of disruption (Ding et al., 2025). Supply chain flexibility through the availability of alternative suppliers, the ability to change transportation routes, and the level of strategic inventory have also been identified as key factors in reducing system fragility.

Supply chain resilience, as the highest level of this conceptual model, also includes the ability to continue operating in crisis conditions, the capacity to respond to major disruptions, and the level of coordination among chain actors. These results show that resilience is not simply a static attribute, but a dynamic and learning capability that is shaped by the interaction between supply chain actors. This is consistent with new perspectives in smart supply chain management that emphasize the role of organizational learning and data-driven analytics in enhancing resilience (Christopher & Peck, 2004).

Comparing the results of this study with previous literature shows that the proposed multi-objective model, unlike traditional single-criteria approaches, is able to simultaneously cover the three key dimensions of risk, cost, and resilience in an integrated framework. While many previous studies have focused on either cost or risk, this model attempts to strike a balance between economic efficiency and operational sustainability. As a result, it can be said that this model is not only in line with new smart supply chain approaches, but also allows for a more accurate assessment of non-dominated solutions in complex power industry conditions by integrating technical, economic, and operational criteria. The results show that success in managing supply chain risk in the electricity industry depends on the ability to understand the interaction between these three clusters of criteria and transform them into a multi-objective decision-making model. Such an approach can lead to improved grid stability, reduced vulnerability to external shocks, and increased overall efficiency of the smart supply chain.

## Conclusion

The most important achievements of the present study are the identification of three main categories of criteria including risk and reliability criteria, economic and cost criteria, and operational and resilience criteria. These three categories, in fact, show the fundamental dimensions of decision-making in complex and multi-objective situations in the electricity industry. Risk and reliability criteria revealed that the probability of supply disruption, the severity of the disruptions, and the level of supplier reliability are key factors in evaluating decision options. These findings indicate that in the electricity industry, supply disruption is not a purely logistical issue, but can also lead to outages, reduced network stability, increased direct and indirect costs, and widespread stakeholder dissatisfaction. Therefore, any non-dominant solution selected in the multi-objective model must be able to control or reduce this category of risks. In the economic and cost dimension, the results of the research also showed that the evaluation of solutions should not be based solely on the purchase cost or current costs, but rather all costs related to the supply chain, including transportation costs, warehousing, inventory maintenance, support contracts, insurance, training, monitoring systems and other risk management costs, should be viewed in an integrated manner. This is important because an option may appear to be low-cost, but in the event of a disruption, it will impose much greater losses on the network. On the other hand, some options, although they have a higher initial cost, will be more cost-effective in the long run due to reduced probability of a crisis, increased reliability and easier recovery. From this perspective, the research findings emphasize that the concept of optimality in the electricity industry is not limited to cost minimization alone, but must be integrated with risk and operational sustainability considerations. The third dimension of the findings, namely operational criteria and resilience, is of particular importance in the research framework. The results showed that the system recovery time, supply chain flexibility and resilience are among the most important components that should be considered in the evaluation of non-dominated solutions. This study developed a thematic framework of multi-objective decision-making indicators for evaluating non-dominated solutions to smart supply chain risks in the electricity industry using the Attride-Stirling thematic network approach. The findings identified Risk and Reliability Criteria, Economic and Cost Criteria, and Operational and Resilience Criteria as the three principal dimensions that collectively determine the quality of Pareto-efficient solutions under multiple conflicting objectives. These dimensions demonstrate that effective supply chain risk management cannot rely on a single evaluation criterion, as improving one objective, such as cost efficiency, may reduce resilience or operational reliability. Instead, decision-makers should evaluate alternatives by simultaneously considering technical, economic, operational, and resilience-related indicators to identify balanced solutions capable of supporting sustainable and intelligent supply chain performance.

The proposed framework contributes to the literature by bridging the gap between multi-objective decision-making theory and practical supply chain risk evaluation in the electricity industry. Beyond identifying key evaluation indicators, the framework offers a structured conceptual basis for comparing non-dominated solutions and supporting strategic decision-making under uncertainty. From a managerial perspective, the findings enable electricity organizations to prioritize investment decisions, improve supplier selection, strengthen supply chain resilience, and enhance risk governance through comprehensive performance evaluation. Future studies may extend the proposed framework by integrating quantitative multi-objective optimization methods, fuzzy and stochastic decision-making models, or machine learning techniques to validate and operationalize the identified indicators in real-world electricity supply chain environments.

The first recommendation is that companies and institutions active in the electricity industry, in evaluating supply options and managing supply chain risk, move away from single-criteria approaches and apply multi-objective frameworks. In many executive decisions, the main focus is on minimizing the cost of purchasing or accelerating the supply of equipment, while the results of this research showed that such an approach may ignore other critical dimensions such as reliability, severity of the impact of disruption, recovery time and resilience of the supply chain. Therefore, it is recommended that managers and decision-makers in the electricity industry, when selecting supply solutions, consider a balanced set of risk, economic and operational indicators simultaneously so that their choices are more comprehensive and effective. The second recommendation is that organizations related to the electricity industry design and implement a coherent system for identifying, monitoring and prioritizing supply chain risks. Based on the findings, the possibility of supply disruption, dependence on limited suppliers, delays in equipment delivery, transportation instability, and political and sanctions risks are among the most important factors threatening the supply chain of this industry. Therefore, it is necessary for supply, logistics, and risk management units to continuously monitor these risks and define exposure scenarios and preventive measures for each. Establishing such a system can reduce the organization's surprise during a crisis and improve operational readiness. The third suggestion is to diversify supply sources and reduce dependence on exclusive suppliers. One of the most important themes extracted in the research was the role of the number of alternative suppliers and the ability to shift supply sources in increasing supply chain flexibility. Accordingly, it is suggested that electricity industry organizations create a diverse network of qualified domestic and foreign suppliers instead of relying too much on one or more limited suppliers. This measure can reduce vulnerability to sudden disruptions, sanctions, market fluctuations, and transportation problems, and also increase the organization's power of choice and bargaining power.

The fourth suggestion is to manage the strategic inventory of critical equipment and sensitive items in the electricity industry with a targeted approach. The research findings showed that the time to provide replacement equipment and the level of rapid access to essential items have a direct impact on the system recovery time and reduce the severity of the consequences of the disruption. Therefore, it is recommended that electricity industry managers, by identifying key equipment, define and maintain an appropriate level of safety reserves and strategic inventory for crisis situations. Of course, this measure should be accompanied by a detailed cost-benefit analysis so that, on the one hand, the risk of equipment shortages is reduced and, on the other hand, warehousing costs and dormant capital are not out of control.

The fifth suggestion is to strengthen the monitoring, warning, and intelligent supply chain management infrastructure in the electricity industry. The results of this research showed that the speed of disruption detection and initial response time are important factors in reducing the effects of the crisis and increasing the efficiency of management solutions. Therefore, it is recommended that organizations continuously monitor supply status, inventory, contracts, and environmental risks using integrated information systems, management dashboards, transportation tracking systems, data analytics, and forecasting tools. This can shift decision-making from reactive to proactive and preventive.

This study has several limitations that should be acknowledged. First, the proposed thematic framework was developed based on qualitative data obtained from a relatively limited number of experts in the electricity industry; therefore, the findings reflect expert perceptions and may not fully represent all operational contexts or geographical regions. Second, the study focused on identifying and organizing multi-objective decision-making indicators rather than quantitatively validating their relative importance or measuring their impact on supply chain performance. Third, the framework was developed specifically for smart supply chain risk management in the electricity industry, which may limit its direct generalizability to other industrial sectors without further adaptation.

Future research should quantitatively validate the proposed framework using multi-criteria decision-making techniques, such as AHP, ANP, DEMATEL, TOPSIS, or integrated fuzzy multi-objective optimization methods. Researchers may also examine the relationships among the identified indicators through structural equation modeling or system dynamics approaches and evaluate their effectiveness using real-world operational data. Furthermore, integrating artificial intelligence, digital twins, blockchain, and machine learning into the proposed framework could improve the evaluation and selection of Pareto-efficient solutions under uncertainty. Comparative studies across different industries or countries would also provide valuable insights into the applicability and robustness of the proposed conceptual framework.

## Declaration of Competing Interest

The author declares that he has no competing financial interests or known personal relationships that would influence the report presented in this article.

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