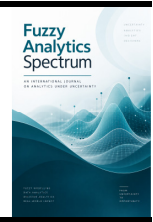




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A Fuzzy Decision Framework for the Energy Security Policy Selection

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ABSTRACT

Energy security policy is a strategic governmental approach aimed at ensuring reliable, affordable, and sustainable energy access by reducing geopolitical risks, minimizing foreign dependency, and promoting diversification in energy sources and infrastructure. The main motivation is to design a decision support system tailored for energy security policy selection. The paper proposes a robust and consistent hybrid method based on multi-criteria decision-making enhanced by fuzzy sets and complex computational models. Specifically, the Aczel-Alsina-spherical cubic fuzzy (SCF)-weights by envelope and slope (WENSLO)-ranking based on the distances and range (RADAR) hybrid method is introduced as a novel approach for selecting energy security policies. Policy selection criteria are weighted using the Aczel-Alsina-SCF-WENSLO method. The ranking of alternative energy security policies is conducted using the Aczel-Alsina-SCF-RADAR method. The proposed method is implemented in a real-world case study focusing on Germany, within the context of the Ukraine-Russia conflict. The policy titled Energy diplomacy based on the interests of Germany is identified as the most suitable, while strategic energy diversification emerges as the most critical criterion. The study presents methodological and practical findings, along with implications for methodology, practice, German policy, and global energy security strategy.

1. Introduction

Energy security has become a cornerstone of national policy agendas, especially in light of intensifying geopolitical tensions, fluctuating fossil fuel markets, and pressing global climate

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objectives [1]. It encompasses not only uninterrupted access to energy resources but also the establishment of sustainable, economically viable, and environmentally responsible energy systems [2,3]. Ensuring energy security requires governments to implement strategic energy policies that prioritize long-term supply stability, reduce dependency on foreign energy sources [4], and foster diversification across energy types [5], suppliers, and infrastructures [6].

Energy security policies involve multiple dimensions, including the development and modernization of energy infrastructure, the establishment of strategic reserves, and the regulation of energy production, transmission, and consumption [7]. The transition towards renewable energy sources, or alternatively, the continued reliance on fossil fuels, significantly influences policy formulation processes [8,9]. Governments are thus tasked with balancing these often-competing objectives (security of supply, affordability, and sustainability) under conditions of high uncertainty.

The formulation of energy security policies is inherently multi-stakeholder and multi-level. Key actors include national and local governments, energy regulatory authorities, private sector companies, international energy organizations (such as the IEA), and civil society institutions [10]. Regulatory frameworks and strategic policy instruments are often developed through collaboration between public authorities and energy companies, who are directly involved in energy generation, distribution, and infrastructure development [11]. In parallel, international actors and supranational institutions (particularly the European Union (EU) for its Member States) play a critical role in shaping binding policy frameworks. Additionally, non-governmental organizations [12] and universities contribute to the policy development process by providing data-driven insights, modeling policy scenarios, and advocating for environmental responsibility, particularly in line with the United Nations' Sustainable Development Goals (SDGs).

In the case of Germany, energy security policymaking is shaped by the country's obligations under the EU's energy and climate framework [13], as well as its national energy transition strategy (Energiewende). The German Federal Ministry for Economic Affairs and Climate Action (BMWK) plays a central role in coordinating national energy strategies, conducting policy research, and guiding infrastructure investments. The energy crisis triggered by the Russia–Ukraine conflict has highlighted Germany's vulnerability due to its previous dependence on Russian natural gas [14]. This situation has prompted a paradigm shift toward a more diversified, resilient, and autonomous energy system [15]. In this context, energy security policy must not only address immediate supply risks but also be aligned with long-term climate neutrality targets and EU Green Deal objectives.

Strategic energy planning in Germany now necessitates comprehensive situation assessments, risk evaluations, and the exploration of multiple policy alternatives. These include expanding liquefied natural gas (LNG) import capacities, accelerating the deployment of renewable energy technologies [16], enhancing international energy diplomacy, and revisiting the pace of nuclear and coal phase-outs [17]. Selecting the most appropriate energy security policy under such conditions requires robust, participatory, and scientifically grounded decision-making tools that can accommodate both expert judgment and uncertainty.

This research responds to this complex challenge by proposing a novel decision support system (DSS) for energy security policy selection. The proposed system adopts a hybrid multi-criteria decision-making (MCDM) methodology "Aczel-Alsina–spherical cubic fuzzy (SCF)–weights by envelope and slope (WENSLO)–ranking, based on the distances and range (RADAR)" that enables structured, transparent, and expert-informed evaluation of policy alternatives. The framework incorporates fuzzy logic to capture linguistic uncertainty, uses advanced aggregation and weighting techniques to reflect differing levels of expertise among stakeholders, and allows for the prioritization and ranking of energy security policy options based on a comprehensive set of geopolitical, economic, and sustainability-oriented criteria.

The hybrid model consists of three primary stages: (i) expert weighting based on linguistic scales and SCF sets [18]; (ii) criteria weighting using Aczel-Alsina–SCF–WENSLO [19], which combines ratio-based weighting with robust fuzzy aggregation; and (iii) policy ranking through the Aczel-Alsina–SCF–RADAR technique [20]. This integrated structure provides a rigorous and adaptable decision-making process capable of reflecting the complexity and stakeholder diversity inherent in energy security governance.

The proposed DSS is applied to a real-world case study of Germany, wherein eight alternative energy security policies were developed and evaluated across 11 criteria. Experts contributed assessments using linguistic variables, which were processed through the hybrid methodology to identify the most suitable energy policy option under current geopolitical risks. The findings not only demonstrate the applicability and robustness of the proposed method but also offer actionable insights for policymakers seeking to reinforce national energy resilience amid uncertainty.

This study aims to establish a robust and comprehensive decision support framework for energy security policy selection by incorporating expert evaluations and advanced decision-making tools. The core aims and contributions are outlined as follows:

- i. *Development of a hybrid DSS* – The study proposes a novel hybrid DSS (i.e., Aczel-Alsina–SCF–WENSLO–RADAR) to enhance the transparency, objectivity, and computational depth of energy policy decision-making under uncertainty.
- ii. *Formulation of strategic policy alternatives and criteria* – Eight energy security policy alternatives were developed for Germany, reflecting diverse strategic orientations. In parallel, 11 evaluation criteria were designed to capture the geopolitical, economic, infrastructural, and sustainability dimensions of policy selection.
- iii. *Integration of expert judgment via SCF sets* – The research utilizes SCF sets to model linguistic uncertainty and varying expert confidence levels, enabling the accurate quantification of subjective judgments.
- iv. *Advanced aggregation through spherical cubic fuzzy Aczel–Alsina weighted averaging (SCFAAWA) operator* – The SCFAAWA aggregation operator (AO), grounded in Aczel-Alsina t -norms and t -conorms, was employed to aggregate expert evaluations more robustly than conventional methods, ensuring greater accuracy in collective decision modeling.
- v. *Ratio-based weighting through SCF–WENSLO* – The SCF–WENSLO technique was applied for the objective weighting of decision criteria, using ratio vector-based logic to better reflect the relative importance of each factor in expert assessments.
- vi. *Application to a real-world geopolitical scenario* – A case study on Germany's energy policy amid the Ukraine–Russia conflict demonstrated the applicability of the proposed method, with the policy "Energy diplomacy based on the interests of Germany" emerging as the most effective option and "strategic energy diversification" as the most influential criterion.
- vii. *Validation through sensitivity and comparative analyses* – The method's robustness was confirmed through two scenario-based sensitivity analyses. Additionally, comparative validation with nine MCDM techniques showed strong correlations, reinforcing the consistency and credibility of the proposed approach.

To achieve the objectives and deliver the expected contributions, this paper is structured into six sections. Section 2 introduces the proposed methodological framework, namely Aczel-

Alsina–SCF–WENSLO–RADAR, designed for energy security policy evaluation. Section 3 presents a real-world case study focused on Germany’s energy security policy selection. This section outlines the alternative policy options developed for Germany, explains the policy selection criteria, and applies the proposed hybrid method step-by-step. Section 4 discusses the results of the case study within a broader analytical context. Section 5 provides methodological insights, practical implications, and key takeaways specific to Germany, as well as general conclusions relevant to global energy policy. Finally, Section 6 concludes the paper with a summary of the main findings and potential avenues for future research.

2. Methodology Framework

In this study, a novel hybrid method (Aczel-Alsina–SCF–WENSLO–RADAR) is proposed for the selection of energy security policies. The proposed hybrid approach facilitates the evaluation and prioritization of energy security strategies based on expert assessments. Structurally, the method comprises three sequential stages, wherein expert evaluations, initially expressed through linguistic terms, are converted into numerical representations using SCF numbers. The aggregation of these expert assessments is conducted through SCFAAWA, which is enhanced by Aczel-Alsina-based t -norm and t -conorm computations to improve robustness and computational accuracy.

In *Stage 1*, expert weight vectors are determined based on their level of expertise, utilizing SCF sets and a predefined linguistic scale. *Stage 2* involves the application of Aczel-Alsina–SCF–WENSLO to compute the weight vectors of the decision criteria. In *Stage 3*, the Aczel-Alsina–SCF–RADAR technique is employed to calculate the ranking scores of the proposed energy security policy alternatives. Each stage includes multiple sub-steps designed to ensure methodological transparency and computational precision.

The flowchart detailing the overall structure of the proposed hybrid methodology is presented in Figure 1. In the methodology section, the operational principles of SCF sets and SCFAAWA (based on Aczel-Alsina t -norm and t -conorm operations) are first introduced. Subsequently, the step-by-step procedural framework of Aczel-Alsina–SCF–WENSLO–RADAR is presented in detail, outlining the full implementation process.

The preliminaries on SCF sets based on Aczel-Alsina t -norm and t -conorm are given in Appendix A. Aczel-Alsina–SCF–WENSLO–RADAR functions as a DSS. Within this framework, the decision-making process is based on expert opinions. The decision model includes three primary input components: energy policy experts ($\Gamma = \{\Gamma_1, \Gamma_2, \dots, \Gamma_r, \dots, \Gamma_R\} (r = 1, 2, \dots, R)$), energy security policy selection criteria ($\Lambda = \{\Lambda_1, \Lambda_2, \dots, \Lambda_f, \dots, \Lambda_F\} (f = 1, 2, \dots, F)$), and alternative energy security policies ($\Omega = \{\Omega_1, \Omega_2, \dots, \Omega_b, \dots, \Omega_B\} (b = 1, 2, \dots, B)$). Aczel-Alsina–SCF–WENSLO–RADAR consists of three main stages, detailed as follows:

- **Stage 1 – Assign weights to the experts for the decision-making process using SCF sets.**

Step 1-1: Experts (Γ_r) with varying levels of expertise are classified according to the expertise levels (Table 1). An SCF-based expertise level vector ($\tilde{\mathcal{F}} = [\tilde{\mathcal{F}}_r]_R$) is constructed accordingly. In this vector, the expertise level of the r -th expert is represented.

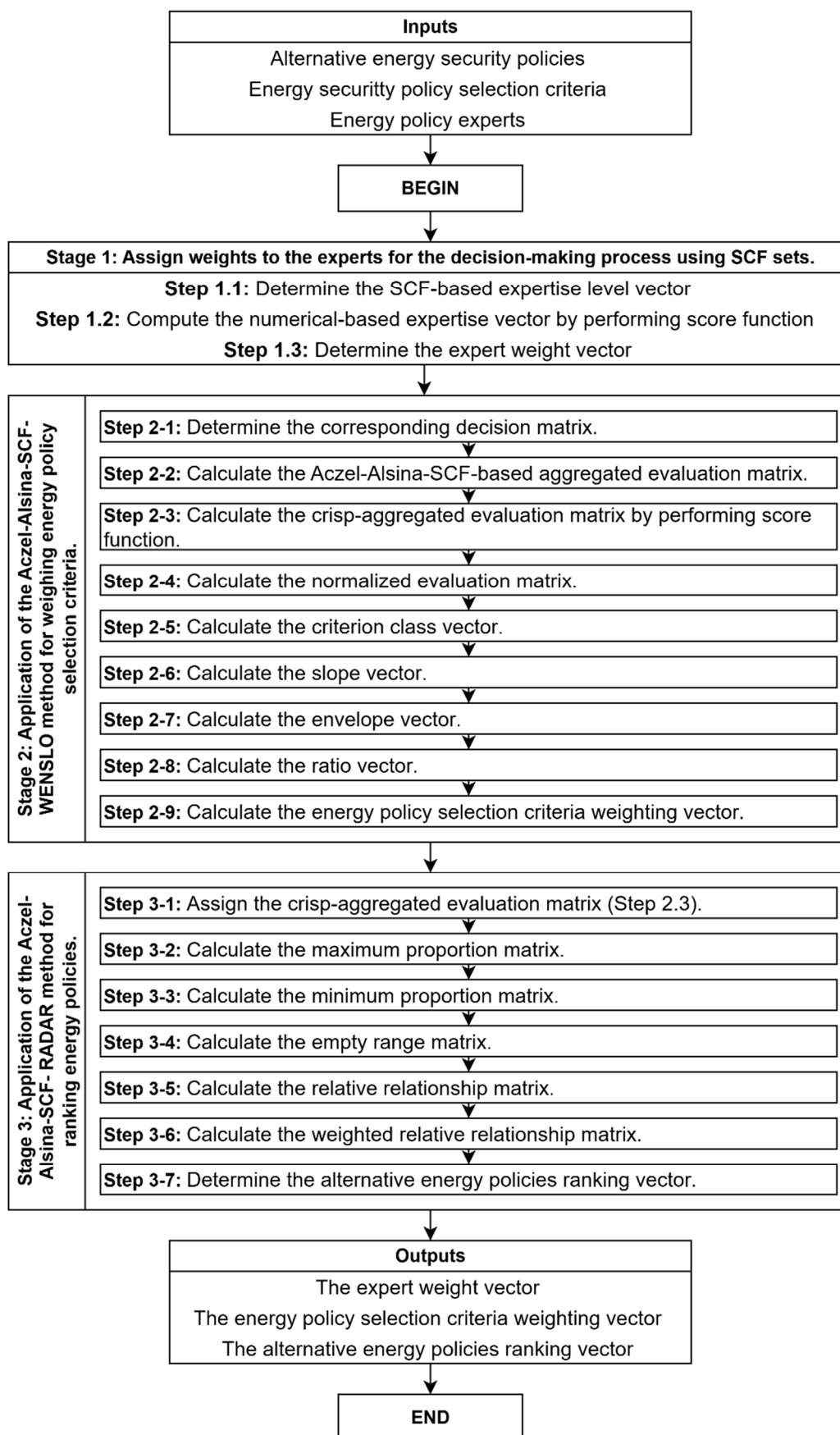


Fig. 1. Diagram of Aczel-Alsina–SCF–WENSLO–RADAR

Table 1

Assessment scales for expertise, criteria, and alternatives [21]

Scales	SCF numbers
	$\{([\kappa^-(\rho), \kappa^+(\rho)], \kappa(\rho)), ([\hbar^-(\rho), \hbar^+(\rho)], \hbar(\rho)), ([\sigma^-(\rho), \sigma^+(\rho)], \sigma(\rho))\}$
Extremely-high-importance (EHI)	$\{([0.8, 0.9], 0.85), ([0, 0.1], 0.05), ([0, 0.1], 0.05)\}$
Very-high-importance (VHI)	$\{([0.7, 0.8], 0.75), ([0.1, 0.2], 0.15), ([0.1, 0.2], 0.15)\}$
High-importance (HI)	$\{([0.6, 0.7], 0.65), ([0.2, 0.3], 0.25), ([0.2, 0.3], 0.25)\}$
Slightly-high-importance (SHI)	$\{([0.5, 0.6], 0.55), ([0.3, 0.4], 0.35), ([0.3, 0.4], 0.35)\}$
Medium-importance (MI)	$\{([0.4, 0.5], 0.45), ([0.4, 0.5], 0.45), ([0.4, 0.5], 0.45)\}$
Slightly-low-importance (SLI)	$\{([0.3, 0.4], 0.35), ([0.3, 0.4], 0.35), ([0.5, 0.6], 0.55)\}$
Low-importance (LI)	$\{([0.2, 0.3], 0.25), ([0.2, 0.3], 0.25), ([0.2, 0.7], 0.65)\}$
Very-low-importance (VLI)	$\{([0.1, 0.2], 0.15), ([0.1, 0.2], 0.15), ([0.1, 0.8], 0.75)\}$
Extremely-low-importance (ELI)	$\{([0, 0.1], 0.05), ([0, 0.1], 0.05), ([0, 0.9], 0.85)\}$

Step 1-2: The process of determining expert weights begins with the conversion of SCF numbers into numerical values. A numerical-based expertise vector ($\mathfrak{F} = [\mathfrak{F}_r]_R$) is then derived using the score function ($S(\mathfrak{F}_r)$) by Eq. (1).

$$\mathfrak{F}_r = S(\mathfrak{F}_r) = \frac{1}{2} \left(1 + \frac{1}{9} \left(\left(\kappa_{\mathfrak{F}_r}^-(\rho) + \kappa_{\mathfrak{F}_r}^+(\rho) + \kappa_{\mathfrak{F}_r}(\rho) \right)^2 + \left(\hbar_{\mathfrak{F}_r}^-(\rho) + \hbar_{\mathfrak{F}_r}^+(\rho) + \hbar_{\mathfrak{F}_r}(\rho) \right)^2 + \left(\sigma_{\mathfrak{F}_r}^-(\rho) + \sigma_{\mathfrak{F}_r}^+(\rho) + \sigma_{\mathfrak{F}_r}(\rho) \right)^2 \right) \right); (r = 1, \dots, R) | S(\mathfrak{F}_r) \in [0, 1] \quad (1)$$

Step 1-3: The numerical-based expertise vector is normalized (Eq. (2)) to derive the expert weight vector ($\vartheta = [\vartheta_r]_R$), which reflects the contribution level of each expert in the decision-making process. In this vector, the decision-making influence of the r -th expert is indicated.

$$\vartheta_r = \frac{\mathfrak{F}_r}{\sum_{r=1}^R \mathfrak{F}_r}; (r = 1, \dots, R) \quad (2)$$

The expert weight vector ($\vartheta = (\vartheta_1, \vartheta_2, \dots, \vartheta_r, \dots, \vartheta_R)$) is identified with each $\vartheta_r \in [0, 1]$ and the constraint as $\sum_{r=1}^R \vartheta_r = 1$.

• **Stage 2 – Application of Aczel-Alsina–SCF–WENSLO for weighting energy policy selection criteria.**

Step 2-1: To apply Aczel-Alsina–SCF–WENSLO for criteria weighting, experts (Γ_r) must first evaluate alternative energy policies (Ω_b) according to the energy policy selection criteria (Λ_f). The evaluation process relies on the scale shown in Table 1, and the expert assessments are used to build a corresponding decision matrix ($\mathfrak{Y}^{(\Gamma_r)} = [\mathfrak{Y}_{bf}^{(\Gamma_r)}]_{BF}$), wherein $\mathfrak{Y}_{bf}^{(\Gamma_r)} (r = 1, 2, \dots, R; b = 1, 2, \dots, B; f = 1, 2, \dots, F)$.

Step 2-2: For the weighted aggregation of expert assessments, the SCFAAWA AO (Eq. (3)) is applied, resulting in the construction of the Aczel-Alsina–SCF-based aggregated evaluation matrix ($\mathfrak{E} = [\mathfrak{E}_{bf}]_{BF}$).

$$SCFAAWA \left(\mathfrak{Y}^{(r_1)}, \mathfrak{Y}^{(r_2)}, \dots, \mathfrak{Y}^{(r_r)}, \dots, \mathfrak{Y}^{(r_R)} \right) = \bigoplus_{r=1}^R \vartheta_r \mathfrak{Y}^{(r_r)} = \left(\left(\left(\sqrt[1]{1 - \exp \left\{ - \left(\sum_{r=1}^R \left(\vartheta_r \left(- \ln \left(1 - \left(\kappa_{\mathfrak{Y}^{(r_r)}}^-(\rho) \right)^2 \right) \right)^\ell \right) \right)^{\frac{1}{\ell}}} \right. \right. \right. \right. \\ \left. \left. \left. \sqrt[1]{1 - \exp \left\{ - \left(\sum_{r=1}^R \left(\vartheta_r \left(- \ln \left(1 - \left(\kappa_{\mathfrak{Y}^{(r_r)}}^+(\rho) \right)^2 \right) \right)^\ell \right) \right)^{\frac{1}{\ell}}} \right. \right. \right. \right. \\ \left. \left. \left. \sqrt[1]{1 - \exp \left\{ - \left(\sum_{r=1}^R \left(\vartheta_r \left(- \ln \left(1 - \left(\kappa_{\mathfrak{Y}^{(r_r)}}(\rho) \right)^2 \right) \right)^\ell \right) \right)^{\frac{1}{\ell}}} \right\} \right. \right. \right. \right. \\ \left. \left(\left(\sqrt[1]{\exp \left\{ - \left(\sum_{r=1}^R \left(\vartheta_r \left(- \ln \left(\left(\hbar_{\mathfrak{Y}^{(r_r)}}^-(\rho) \right)^2 \right) \right)^\ell \right) \right)^{\frac{1}{\ell}}} \right. \right. \right. \right. \\ \left. \left. \left. \sqrt[1]{\exp \left\{ - \left(\sum_{r=1}^R \left(\vartheta_r \left(- \ln \left(\left(\hbar_{\mathfrak{Y}^{(r_r)}}^+(\rho) \right)^2 \right) \right)^\ell \right) \right)^{\frac{1}{\ell}}} \right. \right. \right. \right. \\ \left. \left. \left. \sqrt[1]{\exp \left\{ - \left(\sum_{r=1}^R \left(\vartheta_r \left(- \ln \left(\left(\hbar_{\mathfrak{Y}^{(r_r)}}(\rho) \right)^2 \right) \right)^\ell \right) \right)^{\frac{1}{\ell}}} \right\} \right. \right. \right. \right. \\ \left. \left(\left(\sqrt[1]{\exp \left\{ - \left(\sum_{r=1}^R \left(\vartheta_r \left(- \ln \left(\left(\sigma_{\mathfrak{Y}^{(r_r)}}^-(\rho) \right)^2 \right) \right)^\ell \right) \right)^{\frac{1}{\ell}}} \right. \right. \right. \right. \\ \left. \left. \left. \sqrt[1]{\exp \left\{ - \left(\sum_{r=1}^R \left(\vartheta_r \left(- \ln \left(\left(\sigma_{\mathfrak{Y}^{(r_r)}}^+(\rho) \right)^2 \right) \right)^\ell \right) \right)^{\frac{1}{\ell}}} \right. \right. \right. \right. \\ \left. \left. \left. \sqrt[1]{\exp \left\{ - \left(\sum_{r=1}^R \left(\vartheta_r \left(- \ln \left(\left(\sigma_{\mathfrak{Y}^{(r_r)}}(\rho) \right)^2 \right) \right)^\ell \right) \right)^{\frac{1}{\ell}}} \right\} \right. \right. \right. \right. \right) \right) \right) \mid \rho \in P \quad (3)$$

The expert weight vector ($\vartheta = (\vartheta_1, \vartheta_2, \dots, \vartheta_r, \dots, \vartheta_R)$) has a relation with $\mathfrak{V}^{(r)} (r = 1, 2, \dots, R)$. Also, $\vartheta_r \in [0, 1]$ and $\sum_{r=1}^R \vartheta_r = 1$ and $\ell > 0$.

Step 2-3: Criteria weight determination is initiated by converting SCF values into numerical form. A crisp-aggregated evaluation matrix ($\mathfrak{E} = [\mathfrak{E}_{bf}]_{BF}$) is then obtained by applying the score function ($S(\tilde{\mathfrak{E}}_{bf})$) according to Eq. (4).

$$\mathfrak{E}_{bf} = S(\mathfrak{E}_{bf}) = \frac{1}{2} \left(1 + \frac{1}{9} \left(\left(\kappa_{\mathfrak{E}_{bf}}^-(\rho) + \kappa_{\mathfrak{E}_{bf}}^+(\rho) + \kappa_{\mathfrak{E}_{bf}}(\rho) \right)^2 + \left(\hbar_{\mathfrak{E}_{bf}}^-(\rho) + \hbar_{\mathfrak{E}_{bf}}^+(\rho) + \hbar_{\mathfrak{E}_{bf}}(\rho) \right)^2 + \left(\sigma_{\mathfrak{E}_{bf}}^-(\rho) + \sigma_{\mathfrak{E}_{bf}}^+(\rho) + \sigma_{\mathfrak{E}_{bf}}(\rho) \right)^2 \right) \right); (b = 1, \dots, B; f = 1, \dots, F) | S(\mathfrak{E}_{bf}) \in [0, 1]. \quad (4)$$

Step 2-4: The crisp-aggregated evaluation matrix is assigned as the initial decision matrix for WENSLO. The first step of WENSLO involves applying linear normalization (Eq. (5)) to obtain the normalized evaluation matrix ($\mathfrak{X} = [\mathfrak{x}_{bf}]_{BF}$).

$$\mathfrak{X}_{bf} = \frac{\mathbb{E}_{bf}}{\sum_{b=1}^B \mathbb{E}_{bf}}; (b = 1, \dots, B; f = 1, \dots, F) \quad (5)$$

Step 2-5: Using Sturges' rule (Eq. (6)), a criterion class vector ($\mathfrak{D} = [\mathfrak{D}_f]_F$) is constructed from the normalized evaluation matrix.

$$\mathfrak{D}_f = \frac{\max_{1 \leq b \leq B}(\mathfrak{x}_{bf}) - \min_{1 \leq b \leq B}(\mathfrak{x}_{bf})}{1 + 3.322 \log(B)}; (f = 1, \dots, F) \quad (6)$$

Step 2-6: The slope vector $(\mathfrak{W} = [\mathfrak{W}_f]_F)$ is computed by Eq. (7).

$$\mathfrak{W}_f = \frac{\sum_{b=1}^B \mathfrak{x}_{bf}}{(B-1)(\mathfrak{D}_f)}; (f = 1, \dots, F) \quad (7)$$

Step 2-7: The envelope vector $(\mathfrak{E} = [\mathfrak{E}_f]_F)$ is computed by Eq. (8).

$$\mathfrak{E}_f = \sum_{b=1}^{B-1} \sqrt{(\mathfrak{x}_{b+1,f} - \mathfrak{x}_{bf})^2 + (\mathfrak{D}_f)^2}; (f = 1, \dots, F) \quad (8)$$

Step 2-8: The ratio vector $(\mathfrak{V} = [\mathfrak{V}_f]_F)$ is computed by Eq. (9).

$$\mathfrak{V}_f = \frac{\mathfrak{E}_f}{\mathfrak{W}_f}; (f = 1, \dots, F) \quad (9)$$

Step 2-9: The energy policy selection criteria weighting vector $(\eta = [\eta_f]_F)$ is computed by performing Eq. (10).

$$\eta_f = \frac{\mathfrak{V}_f}{\sum_{f=1}^F \mathfrak{V}_f}; (f = 1, \dots, F) \quad (10)$$

The energy policy selection criteria weighting vector $(\eta = (\eta_1, \eta_2, \dots, \eta_f, \dots, \eta_F))$ is identified with each criterion $\eta_f \in [0,1]$ and the constraint as $\sum_{f=1}^F \eta_f = 1$.

• **Stage 3 – Application of Aczel-Alsina–SCF–RADAR for ranking energy policies.**

Step 3-1: The initial matrix constructed in Steps 2–4 is utilized within RADAR. Thus, the Aczel-Alsina–SCF-based initial decision matrix $(\mathfrak{X} = [\mathfrak{x}_{bf}]_{BF})$ is established.

Step 3-2: The maximum proportion matrix $(\mathfrak{U} = [\mathfrak{u}_{bf}]_{BF})$ is computed by Eq. (11).

$$\mathfrak{u}_{bf} = \begin{cases} \mathfrak{u}_{bf}^+ = \frac{\frac{\max_{1 \leq b \leq B}(\mathfrak{x}_{bf})}{\mathfrak{x}_{bf}}}{\frac{\max_{1 \leq b \leq B}(\mathfrak{x}_{bf})}{\mathfrak{x}_{bf}} + \frac{\min_{1 \leq b \leq B}(\mathfrak{x}_{bf})}{\mathfrak{x}_{bf}}} \text{ for } f \in \Lambda^+ \\ \mathfrak{u}_{bf}^- = \frac{\frac{\min_{1 \leq b \leq B}(\mathfrak{x}_{bf})}{\mathfrak{x}_{bf}}}{\frac{\max_{1 \leq b \leq B}(\mathfrak{x}_{bf})}{\mathfrak{x}_{bf}} + \frac{\min_{1 \leq b \leq B}(\mathfrak{x}_{bf})}{\mathfrak{x}_{bf}}} \text{ for } f \in \Lambda^- \end{cases}; (b = 1, 2, \dots, B; f = 1, 2, \dots, F) \quad (11)$$

Step 3-3: The minimum proportion matrix $(\mathfrak{B} = [\mathfrak{b}_{bf}]_{BF})$ is computed by Eq. (12).

$$\mathfrak{B}_{bf} = \begin{cases} \mathfrak{B}_{bf}^+ = \frac{\frac{x_{bf}}{\min_{1 \leq b \leq B}(x_{bf})}}{\frac{\max_{1 \leq b \leq B}(x_{bf})}{x_{bf}} + \frac{x_{bf}}{\min_{1 \leq b \leq B}(x_{bf})}} \text{ for } f \in \Lambda^+ \\ \mathfrak{B}_{bf}^- = \frac{\frac{x_{bf}}{\max_{1 \leq b \leq B}(x_{bf})}}{\frac{\max_{1 \leq b \leq B}(x_{bf})}{x_{bf}} + \frac{x_{bf}}{\min_{1 \leq b \leq B}(x_{bf})}} \text{ for } f \in \Lambda^- \end{cases}; (b = 1, 2, \dots, B; f = 1, 2, \dots, F) \quad (12)$$

Step 3-4: The empty range matrix ($\mathfrak{T} = [\mathfrak{T}_{bf}]_{BF}$) is computed by Eq. (13).

$$\mathfrak{T}_{bf} = |\mathfrak{U}_{bf} - \mathfrak{B}_{bf}|; (b = 1, \dots, B; f = 1, \dots, F) \quad (13)$$

Step 3-5: The relative relationship matrix ($\mathfrak{U} = [\mathfrak{U}_{bf}]_{BF}$) is computed by Eq. (14).

$$\mathfrak{U}_{bf} = \frac{\mathfrak{U}_{bf}}{\mathfrak{B}_{bf} + \mathfrak{T}_{bf}}; (b = 1, \dots, B; f = 1, \dots, F) \quad (14)$$

Step 3-6: The weighted relative relationship matrix ($\mathfrak{Z} = [\mathfrak{Z}_{bf}]_{BF}$) is computed by Eq. (15). Here, the energy-policy selection criteria weighing vector ($\eta = (\eta_1, \eta_2, \dots, \eta_f, \dots, \eta_F)$) is utilized.

$$\mathfrak{Z}_{bf} = (\mathfrak{U}_{bf} * \eta_f); (b = 1, \dots, B; f = 1, \dots, F) \quad (15)$$

Step 3-7: The ranking vector ($\varrho = [\varrho_b]_B$) of the alternative energy policies is computed by performing Eq. (16).

$$\varrho_b = \frac{\min(\sum_{f=1}^F \mathfrak{Z}_{bf})}{\sum_{f=1}^F (\mathfrak{Z}_{bf})}; (b = 1, \dots, B) \quad (16)$$

3. Selection of Germany's Energy Security Policy in the Context of the Ukraine–Russia Conflict

In this section, the proposed Aczel-Alsina-SCF-WENSLO-RADAR hybrid method is applied to the selection process of Germany's energy security policy. The core components of the decision model (including the alternative energy security policies, the selection criteria, and the panel of experts) are first introduced within the framework of the decision model. Subsequently, the step-by-step implementation of the proposed hybrid methodology is presented.

3.1 Decision Model for Selecting Germany's Energy Security Policy

3.1.1 Alternative energy security policies of Germany

In this study, eight distinct energy security policy alternatives were formulated for Germany, each based on a unique strategic approach. These policy alternatives were designed in alignment with current geopolitical developments, national energy priorities, and the broader objectives of sustainable development and energy independence. The selection of these alternatives reflects Germany's need to address both short-term supply disruptions and long-term energy transition goals in the context of increasing global uncertainties, particularly considering the Ukraine-Russia conflict. The proposed energy security policy alternatives are outlined as follows:

- i. *1st Policy - "Cooperation with global players in international politics"* (Ω_1): Germany is aiming to stay as a leading economic power in the EU and continue its competitiveness in global markets. So, going alone to meet the energy needs of Germany in a globalized world is limited [22]. As a matter of fact, the Russia-Ukraine conflict has mostly affected German industry in terms of rising energy prices and decreasing competitiveness of German products in the international markets [23]. To keep German producers more competitive, Germany's subsidy to empower market is more than 660 billion Euros. This picture shows that more international cooperation for Germany is necessary to achieve its energy security and to keep its development policy running to be more competitive in international markets. In this process, new supply routes were created as an alternative to Russian Gas, such as LNG and Gas imports from Canada [24]. With the current situation, Germany is facing the closure of some of its factories and moving production spheres to countries where energy and labor costs are cheaper. Actively involving global players in Germany's energy security through close collaboration is important not only to increase energy supply, but also to ensure Germany's involvement in the energy agreements for the sustainability of energy security. Particularly, Germany's cooperation agreements with the effective players on energy, such as with Algeria in 2024, is an important example. The agreement is important for overcoming challenges to the energy security of Germany [25]. This presents the importance of effective cooperation with global players in energy supply. As a result, a cooperation policy with global players in international politics can contribute to Germany's effective energy security policy. This approach can be regarded as an effective strategy for Germany's energy security policy and a strong alternative to the limitations of Germany's energy security policy that acts alone.
- ii. *2nd Policy - "Collaboration with the EU in the field of energy"* (Ω_2): As a matter of fact, Germany is a leading country of the EU in terms of economic and political matters. In this regard, Germany should adopt a strategy of creating a collaboration mechanism for the EU members for their energy security. The necessity of this policy strategy is that energy security is not only important for Germany but for all EU Member States. Germany's actions alone are not important to secure its energy needs. However, it is important for Germany to secure its energy needs to stop the negative impact of global economic competition in the German industry [26]. The EU, therefore, becomes the leader for energy diplomacy and building connections among the countries with huge energy supplies around the world. With its economic power and cultural influence, the EU has been regarded as having a soft-power mechanism to influence global politics [27]. This position gives the EU an important place in global energy policy negotiations. After the Russia-Ukraine conflict, the EU's position towards Russia has been on securitization dynamics, which also covers energy security [28]. So, the EU has already been positioned as the EU Member States' collaboration ground under the supranational institutions. Based on the EU Member States' facing an energy crisis, this policy aims to reinforce the EU as a global player for energy policies and an effective ground for collaboration among the Member States. The EU and its 27 Member States consist of one of the world's greatest energy markets, with increasing demands for energy because of the industrialized function. This policy approach of collaboration with the EU in the field of energy can contribute to the realization of energy security of Germany through more effective diplomacy and cooperation function in global politics.
- iii. *3rd Policy - "Harmonizing energy policy with the needs of Germany"* (Ω_3): Germany's Energiewende policy, which was declared in 2010, has been designed to cover the

strategic needs of Germany [29]. In this sense, the focus has been on the rise of producing energy from renewable energy resources as a strategic target of Germany. It is possible to say that energy security needs are not the same in all parts of Germany, as different regions are affected differently by the energy crisis. As proposed by the Energiewende policy, harmonization of energy policy mainly focuses on renewable energy in Germany [29]. This policy is not dismissing other energy resources but gives emphasis on the harmonization of other energy resources with renewable energies. The research shows that self-sufficiency in Germany for energy supply is changing based on the location since urban areas are more self-sufficient while rural areas have less self-sufficiency [30]. With the rise of the self-sufficiency level, investment in renewable energy occupies an important place. Therefore, a cohesion policy with the needs of different parts of Germany is necessary to consider in terms of energy security. Such a policy could also impact the policies of other EU Member States as an effective policy way in Germany. This alternative policy, which considers the regional differences, is an effective way to create a harmonization of the energy policy of Germany based on the needs of different regions. It will also contribute to securing the energy security target of Germany with an efficient use of the energy.

- iv. *4th Policy - "Energy diplomacy based on the interests of Germany" (Ω_4):* The Russia-Ukraine conflict affected Germany to form a new energy diplomacy in terms of an interest-based approach. This approach also combines the EU's soft power to have effective diplomacy for the energy security of Germany. Germany would like to be effective in energy diplomacy with the help of the EU through a liberal approach and democratic integrity [31]. The struggle to achieve energy security is not only a technical issue, but it is also related to the global energy market and affects investors, energy policies, and climate governance. As Germany gives importance to stopping the impact of global warming and focuses on renewable energy as a strategic source, it positions itself as a normative power to share universal values on effective policy by protecting the environment. Thus, Germany's Energiewende policy positions the country as a soft power in energy diplomacy through covering its focus on renewable energy [31]. This value-oriented stance reinforces Germany to role as an effective actor in global energy diplomacy. This value-oriented policy is also related to Germany's position in international politics. As an emerging soft-power, Germany has been an influential country in world politics in the last 20 years. This has been related to Germany's hegemonic position in European politics as a leading economic power and industry that affects global markets [32]. So, the continuation of the policy of influential Germany and powerful EU, with the impact of Germany in global politics, has been related to an effective energy diplomacy of Germany. Thus, reaching energy and controlling the energy resources affects the success of this policy. In short, Germany can apply an effective energy diplomacy based on its interests through its soft-power function as well as using the powerful position of the EU in global politics. This alternative policy approach is essential for reaching the interests of Germany since it gives benefits for German industry with the way to reach new energy resources, and it will strengthen Germany's position in global politics.
- v. *5th Policy - "Integration of the energy policy transition into the German industry" (Ω_5):* Policies about energy security should include both energy efficiency and renovation of infrastructure in need of industry. In this sense, integration into the German industry is necessary for the energy policy transition. Formation of energy efficiency policies in a legal and institutional way is necessary for to effective implementation of this policy in the

German industry. This was already proposed with the "Energy concept for an environmentally sound, reliable and affordable energy supply" in 2010. With this strategy primary energy demand is aimed to be reduced by 50 % by 2050 and focus more on renewable energy for applying infrastructure. Therefore, effective implementation of energy efficiency requires integrating infrastructure into German industry. In addition, modernizing energy infrastructure based on new energy sources, as well as the requirement of renewable energy production, is necessary in this policy [33]. As a matter of fact, Germany built new LNG infrastructure in 2023 to adapt the industry to these new energy sources. In this way, new gas imports to Germany are expected to be facilitated. Overall, energy policy transition with the requirement of German industry can be achieved with the social consensus through integrating industry in this transformation process.

- vi. *6th Policy - "Energy supply based on local needs" (Ω_6):* There is a need to consider local needs for the energy supply within this energy security approach. In Germany, the need for energy is not the same in every region, which differs based on the power of the industry. Especially, West Germany is more vulnerable to any changes in energy supply due to historical industry areas located in the West [34]. In this sense, the change in energy supply does not affect each region in the same way. So, there is a requirement to consider specific features of each region. The Energiewende policy of Germany was also designed in this way by considering the regional differences and applying energy transformations based on the specific features of the region. As an important example, the North Rhine-Westphalia region of Germany with a policy of changing electricity production bases from coal to renewable resources such as wind and solar panels [35]. There are criticisms in this case about Germany's Energiewende policy only considers renewable energy in the energy supply of all of Germany, that may not be compatible with the needs of local areas. However, the plan is designed to effectively supply energy based on the needs of local communities and industry. Under these circumstances, it is important to consider the needs of the local industries in terms of the type of energy they demand, and which energy resources and infrastructure are required to keep their competitiveness higher in international markets. This approach opens the way for other energy resources, not only renewable energy, but other conventional energy resources can be employed based on the needs of the local population.
- vii. *7th Policy - "Equal distribution of energy resources among regions" (Ω_7):* The distribution of energy resources unevenly affects inequality among the regions, which causes social problems with internal migrations and social clashes based on economic inequalities [36]. In this sense, studies show that economic inequalities trigger migration throughout the world [37]. This situation can be regarded as a threat multiplier if the government does not share resources equally, such as energy resources. Since energy resources are important for economic development and the well-being of the countries that are supported by the governments' policies. Current policy in Germany focuses on replacing energy resources with renewable energy with an aim of meeting global standards about fighting climate change [35]. From an energy security perspective, this does not meet the standards of an equal approach in all areas since it does not consider the type of energy they need. For this reason, as an alternative approach for the EU, this approach considers equal distribution of energy resources by also considering conventional energies. As an important fact, each region has no specific development and infrastructure facilities, and an equal distribution of energy resources would be beneficial to meet their own needs of energy needs.

- viii. *8th Policy - "Further investment in energy technologies" (Ω_8)*: Technological developments facilitate the process of reaching the necessary resources of the countries. In this sense, further development of energy technologies is necessary for an efficient way of supplying energy to the industry [38]. Indeed, these innovative approaches to energy technologies focus on not only energy development and efficiency processes but also environmentalist approaches that have been the major focus of Germany in line with the emission reduction policy of the EU. The investment in energy technologies includes mainly the investment in renewable energy resources such as wind energy and solar energy [39]. These have been vital for Germany to achieve the energy security of the country. So, producing energy itself would empower the self-sufficiency of Germany in achieving energy security with technological development. In addition to environmental benefits, the investment in energy technologies gives benefits to German industry to be the leading producer in energy technologies. As a matter of competition in international markets, it had a peak point with the impact of neoliberal policies. In this sense, investing in energy technologies is also necessary to be more competitive in international markets in terms of energy technologies. Overall, through this policy, Germany would be a leading power for innovation of new energy technologies and achieve energy security through applying this technology to its own industry, which would be important for an effective energy supply in Germany.

3.1.2 Alternative energy security policy selection criteria

In the context of energy policy decision-making, the identification and precise definition of evaluation criteria are of paramount importance for ensuring the robustness and relevance of the decision model. In this study, a comprehensive set of eleven criteria has been established to evaluate alternative energy security policies for Germany. These criteria were formulated based on a multidisciplinary perspective, encompassing geopolitical, economic, environmental, and infrastructural dimensions. Each criterion reflects a specific aspect of energy security, ranging from strategic energy diversification and energy independence to infrastructure resilience and alignment with sustainability goals. The selection of these criteria was guided by both expert input and existing literature, ensuring that the decision-making process is grounded in both theory and practical relevance. The following presents detailed descriptions of the criteria considered in this study:

- i. *Implications for energy supply (Λ_1)* – This criterion is a central criterion that includes the generation and distribution of energy to the needs of local and international markets [40]. The total energy supply of Germany includes mainly oil and natural gas, as in the case of the 2023 energy supply includes 34.3 % oil and 26.4 % natural gas [41]. The huge dependency on oil and natural gas, which are mostly imported, has led Germany to change the laws about energy efficiency. With the energy efficiency law, Germany is trying to reduce energy consumption within the country by 26.5 % by 2030 and by 45 % by 2045 compared to the numbers in 2008 [42]. This policy approach reflects the efficient use of energy as well as the setting of necessary targets to meet the needs of energy needs. Nevertheless, while finding energy resources is necessary, effective use of energy is also regarded as vital. So, this policy not only gives priority to the state actions but also involves the public in effectively finding a solution to the energy security problems of Germany.
- ii. *Engagement with the European Union (Λ_2)* – Giving priority to collaborate with the EU and the Member States for the formation of an effective energy policy constitutes a fundamental criterion for Germany [26]. As the industrial power of the EU and a leading

economy, collaboration with the EU is central to Germany's energy policy. The collaboration with the EU not only plays a central role in the cost reduction of the energy policy but also enhances energy security by reaching potential suppliers. So, collaboration with the EU is an economic way to reach energy sources and reinforce the energy security of Germany. As a matter of fact, Germany's already existing collaboration with the EU Member States by having a leading role in the energy security of Europe is the key indicator of commitment to the common policy of the EU.

- iii. *Efficient utilization of energy* (Λ_3) – The existence of energy efficiency policies in a legal and institutional way is an important criterion in evaluating the energy security policy of Germany [43]. As a matter of fact, in Germany and in the EU-wide, efficient use of energy policies emerged in the process of the integration of Europe. In 2010, the German government adopted the "Energy concept for an environmentally sound and affordable energy supply" to regulate energy efficiency. The strategy is designed to apply until 2050, which includes the reduction of energy demand and covering existing energy demand with renewable energy. So, primary energy demand shall be reduced by 50 % by 2050 compared to 2008. This strategy, in some cases, is criticized for affecting Germany's competitiveness in global markets. Therefore, efficient utilization of energy should be considered as a key policy criterion that has strategic value for Germany's energy security.
- iv. *Modernization of energy infrastructure* (Λ_4) – This criterion is a fundamental criterion that is related to all areas of social and economic life, including development, social integration, and the government's policies over the delivery of energy to the people. Germany's energy security policy covers finding new energy sources, investing in renewable energies, as well as having a modernized energy infrastructure to effectively use the energy throughout the country [33]. The interlink of modernization of energy infrastructure with all other areas of energy security and development policy makes it a core strategy for Germany. For instance, Germany built new liquefied natural gas infrastructure in 2023 to facilitate new gas imports to the country. So, this policy is important to evaluate both economic interests and the sustainability of energy imports to the country. In the overall energy security dimension of Germany in the wake of the Russia-Ukraine conflict, this policy seems compatible with the new energy security narrative. Hence, the best energy security policy includes also modernization of energy infrastructure to facilitate the industry to reach energy resources easily, which covers also different economic and ecological interests.
- v. *Strategic energy diversification* (Λ_5) – "Strategic energy diversification" constitutes a critical criterion for the energy security of Germany, as it directly relates to energy security and the development policy of the country [44]. The policy of strategic energy diversification gives greater benefit to providing necessary energy for the industry. Energy diversification reduces reliance on only certain energy resources, and it provides greater use of various energy resources [45]. Moreover, energy diversification provides greater benefit for increasing competitiveness, and it is good for all sectors with the possibility of lower costs for energy use. Strategic energy diversification is not only important for energy security but also for environmental sustainability, compatible with Germany's overall policy with the EU. Furthermore, energy diversification requires creating public awareness about the new energy sources (such as renewable energy) and, importantly, it is necessary to train the people on the new energy resources. Therefore, the most effective policy on strategic energy diversification covers new technologies for the production of energy resources and rising public awareness about these resources.

- vi. *International partnerships in energy development* (Λ_6) – This criterion is a key criterion for the energy security policy of Germany through having international partnerships in energy development [46]. Germany's energy policy emphasizes reaching global energy markets through collaborating with global actors. Effective policies on energy development should include building partnerships with international actors that are effective in the energy market. This approach is compatible with Germany's energy policy in the wake of the Russia-Ukraine conflict through collaborating with Norway and the US to reach new energy resources as well as acting in cohesion with the EU's common energy policy. In the energy security of Germany debate, this policy can be regarded as rational and pointing to the interest of Germany in the recent process.
- vii. *Deployment of strategic energy reserves* (Λ_7) – The success of energy security policy has been related to the deployment of strategic energy reserves [47]. This involves the deployment of sources that exist in limited areas of the country and focusing on new energy resources that are newly produced in a certain territory. Germany's Energiewende policy, which was declared in 2010, as a transition in energy areas, included the regulations on strategic reserves that are expected to be 5 % of the current peak load [29]. This mainly focuses on renewable energies as strategic energy reserves. The development of technology for the storage of electricity produced with renewable energy technologies is necessary for the effective deployment of this strategic energy reserve. Such initiatives to support financially the development of technology in this field are important to facilitate a smooth transition to use this strategic energy reserve. Overall, technological development is necessary for the sustainability of Germany's policy in the long term.
- viii. *Investment in renewable energy* (Λ_8) – A comprehensive energy security policy must include alternative energy resources in addition to conventional energies [48]. Germany was one of the first countries in Europe that invest in the renewable energy sector. The share of electricity production from renewable energies in Germany was 3.5 % in 1990, and it increased to 52.4 % in 2023. So, renewable energy is given strategic importance, and investment in electricity production from renewable energies was given special importance by the German government. Germany's Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz) was implemented in 2000 to attract investment in the renewable energy sector. Moreover, there is a strategic target for Germany to increase the consumption of electricity produced from renewable energies to at least 80% in 2050 [49]. Prioritizing the investment in renewable energy has been visible already in Germany's policies. Consequently, the impact to energy market of renewable energy in Germany is important to evaluate an effective energy security policy for Germany.
- ix. *Coalition for alternative energy pathways in the European Union* (Λ_9) – An effective implementation of investment in renewable energy requires collaboration with other EU Member States to have a common policy on EU-wide [50]. The EU's approach has been to further invest in renewable energy in cohesion with all the Member States. Responsibility and engagement of all the Member States for an effective renewable energy policy are expected to contribute to Germany's further investment in renewable energy. Moreover, collaboration with the EU institutions and receiving funds from the EU would facilitate the development of the alternative energy sector in Germany. This would ease policy coordination in Germany by including the public through increasing awareness in coordination with the state institutions.
- x. *Coal utilization in energy production* (Λ_{10}) – Energy security policy requires the idea of using traditional energy sources in the industrialized countries, such as the use of coal in

Germany [51]. As a result of the problems of energy supply to the German market after the Russia-Ukraine conflict, coal has again been on the agenda as an alternative to oil and gas. Thus, 44 % of electricity in Germany is produced in coal power plants, even though there is a policy to reduce emissions over time. Consequently, the use of coal for energy production in Germany is still important, and it seems it will continue to be important for the energy security policy in Germany.

- xi. *Investment in nuclear energy (Λ_{11})* – One of the most important criteria for the development of an effective energy security policy has been investment in nuclear energy [52]. Kahl Experimental Reactor is the oldest reactor in Germany, which started the production of electricity in 1960. In the aftermath of the OPEC crisis in 1973, nuclear power plants have been useful to fulfill industry needs. In this sense, the building of new nuclear power plants has been accelerated since the post-1970s. Germany had a policy of closing nuclear power plants after the Fukushima Disaster in 2011. In 2023, the last reactors of Germany were shut down to produce electricity from clean energy. However, the newly elected government had a plan for reactivating nuclear power plants [53]. These approaches have been related to the recent decline of German industry because of the rising competition in global trade. Thus, the impact of investment in nuclear energy is an important criterion to meet the energy security needs of Germany.

3.1.3 Experts participating in the energy security policy process of Germany

In the process of determining energy security policies, expert judgments were utilized to incorporate subjective assessments. For this purpose, experts specializing in energy security policies were selected. A total of 10 energy policy experts participated in the study. Expert 1 specializes in energy transition, citizen energy, renewables, decentralized energy supply, heating, electricity grids, and energy policy development. Expert 2 is a professor of international relations and a researcher focusing on energy policies. Expert 3 is a post-doctoral researcher specializing in energy policy and international energy policies. Expert 4 holds a PhD in computer engineering and works as an expert in energy technologies and a project manager in Germany. Expert 5 is an associate professor of international relations and conducts research on international energy agreements and Russia's energy policy towards Europe. Expert 6 holds an MA in renewable energy and works as a technical asset manager in Germany, with expertise in wind farm management. Expert 7 is an associate professor and a researcher in European studies and European energy policy. Expert 8 is a post-doctoral researcher focusing on energy law and international energy development law. Expert 9 is an associate professor with 15 years of experience in researching energy security policies. Expert 10 is an associate professor and advisor to an energy company, with 20 years of expertise in the field.

Initially, these experts were briefed on the energy security policies developed for Germany. Following this, they were asked to evaluate alternative energy security policies based on specific energy policy selection criteria, as presented in Table 1. Based on the evaluations provided by the experts, an initial decision matrix was constructed. Furthermore, the expertise levels of each expert were determined and are presented in Table 2. Figure 2 presents the decision-making model for energy security policy selection specific to the case of Germany.

3.2 Selection of Energy Security Policy using Aczel-Alsina–SCF–WENSLO–RADAR

This part outlines the sequential implementation steps Aczel-Alsina–SCF–WENSLO–RADAR, which is applied to determine the optimal energy security policy for Germany in the context of the Ukraine–Russia conflict.

Table 2

Expert group

Experts	Expertise levels	SCF numbers
Expert -1 (Γ_1)	SHI	$\{([0.5,0.6],0.55),([0.3,0.4],0.35),([0.3,0.4],0.35)\}$
Expert -2 (Γ_2)	HI	$\{([0.6,0.7],0.65),([0.2,0.3],0.25),([0.2,0.3],0.25)\}$
Expert -3 (Γ_3)	SHI	$\{([0.5,0.6],0.55),([0.3,0.4],0.35),([0.3,0.4],0.35)\}$
Expert -4 (Γ_4)	VHI	$\{([0.7,0.8],0.75),([0.1,0.2],0.15),([0.1,0.2],0.15)\}$
Expert -5 (Γ_5)	VHI	$\{([0.7,0.8],0.75),([0.1,0.2],0.15),([0.1,0.2],0.15)\}$
Expert -6 (Γ_6)	VHI	$\{([0.7,0.8],0.75),([0.1,0.2],0.15),([0.1,0.2],0.15)\}$
Expert -7 (Γ_7)	HI	$\{([0.6,0.7],0.65),([0.2,0.3],0.25),([0.2,0.3],0.25)\}$
Expert -8 (Γ_8)	SHI	$\{([0.5,0.6],0.55),([0.3,0.4],0.35),([0.3,0.4],0.35)\}$
Expert -9 (Γ_9)	HI	$\{([0.6,0.7],0.65),([0.2,0.3],0.25),([0.2,0.3],0.25)\}$
Expert -10 (Γ_{10})	VHI	$\{([0.7,0.8],0.75),([0.1,0.2],0.15),([0.1,0.2],0.15)\}$

Alternative Energy Security Policies of Germany	Alternative Energy Security Policy Selection Criteria		Experts
1 st Policy - Cooperation with global players in international politics (Ω_1)	Implications for Energy Supply (A_1)	Benefit-based criteria	Expert-1 (Γ_1)
2 nd Policy - Collaboration with the EU in the field of energy (Ω_2)	Engagement with the European Union (A_2)	Benefit-based criteria	Expert-2 (Γ_2)
	Efficient Utilization of Energy (A_3)	Benefit-based criteria	Expert-3 (Γ_3)
3 rd Policy - Harmonizing energy policy with the needs of Germany (Ω_3)	Modernization of Energy Infrastructure (A_4)	Benefit-based criteria	Expert-4 (Γ_4)
	Strategic Energy Diversification (A_5)	Benefit-based criteria	Expert-5 (Γ_5)
4 th Policy - Energy diplomacy based on the interests of Germany (Ω_4)	International Partnerships in Energy Development (A_6)	Benefit-based criteria	Expert-6 (Γ_6)
	Deployment of Strategic Energy Reserves (A_7)	Benefit-based criteria	Expert-7 (Γ_7)
5 th Policy - Integration of the Energy Policy Transition into the German Industry (Ω_5)	Investment in Renewable Energy (A_8)	Benefit-based criteria	Expert-8 (Γ_8)
	Coalition for Alternative Energy Pathways in the European Union (A_9)	Benefit-based criteria	Expert-9 (Γ_9)
6 th Policy - Energy Supply based on Local Needs (Ω_6)	Coal Utilization in Energy Production (A_{10})	Cost-based criteria	Expert-10 (Γ_{10})
	Investment in Nuclear Energy (A_{11})	Cost-based criteria	

Fig. 2. Decision model for the selection of energy security policy for Germany

- **Stage 1** – Assign weights to the experts for the decision-making process using Aczel-Alsina-SCF sets.

Step 1-1: The expertise levels of the experts (Γ_r) involved in the decision model were determined using Table 1. Accordingly, the Aczel-Alsina–SCF-based expertise level vector ($\tilde{\mathfrak{F}} = [\tilde{\mathfrak{F}}_r]_R$) (Table A.1 In Appendix B) was constructed.

Step 1-2: The Aczel-Alsina–SCF-based expertise level vector was converted into crisp values using the score function ($S(\tilde{\mathfrak{F}}_r)$) (Eq. (1)), and the resulting numerical-based expertise vector ($\mathfrak{F} = [\mathfrak{F}_r]_R$) was presented in Table A.1.

Step 1-3: The expert weight vector ($\vartheta = [\vartheta_r]_R$) (Table 3) to be used in the criteria weighting process was determined through linear normalization (Eq. (2)).

- **Stage 2** – Application of Aczel-Alsina–SCF–WENSLO for weighting energy policy selection criteria.

Step 2-1: To determine the corresponding decision matrix required for criteria weighing, interviews were conducted with each expert. Based on Table 1, each expert (Γ_r) evaluated each energy security policy (Ω_b) with respect to each energy security policy selection criterion (A_f). The

expert evaluations are presented in Table A.2, and the corresponding decision matrices ($\tilde{\mathfrak{Y}}^{(\Gamma_r)} = [\tilde{\mathfrak{Y}}_{bf}^{(\Gamma_r)}]_{BF}$) are provided in Table A.3.

Table 3

Expert weight vector ($\vartheta = [\vartheta_r]_R$)

Experts	Γ_1	Γ_2	Γ_3	Γ_4	Γ_5	Γ_6	Γ_7	Γ_8	Γ_9	Γ_{10}
ϑ_r	0.0903	0.0986	0.0903	0.1083	0.1083	0.1083	0.0986	0.0903	0.0986	0.1083

Step 2-2: The corresponding decision matrices were aggregated using SCFAAWA (Eq. (3)) ($\ell = 2$), resulting in the Aczel-Alsina–SCF-based aggregated evaluation matrix ($\tilde{\mathfrak{E}} = [\tilde{\mathfrak{E}}_{bf}]_{BF}$) (Table A.4).

Step 2-3: The Aczel-Alsina–SCF-based aggregated evaluation matrix was converted into crisp values using the score function ($S(\tilde{\mathfrak{E}}_{bf})$) (Eq. (4)), and the resulting crisp-aggregated evaluation matrix ($\mathfrak{E} = [\mathfrak{E}_{bf}]_{BF}$) was presented in Table A.5.

Step 2-4: The normalized evaluation matrix ($\mathfrak{X} = [\mathfrak{X}_{bf}]_{BF}$) (Table A.6) was computed by Eq. (5).

Step 2-5 to Step 2-8: By Eq. (6), Eq. (7), Eq. (8), and Eq. (9), the criterion class vector ($\mathfrak{D} = [\mathfrak{D}_f]_F$) (Table A.6), the slope vector ($\mathfrak{W} = [\mathfrak{W}_f]_F$) (Table A.6), envelope vector ($\mathfrak{C} = [\mathfrak{C}_f]_F$) (Table A.6), and ratio vector ($\mathfrak{B} = [\mathfrak{B}_f]_F$) (Table A.6) were computed, respectively.

Step 2-9: The energy policy selection criteria weighting vector ($\eta = [\eta_f]_F$) (Table 4) to be used in the policy ranking process was determined through linear normalization (Eq. (10)).

Table 4

Energy policy selection criteria weighting vector

Criteria	Λ_1	Λ_2	Λ_3	Λ_4	Λ_5	Λ_6	Λ_7	Λ_8	Λ_9	Λ_{10}	Λ_{11}
η_f	0.0530	0.1624	0.0736	0.1484	0.1733	0.0948	0.0257	0.0952	0.0546	0.0933	0.0256

• **Stage 3 – Application of Aczel-Alsina–SCF–RADAR for ranking energy policies.**

Step 3-1: The Aczel-Alsina–SCF-based initial decision matrix ($\mathfrak{X} = [\mathfrak{X}_{bf}]_{BF}$) was established as the initial matrix.

Step 3-2: The maximum proportion matrix ($\mathfrak{U} = [\mathfrak{U}_{bf}]_{BF}$) (Table A.7) was computed by Eq. (11).

Step 3-3: The minimum proportion matrix ($\mathfrak{B} = [\mathfrak{B}_{bf}]_{BF}$) (Table A.8) was computed by Eq. (12).

Step 3-4: The empty range matrix ($\mathfrak{T} = [\mathfrak{T}_{bf}]_{BF}$) (Table A.9) was computed by Eq. (13).

Step 3-5: The relative relationship matrix ($\mathfrak{A} = [\mathfrak{A}_{bf}]_{BF}$) (Table A.10) was computed by Eq. (14).

Step 3-6: The weighted relative relationship matrix ($\mathfrak{Z} = [\mathfrak{Z}_{bf}]_{BF}$) (Table A.11) was computed by Eq. (15).

Step 3-7: The alternative energy policies ranking vector ($\varrho = [\varrho_b]_B$) (Table 5) was determined through Eq. (16). Based on the ranking scores, the fourth energy security policy (i.e., 4th Policy - "Energy diplomacy based on the interests of Germany" (Ω_4)) was identified as the best option.

Table 5

Alternative energy policies ranking vector

Policy	1 st Policy (Ω_1)	2 nd Policy (Ω_2)	3 rd Policy (Ω_3)	4 th Policy (Ω_4)	5 th Policy (Ω_5)	6 th Policy (Ω_6)	7 th Policy (Ω_7)	8 th Policy (Ω_8)
q_b	0.9170	0.9066	0.9449	1	0.9124	0.8995	0.9062	0.9333
Rank	4	6	2	1	5	8	7	3

3.3 Robustness and Consistency Analyses

3.3.1 Robustness analyses

As a result of the real-world case study conducted for the selection of energy security policies in Germany, the fourth policy was identified as the best one. To support the robustness of this result, scenario-based sensitivity analyses were developed. Two distinct sensitivity analysis scenarios were implemented.

In the first scenario, the analysis was carried out by assigning different values to the ℓ parameter within SCFAAWA used to aggregate expert evaluations of alternative energy security policies based on policy selection parameters. The primary objective of this scenario was to observe how variations in aggregation calculations affect the ranking scores of the policies, thereby validating the consistency of the fourth policy being ranked as the best option. This analysis was conducted by varying the ℓ parameter from 1 to 7. The ranking scores of the policies under each ℓ value are presented in Figure 3. In all tested values, the fourth policy consistently emerged as the top-ranked alternative, thereby reinforcing the reliability of the initial findings.

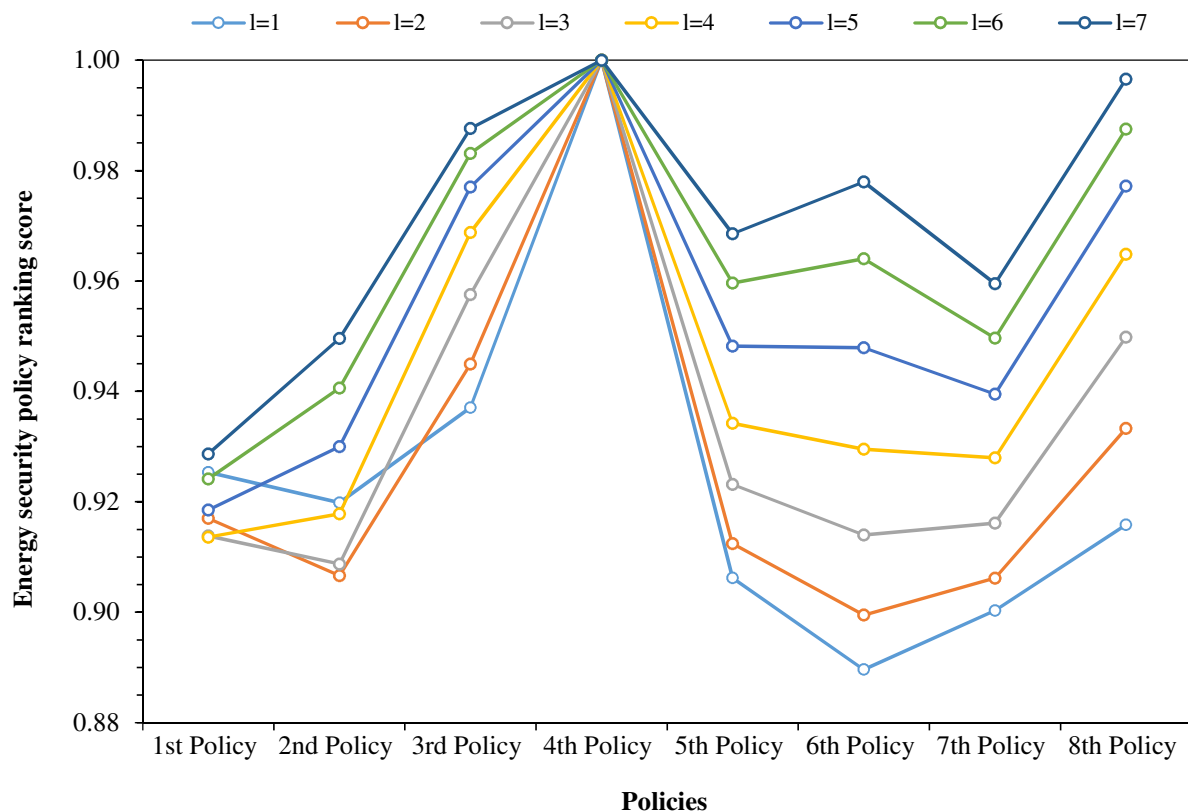


Fig. 3. Ranking scores for the first sensitivity analysis

In the second scenario, sensitivity analysis was performed by systematically removing alternative energy security policies from the decision model based on their ranking scores. The aim was to test

whether the fourth policy would remain the most optimal choice under different combinations of policy alternatives. Initially, the sixth policy (identified as the lowest ranked in the original analysis) was excluded from the model. No change was observed in the new ranking results, with the seventh policy becoming the lowest ranked. Subsequently, the seventh policy was removed, resulting in the first policy occupying the last position. This process continued with the sequential removal of the first, fifth, and second policies. After each iteration, the fourth policy consistently remained the top-ranked alternative. In the final step, a direct comparison was conducted between the fourth and eighth policies, and once again, the fourth policy was identified as the most optimal. The ranking scores from this analysis are presented in Figure 4.

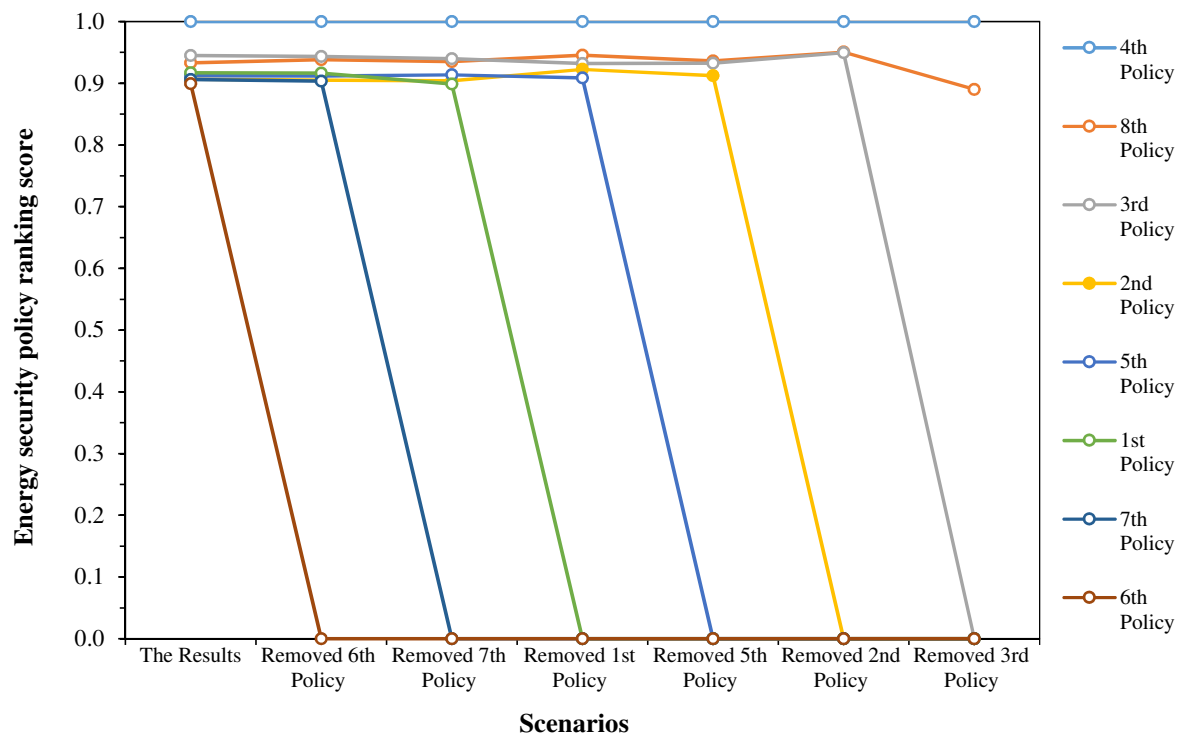


Fig. 4. Ranking scores for the second sensitivity analysis

The corresponding rankings are shown in Table 6. The results of these sensitivity analysis scenarios confirm that Aczel-Alsina–SCF–WENSLO–RADAR provides robust and reliable outcomes under varying conditions

Table 6

Alternative energy policies ranking according to the second sensitivity analysis

Scenario	Ranking	Best policy	Worst policy
<i>Our results</i>	$\Omega_4 > \Omega_3 > \Omega_8 > \Omega_1 > \Omega_5 > \Omega_2 > \Omega_7 > \Omega_6$	4 th Policy	6 th Policy
Removed 6 th Policy	$\Omega_4 > \Omega_3 > \Omega_8 > \Omega_1 > \Omega_5 > \Omega_2 > \Omega_7$	4 th Policy	7 th Policy
Removed 7 th Policy	$\Omega_4 > \Omega_3 > \Omega_8 > \Omega_5 > \Omega_2 > \Omega_1$	4 th Policy	1 st Policy
Removed 1 st Policy	$\Omega_4 > \Omega_8 > \Omega_3 > \Omega_2 > \Omega_5$	4 th Policy	5 th Policy
Removed 5 th Policy	$\Omega_4 > \Omega_8 > \Omega_3 > \Omega_2$	4 th Policy	2 nd Policy
Removed 2 nd Policy	$\Omega_4 > \Omega_8 > \Omega_3$	4 th Policy	3 rd Policy
Removed 3 rd Policy	$\Omega_4 > \Omega_8$	4 th Policy	8 th Policy

3.3.2 Comparative analyses

In this study, Aczel-Alsina–SCF–WENSLO–RADAR was proposed for the selection of energy security policies and applied to Germany's energy policy decision-making process in the context of

the Ukraine–Russia conflict. The implementation results of the proposed hybrid method, as well as the findings from the sensitivity analyses, were successfully obtained and confirmed the robustness and reliability of the method.

However, to further assess the validity of the findings, a comparative analysis was conducted by replacing the RADAR ranking method used in the proposed model with alternative ranking techniques. For this purpose, widely utilized methods from the literature—AROMAN [54], ARTASI [55], MABAC [56], MARCOS [57], SAW, TOPSIS [58], WASPAS [59], ARLON [60], and RAM [61]—were applied to rank the alternative energy security policies. Their results were compared with those obtained using Aczel-Alsina–SCF–WENSLO–RADAR. Figure 5 displays the ranking scores of energy security policies for each method. To ensure comparability, all results were normalized using the max-min normalization technique.

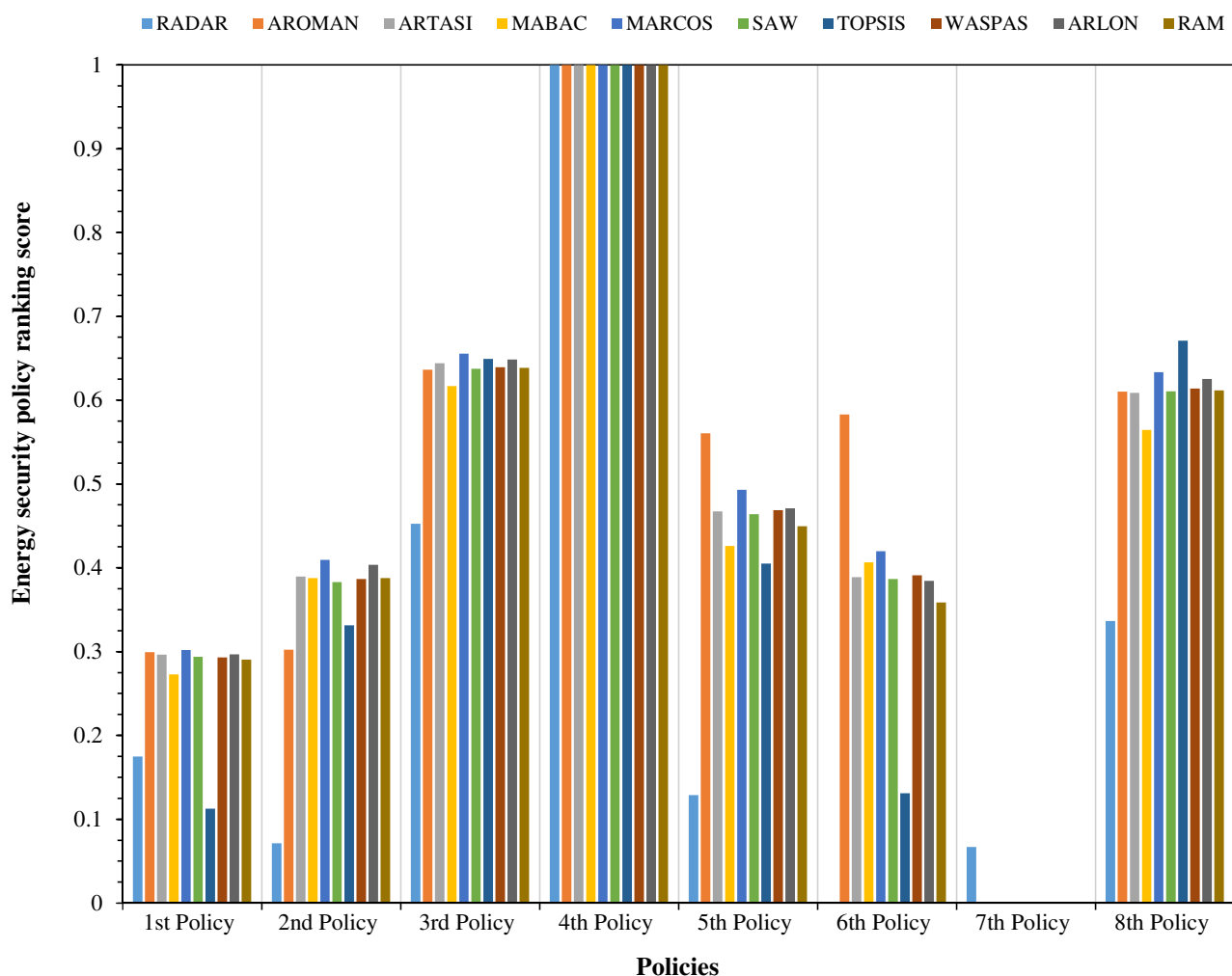


Fig. 5. Ranking scores for the comparative analysis

The rankings of the policies for each method are presented in Table 7. Across all methods, the fourth policy was consistently identified as the best energy security policy. The second-best policies varied slightly and were suggested as alternative recommendations. In all methods except TOPSIS, the third policy was ranked as the second-best alternative. In contrast, the TOPSIS method identified the eighth policy as the second-best.

Table 7

Alternative energy policies rankings

Scenario	Ranking	Best policy	Alternative policy
<i>Our results</i>	$\Omega_4 > \Omega_3 > \Omega_8 > \Omega_1 > \Omega_5 > \Omega_2 > \Omega_7 > \Omega_6$	4 th Policy	3 rd Policy
AROMAN	$\Omega_4 > \Omega_3 > \Omega_8 > \Omega_6 > \Omega_5 > \Omega_2 > \Omega_1 > \Omega_7$	4 th Policy	3 rd Policy
ARTASI	$\Omega_4 > \Omega_3 > \Omega_8 > \Omega_5 > \Omega_2 > \Omega_6 > \Omega_1 > \Omega_7$	4 th Policy	3 rd Policy
MABAC	$\Omega_4 > \Omega_3 > \Omega_8 > \Omega_5 > \Omega_6 > \Omega_2 > \Omega_1 > \Omega_7$	4 th Policy	3 rd Policy
MARCOS	$\Omega_4 > \Omega_3 > \Omega_8 > \Omega_5 > \Omega_6 > \Omega_2 > \Omega_1 > \Omega_7$	4 th Policy	3 rd Policy
SAW	$\Omega_4 > \Omega_3 > \Omega_8 > \Omega_5 > \Omega_6 > \Omega_2 > \Omega_1 > \Omega_7$	4 th Policy	3 rd Policy
TOPSIS	$\Omega_4 > \Omega_8 > \Omega_3 > \Omega_5 > \Omega_2 > \Omega_6 > \Omega_1 > \Omega_7$	4 th Policy	8 th Policy
WASPAS	$\Omega_4 > \Omega_3 > \Omega_8 > \Omega_5 > \Omega_6 > \Omega_2 > \Omega_1 > \Omega_7$	4 th Policy	3 rd Policy
ARLON	$\Omega_4 > \Omega_3 > \Omega_8 > \Omega_5 > \Omega_2 > \Omega_6 > \Omega_1 > \Omega_7$	4 th Policy	3 rd Policy
RAM	$\Omega_4 > \Omega_3 > \Omega_8 > \Omega_5 > \Omega_2 > \Omega_6 > \Omega_1 > \Omega_7$	4 th Policy	3 rd Policy

Table 8 presents the correlation analysis results between the ranking scores produced by different methods. The analysis revealed a high correlation between Aczel-Alsina–SCF–WENSLO–RADAR and the other ranking techniques.

Table 8

Correlation analysis among the methods

Methods	RADAR	AROMAN	ARTASI	MABAC	MARCOS	SAW	TOPSIS	WASPAS	ARLON	RAM
RADAR	1	0.7704	0.8642	0.8678	0.8432	0.8662	0.8878	0.8628	0.8602	0.8754
AROMAN		1	0.9597	0.9613	0.9650	0.9603	0.8628	0.9612	0.9553	0.9495
ARTASI			1	0.9971	0.9991	0.9999	0.9543	0.9999	0.9997	0.9993
MABAC				1	0.9957	0.9970	0.9414	0.9969	0.9959	0.9956
MARCOS					1	0.9990	0.9494	0.9993	0.9991	0.9974
SAW						1	0.9549	1	0.9996	0.9993
TOPSIS							1	0.9545	0.9582	0.9625
WASPAS								1	0.9997	0.9991
ARLON									1	0.9995
RAM										1

The specific findings from the comparative analysis are as follows:

- The fourth policy was ranked as the best energy security policy in all methods.
- The seventh policy was identified as the lowest-ranked option in all methods except Aczel-Alsina–SCF–WENSLO–RADAR.
- The lowest correlation was observed between Aczel-Alsina–SCF–WENSLO–RADAR and AROMAN. Despite the lowest correlation, the highest similarity in ranking order with Aczel-Alsina–SCF–WENSLO–RADAR was observed in AROMAN.
- The highest correlation with Aczel-Alsina–SCF–WENSLO–RADAR was found in TOPSIS. Conversely, despite the highest correlation, the greatest divergence in ranking orders was identified between Aczel-Alsina–SCF–WENSLO–RADAR and TOPSIS.

These results further validate the robustness of the proposed hybrid model and support the reliability of the RADAR-based policy rankings within the broader decision-making framework.

4. Discussion and Research Results

The process of determining energy security policies is conducted at the macro level, and countries adopt a variety of approaches to ensure long-term and sustainable energy security. Governments develop comprehensive policy frameworks and pursue diplomatic strategies accordingly in the international arena. This study addresses the formulation of a sustainable and long-term applicable energy security policy for Germany, particularly in the context of the recent Ukraine–Russia conflict and its implications for Europe’s energy landscape.

In this research, a decision support framework was developed and proposed for the selection of energy security policies. The proposed Aczel–Alsina–SCF–WENSLO–RADAR was applied specifically to Germany’s energy policy selection process. As a result, the study yielded both methodological and practical outcomes.

4.1 Methodological Results

The methodological contribution of this study lies in the design, application, and validation of Aczel–Alsina–SCF–WENSLO–RADAR for energy security policy selection. In light of the complex, multi-dimensional nature of energy policymaking (especially under geopolitical uncertainty such as the Ukraine–Russia conflict), this hybrid method provides a structured, flexible, and evidence-based framework that facilitates rational decision-making in policy environments characterized by both technical and strategic ambiguity.

The hybrid model integrates several advanced decision-making components, including fuzzy AOs, subjective expert judgments, and robust ranking mechanisms, to reflect the multifaceted nature of real-world energy decisions. Specifically, SCFAAWA enables the aggregation of expert opinions in a way that accounts for their individual expertise levels, while the Aczel–Alsina aggregation function provides a non-linear combination mechanism that captures the relative strength of preferences. SCF–WENSLO structures criteria weighting through a fuzzy-based process, allowing for a balanced reflection of both subjective and objective importance across decision criteria. Finally, SCF–RADAR ranks the alternatives using a normalized distance-based logic, offering transparent comparability among policy options.

One key methodological strength of the proposed approach is its ability to incorporate expert heterogeneity. Rather than treating all expert opinions as equal, the model quantifies the relative influence of each expert based on predefined competence levels, which contributes to more realistic and nuanced decision outcomes. This is particularly critical in energy policy domains, where subject matter expertise varies significantly across technical, economic, and geopolitical dimensions.

Another methodological advantage is the scenario-based sensitivity analysis, which tests the robustness of the method under different parameters and model assumptions. The two sensitivity scenarios implemented in this study demonstrated that the hybrid method produces stable and consistent outputs. Across both scenarios, the highest-ranked policy remained unchanged, reinforcing the reliability and resilience of the hybrid structure.

In addition, the comparative validation of the Aczel–Alsina–SCF–WENSLO–RADAR ranking component against nine alternative MCDM methods further supports the methodological soundness of the model. Despite methodological differences, all comparative methods yielded highly consistent rankings, with strong correlation scores and the same top-ranked policy, confirming that the hybrid method is not only internally coherent but also externally validated within the broader decision-making literature.

In summary, the methodological findings of this research demonstrate that Aczel–Alsina–SCF–WENSLO–RADAR offers a rigorous, adaptable, and decision-maker-oriented tool for energy security policy selection. Its modular design allows for the incorporation of new criteria,

stakeholders, or contextual constraints, making it highly suitable for complex policy environments where both technical rigor and strategic insight are essential.

4.2 Practical Results

The practical outcomes of this study are centered on the development, evaluation, and prioritization of energy security policy alternatives for Germany in the context of heightened geopolitical risk, specifically the Ukraine–Russia conflict. By applying the proposed hybrid decision-making model, the study has produced several important results that can inform national energy policy design and contribute to more secure, resilient, and strategically aligned energy systems.

4.2.1 Development of alternative energy security policies

A major contribution of the research is the formulation of eight distinct energy security policy alternatives tailored to Germany's strategic, economic, and infrastructural context. These alternatives were designed by integrating key selection criteria derived from both literature and expert consultations. The eight policies include:

- i. diplomacy-based policy focused on Germany's international interests;
- ii. collaboration-based policy emphasizing joint action with EU partners;
- iii. domestic demand-oriented policy addressing internal consumption and supply-demand balance;
- iv. energy transition-focused policy supporting renewable integration;
- v. supply security-driven policy aimed at minimizing external dependency;
- vi. equal distribution policy ensuring social equity in energy access;
- vii. investment-oriented policy promoting long-term infrastructure development;
- viii. harmonized policy framework balancing national and EU-level regulations.

These policies represent a broad strategic spectrum and were constructed based on the fundamental criteria of sustainability, reliability, diversification, and strategic alignment, critical concerns in Germany's current and future energy landscape.

4.2.2 Weighting of experts and criteria in the decision process

Aczel-Alsina–SCF–WENSLO–RADAR allowed for the inclusion of expert influence levels, ensuring that more experienced or contextually relevant experts had a proportionally greater impact on the final decision outcomes. The results showed that experts 4, 5, 6, and 10 were the most influential, indicating their evaluations carried more weight in the aggregation process due to their technical expertise or strategic relevance. This approach enhances the legitimacy and quality of the final policy ranking.

The criteria weighting process revealed two dominant factors in the evaluation of policies:

- i. energy diversification emerged as the most critical criterion, highlighting Germany's strategic need to reduce dependency on a limited number of energy sources or suppliers;
- ii. modernization of energy infrastructure was ranked second in importance, reflecting the necessity of upgrading physical and digital infrastructures to accommodate decentralized and renewable energy sources.

These findings align with current European energy policy discussions, where diversification and modernization are seen as twin pillars for achieving long-term energy security.

4.2.3 Policy ranking results

Based on expert evaluations and weighted criteria, the analysis produced a ranked list of the eight energy policy alternatives. The top-ranked policy was the diplomacy-based approach aligned with Germany's national interests. This result emphasizes the strategic importance of diplomatic engagement, international agreements, and active participation in global energy governance. It suggests that energy diplomacy, when aligned with national priorities, can serve as a critical instrument for managing both risks and opportunities in the global energy landscape. Following this, harmonization-focused and investment-driven policies were also identified as high-potential alternatives. These results highlight the complementary nature of internal capacity building and external diplomatic efforts in establishing a robust energy security posture.

4.2.4 Robustness through sensitivity analysis

To evaluate the stability of these practical findings, two scenario-based sensitivity analyses were conducted. The first scenario tested different values of the parameter in the SCFAAWA aggregation function. Across all tested parameter values, the fourth policy (diplomacy-based) consistently remained the top-ranked option, reinforcing its robustness as the most favorable choice. The second scenario involved systematically removing lower-ranked policies from the decision model to observe any shifts in ranking. Even when various alternatives were excluded, the top-ranked policy remained unchanged. These results demonstrate the resilience of the decision-making process and confirm that the outcome is not heavily dependent on model-specific assumptions or the inclusion/exclusion of certain alternatives.

4.2.5 Validation through comparative analysis

To further confirm the validity of the practical outcomes, a comparative analysis was conducted using nine well-established MCDM methods. All methods identified the diplomacy-based policy as the best energy security policy. Moreover, correlation analysis revealed high consistency between Aczel-Alsina–SCF–WENSLO–RADAR and alternative approaches, reinforcing the credibility and consistency of the proposed hybrid model. Notably, while TOPSIS showed the highest correlation with Aczel-Alsina–SCF–WENSLO–RADAR in terms of scoring, the greatest divergence in rankings occurred between these two methods. Conversely, AROMAN, despite having the lowest statistical correlation, produced the most similar ranking order. This highlights the importance of considering both numerical correlation and ordinal consistency when validating decision models.

5. Implications

This study offers a set of methodological, practical, and policy-specific implications for researchers, decision-makers, and energy policy institutions, particularly in the context of geopolitical uncertainties.

5.1 Methodological Implications

- i. *Integration of hybrid MCDM framework* – The proposed Aczel-Alsina–SCF–WENSLO–RADAR introduces a hybrid MCDM framework that enhances the reliability, transparency, and cognitive depth of energy policy evaluations under uncertainty.
- ii. *Advancement in fuzzy decision-making tools* – By incorporating SCF sets, the model allows the quantification of linguistic expert judgments and expert confidence, offering a more nuanced and realistic approach to modeling uncertainty in expert-based decisions.

- iii. *Robust aggregation and weighting mechanisms* – The use of SCFAAWA and SCF–WENSLO ratio-based weighting contributes to the development of more robust and mathematically grounded aggregation of subjective inputs, which is critical in high-stakes policy analysis.
- iv. *Validation through sensitivity and comparative analyses* – The framework demonstrates strong robustness and consistency through sensitivity analysis and comparative correlation with nine established MCDM methods, supporting its methodological soundness.

5.2 Practical Implications

- i. *Support for evidence-based policy design* – The proposed DSS provides policymakers with a systematic and quantifiable approach to evaluate competing policy alternatives, making it easier to justify and communicate policy choices to stakeholders under complex scenarios.
- ii. *Enhanced transparency in expert-driven decisions* – The explicit modeling of expert judgments and aggregation techniques enhances transparency and accountability in group decision-making, which is essential for participatory governance in energy security.
- iii. *Scenario-based sensitivity for strategic planning* – The model enables the design of scenario-based sensitivity analyses, which aid in stress-testing policy alternatives and preparing for potential shifts in geopolitical or economic environments.

5.3 Policy Implications for Germany

- i. *Strategic policy prioritization* – The case study identifies "Energy diplomacy based on the interests of Germany" as the most effective policy under current geopolitical conditions, offering a clear direction for short- to medium-term energy security strategy.
- ii. *Criteria emphasis in national planning* – The recognition of "strategic energy diversification" as the most influential criterion underscores the importance of diversified energy sourcing and infrastructure planning in Germany's national energy strategy.
- iii. *Tailored policy evaluation for crisis contexts* – The proposed model serves as a crisis-responsive tool for governments like Germany to evaluate policies quickly and accurately during global disruptions such as war, economic sanctions, or energy shortages.

5.4 Contributions to Global Energy Policy Research

- i. *Transferability to other geopolitical contexts* – While applied to Germany, the proposed method is adaptable to other national contexts facing energy security challenges, providing a replicable model for international energy policy analysis.
- ii. *Bridging theory and practice in energy governance* – The study demonstrates how advanced decision analytics can bridge the gap between theoretical modeling and practical policymaking, particularly under geopolitical uncertainty.

6. Conclusion

This research fundamentally contributed to the advancement of DSS tailored for the complex domain of energy security policy selection. By proposing Aczel-Alsina–SCF–WENSLO–RADAR, the

study introduced an innovative framework that effectively integrated linguistic uncertainty modeling, ratio-based criteria weighting, advanced AOs, and sophisticated ranking techniques. This methodological amalgamation addressed inherent challenges in MCDM under uncertainty, facilitating a more systematic, transparent, and cognitively grounded approach to policy evaluation and selection.

Within the geopolitical context shaped by the Ukraine–Russia conflict, the study formulated eight comprehensive energy security policy alternatives for Germany, encompassing diverse strategic orientations such as diplomacy, collaboration, domestic demand management, energy transition, supply security, equitable distribution, investment, and harmonization. The evaluation employed 11 rigorously identified criteria spanning geopolitical, economic, infrastructural, and sustainability dimensions. The involvement of a multidisciplinary expert panel enabled the nuanced capture of subjective judgments, operationalized through spherical fuzzy set theory and robust aggregation via Aczel-Alsina-based operators, thereby enhancing the validity of the evaluation outcomes.

The empirical application of the proposed hybrid DSS to the German case demonstrated its practical utility and robustness. The policy "Energy diplomacy based on the interests of Germany" was identified as the most favorable alternative, with "strategic energy diversification" emerging as the paramount criterion influencing policy prioritization. The robustness of these results was corroborated through comprehensive sensitivity analyses and comparative assessments against nine alternative MCDM methods, which revealed high correlations and reinforced the consistency and reliability of the proposed framework.

In summation, this study makes a significant contribution both theoretically and practically to the field of energy security policy analysis. The integration of advanced fuzzy logic constructs with complex aggregation and ranking mechanisms provides a versatile and rigorous tool for policy decision-making under uncertainty. The findings from the German case study furnish critical insights for policymakers contending with evolving geopolitical challenges. Future research should endeavor to extend this hybrid methodology across different national contexts, incorporate dynamic real-time data inputs, and enhance the accessibility of the DSS through the development of interactive decision-support platforms, thereby further bridging the gap between methodological innovation and practical policymaking.

6.1 Study Limitations

Despite the comprehensive structure and methodological innovation introduced in this study, several limitations need to be acknowledged for the sake of transparency, academic rigor, and to guide future improvements:

- i. *Context-bound case study focused on Germany* – The real-world application of the proposed hybrid DSS was conducted exclusively for Germany, within the geopolitical context of the Ukraine–Russia conflict. This localized application, while providing depth and relevance to the German policy landscape, may not be directly transferable to countries with different energy infrastructures, risk exposures, or political priorities. Therefore, the findings, such as the prioritization of "Energy diplomacy based on the interests of Germany", may not hold the same weight in other national contexts.
- ii. *Model complexity and technical accessibility* – The hybrid DSS method integrates multiple advanced mathematical tools, including t -norms and t -conorms, vector-based weighting, fuzzy set theory, and distance-based ranking. While this complexity allows for a highly robust policy evaluation, it also presents challenges for implementation by policy

- practitioners or government agencies without access to specialized decision analysts or computational tools.
- iii. *Fixed weights and static expert inputs* – The model assumes that expert-assigned weights for selection criteria and evaluations of policy alternatives remain valid over time. However, energy security dynamics—particularly in volatile geopolitical environments like the EU-Russia energy corridor—can shift rapidly due to new sanctions, technological breakthroughs, or market disruptions. The current framework does not incorporate mechanisms for dynamic updates or continuous learning, potentially limiting its adaptability in real-time decision-making environments.
 - iv. *Validation through simulated scenarios only* – Although the robustness of the proposed method was tested using two sensitivity analysis scenarios and cross-validated with nine different MCDM techniques, the outcomes were not tested against real-time policy results or historical policy performance. The validation remains confined to simulated environments, meaning the practical impact and effectiveness of the selected policy (such as energy diplomacy based on the interests of Germany) still needs to be assessed in future longitudinal or empirical studies.

6.2 Future Research Suggestions

Based on the scope, methodology, and findings of this research on developing an Aczel-Alsina–SCF–WENSLO–RADAR hybrid DSS for energy security policy selection, the following specific directions are recommended for future studies:

- i. *Incorporation of larger and more diverse expert panels* – This study used a panel of 10 experts with varying expertise to evaluate energy security policies for Germany. Future research could expand this expert base to include a wider array of stakeholders such as policymakers from different government departments, representatives from the energy industry, environmental organizations, and international experts. Including a broader expert spectrum would enhance the representativeness of subjective judgments and allow multi-perspective evaluation of energy security criteria.
- ii. *Application of the hybrid DSS framework to other countries and contexts* – While this study focused on Germany amid the Ukraine–Russia conflict, subsequent research should test the applicability of Aczel-Alsina–SCF–WENSLO–RADAR in different geopolitical and socio-economic environments. For instance, applying the framework to emerging economies with different energy dependency profiles or to countries facing other energy security challenges would verify its robustness and adaptability.
- iii. *Development of interactive and user-friendly DSS tools* – The study presented the hybrid method with pseudo-algorithms and flow diagrams. Future work could focus on developing software tools or interactive platforms that embed the Aczel-Alsina–SCF–WENSLO–RADAR approach. Such tools would allow policymakers and analysts to input data, adjust criteria weights, and run sensitivity analyses without needing deep expertise in fuzzy logic or MCDM methods.
- iv. *Expansion of evaluation criteria to include social and environmental dimensions* – Although 11 selection criteria were defined focusing on geopolitical, economic, and supply aspects, future research should incorporate broader sustainability-related criteria such as social acceptance, environmental impact, and climate resilience. This would enable a

more holistic assessment of energy security policies, aligning the DSS with contemporary priorities like sustainable development and energy justice.

- v. *Alignment with climate change mitigation and energy transition goals* – Given the importance of sustainable energy transitions, future studies should explore integrating climate policy targets into the DSS framework. This may include evaluating how selected energy security policies contribute to Germany's Energiewende goals or broader EU decarbonization commitments, by adding criteria related to greenhouse gas emissions, renewable energy adoption, and carbon neutrality trajectories.

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Conflicts of Interest

The authors declare no conflicts of interest.

Declaration on the Use of Artificial Intelligence Tools

During the preparation of this work the authors used Grammarly and DeepL solely for language editing and proofreading. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Appendix A: Preliminaries on Spherical Cubic Fuzzy Sets based on Aczel-Alsina t -norm and t -conorm

Definition 1. The SCF set $(\tilde{G})$ for a P universe's ρ elements is defined as $\tilde{G} = \{ \langle \rho, ([\kappa_{\tilde{G}}^-(\rho), \kappa_{\tilde{G}}^+(\rho)], \kappa_{\tilde{G}}(\rho)), ([\hbar_{\tilde{G}}^-(\rho), \hbar_{\tilde{G}}^+(\rho)], \hbar_{\tilde{G}}(\rho)), ([\sigma_{\tilde{G}}^-(\rho), \sigma_{\tilde{G}}^+(\rho)], \sigma_{\tilde{G}}(\rho)) \mid \rho \in P \}$. The first member of this SCF set is positive $([\kappa_{\tilde{G}}^-(\rho), \kappa_{\tilde{G}}^+(\rho)], \kappa_{\tilde{G}}(\rho))$, the second member is neutral $([\hbar_{\tilde{G}}^-(\rho), \hbar_{\tilde{G}}^+(\rho)], \hbar_{\tilde{G}}(\rho))$, and the third member is negative $([\sigma_{\tilde{G}}^-(\rho), \sigma_{\tilde{G}}^+(\rho)], \sigma_{\tilde{G}}(\rho))$. Two fundamental conditions exist for this SCF set, formulated for each ρ element of the P universe as follows: $0 \leq \left(\sup([\kappa_{\tilde{G}}^-(\rho), \kappa_{\tilde{G}}^+(\rho)]) \right)^2 + \left(\sup([\hbar_{\tilde{G}}^-(\rho), \hbar_{\tilde{G}}^+(\rho)]) \right)^2 + \left(\sup([\sigma_{\tilde{G}}^-(\rho), \sigma_{\tilde{G}}^+(\rho)]) \right)^2 \leq 1$ and $0 \leq (\kappa_{\tilde{G}}(\rho))^2 + (\hbar_{\tilde{G}}(\rho))^2 + (\sigma_{\tilde{G}}(\rho))^2 \leq 1$ [18].

Definition 2. In Aczel–Alsina binary operations, the t -norm (T_{AA}^ℓ) and t -conorm (S_{AA}^ℓ) operations are calculated using Eq. (1a) and Eq. (2a), respectively [62]:

$$T_{AA}^\ell(a, b) = \exp \left\{ - \left((-\ln(a))^\ell + (-\ln(b))^\ell \right)^{\frac{1}{\ell}} \right\}, \quad (1a)$$

$$S_{AA}^\ell(a, b) = 1 - \exp \left\{ - \left((-\ln(1-a))^\ell + (-\ln(1-b))^\ell \right)^{\frac{1}{\ell}} \right\}, \quad (2a)$$

herein, $a, b \in [0, 1]$ and $\ell > 0$.

Definition 3. Under Aczel–Alsina t -norm (T_{AA}^ℓ) and t -conorm (S_{AA}^ℓ) , consider two different SCF sets as: $\tilde{G}_1$ and $\tilde{G}_2$. To obtain numerical values for $\tilde{G}_1$, a score function $(S(\tilde{G}_1))$ (Eq. (3a)) is applied to the SCF sets. When the score functions result in a tie, the accuracy function $(A(\tilde{G}_1))$ (Eq. (4a)) is applied as a tiebreaker [18]:

$$S(\tilde{G}_1) = \frac{1}{2} \left(1 + \frac{1}{9} \left(\left(\kappa_{\tilde{G}_1}^-(\rho) + \kappa_{\tilde{G}_1}^+(\rho) + \kappa_{\tilde{G}_1}(\rho) \right)^2 + \left(\hbar_{\tilde{G}_1}^-(\rho) + \hbar_{\tilde{G}_1}^+(\rho) + \hbar_{\tilde{G}_1}(\rho) \right)^2 + \left(\sigma_{\tilde{G}_1}^-(\rho) + \sigma_{\tilde{G}_1}^+(\rho) + \sigma_{\tilde{G}_1}(\rho) \right)^2 \right) \right), \quad (3a)$$

$$A(\tilde{G}_1) = \frac{1}{9} \left(\left(\kappa_{\tilde{G}_1}^-(\rho) + \kappa_{\tilde{G}_1}^+(\rho) + \kappa_{\tilde{G}_1}(\rho) \right)^2 + \left(\hbar_{\tilde{G}_1}^-(\rho) + \hbar_{\tilde{G}_1}^+(\rho) + \hbar_{\tilde{G}_1}(\rho) \right)^2 + \left(\sigma_{\tilde{G}_1}^-(\rho) + \sigma_{\tilde{G}_1}^+(\rho) + \sigma_{\tilde{G}_1}(\rho) \right)^2 \right). \quad (4a)$$

To investigate the relationship between two SCF sets, the subsequent conditions are considered:

- (i) If $S(\tilde{G}_1) > S(\tilde{G}_2)$, then $\tilde{G}_1 > \tilde{G}_2$,
- (ii) If $S(\tilde{G}_1) = S(\tilde{G}_2)$ and $A(\tilde{G}_1) > A(\tilde{G}_2)$, then $\tilde{G}_1 > \tilde{G}_2$,
- (iii) If $S(\tilde{G}_1) = S(\tilde{G}_2)$ and $A(\tilde{G}_1) = A(\tilde{G}_2)$, then $\tilde{G}_1 = \tilde{G}_2$.

Definition 4. Under Aczel–Alsina t -norm (T_{AA}^ℓ) and t -conorm (S_{AA}^ℓ), consider a group of SCF sets $(\tilde{G}_m (m = 1, 2, \dots, M))$. SCFAAWA is computed by performing Eq. (5a) [18]:

$$SCFAAWA(\tilde{G}_1, \tilde{G}_2, \dots, \tilde{G}_m, \dots, \tilde{G}_M) = \bigoplus_{m=1}^M \beta_m \tilde{G}_m = \left(\left(\left(\left(\sqrt[\ell]{1 - \exp \left\{ - \left(\sum_{m=1}^M \left(\beta_m \left(- \ln \left(1 - \left(\kappa_{\tilde{G}_m}^-(\rho) \right)^2 \right)^\ell \right) \right)^\ell \right\}} \right)^{\frac{1}{\ell}} \right), \right. \right. \right. \left. \left. \left(\sqrt[\ell]{1 - \exp \left\{ - \left(\sum_{m=1}^M \left(\beta_m \left(- \ln \left(1 - \left(\kappa_{\tilde{G}_m}^+(\rho) \right)^2 \right)^\ell \right) \right)^\ell \right\}} \right)^{\frac{1}{\ell}} \right), \right. \right. \left. \left. \left(\sqrt[\ell]{1 - \exp \left\{ - \left(\sum_{m=1}^M \left(\beta_m \left(- \ln \left(1 - \left(\kappa_{\tilde{G}_m}(\rho) \right)^2 \right)^\ell \right) \right)^\ell \right\}} \right)^{\frac{1}{\ell}} \right) \right) \right), \right. \right. \left. \left. \left(\left(\sqrt[\ell]{\exp \left\{ - \left(\sum_{m=1}^M \left(\beta_m \left(- \ln \left(\left(\hbar_{\tilde{G}_m}^-(\rho) \right)^2 \right)^\ell \right) \right)^\ell \right\}} \right)^{\frac{1}{\ell}} \right), \right. \right. \right. \left. \left. \left(\sqrt[\ell]{\exp \left\{ - \left(\sum_{m=1}^M \left(\beta_m \left(- \ln \left(\left(\hbar_{\tilde{G}_m}^+(\rho) \right)^2 \right)^\ell \right) \right)^\ell \right\}} \right)^{\frac{1}{\ell}} \right), \right. \right. \left. \left. \left(\sqrt[\ell]{\exp \left\{ - \left(\sum_{m=1}^M \left(\beta_m \left(- \ln \left(\left(\hbar_{\tilde{G}_m}(\rho) \right)^2 \right)^\ell \right) \right)^\ell \right\}} \right)^{\frac{1}{\ell}} \right) \right) \right), \right. \right. \left. \left. \left(\left(\sqrt[\ell]{\exp \left\{ - \left(\sum_{m=1}^M \left(\beta_m \left(- \ln \left(\left(\sigma_{\tilde{G}_m}^-(\rho) \right)^2 \right)^\ell \right) \right)^\ell \right\}} \right)^{\frac{1}{\ell}} \right), \right. \right. \right. \left. \left. \left(\sqrt[\ell]{\exp \left\{ - \left(\sum_{m=1}^M \left(\beta_m \left(- \ln \left(\left(\sigma_{\tilde{G}_m}^+(\rho) \right)^2 \right)^\ell \right) \right)^\ell \right\}} \right)^{\frac{1}{\ell}} \right), \right. \right. \left. \left. \left(\sqrt[\ell]{\exp \left\{ - \left(\sum_{m=1}^M \left(\beta_m \left(- \ln \left(\left(\sigma_{\tilde{G}_m}(\rho) \right)^2 \right)^\ell \right) \right)^\ell \right\}} \right)^{\frac{1}{\ell}} \right) \right) \right) \right) \right), \quad |\rho \in P|. \quad (5a)$$

The weight vector $\beta_m = (\beta_1, \beta_2, \dots, \beta_m, \dots, \beta_M)$ has a relation with $\tilde{G}_m (m = 1, 2, \dots, M)$. Also, $\beta_m > 0$, $\sum_{m=1}^M \beta_m = 1$, and $\ell > 0$ [18].

Appendix B: Supplementary Tables

Table A.1

Aczel-Alsina-SCF-based expertise level vector and numerical-based expertise vector

Experts	Expertise levels	Aczel-Alsina-SCF-based expertise level vector	$\mathfrak{F}_r$
Γ_1	SHI	{{[0.50, 0.60],0.55}, {[0.30, 0.40],0.35}, {[0.30, 0.40],0.35}}	0.6513
Γ_2	HI	{{[0.60, 0.70],0.65}, {[0.20, 0.30],0.25}, {[0.20, 0.30],0.25}}	0.7113
Γ_3	SHI	{{[0.50, 0.60],0.55}, {[0.30, 0.40],0.35}, {[0.30, 0.40],0.35}}	0.6513
Γ_4	VHI	{{[0.70, 0.80],0.75}, {[0.10, 0.20],0.15}, {[0.10, 0.20],0.15}}	0.7813
Γ_5	VHI	{{[0.70, 0.80],0.75}, {[0.10, 0.20],0.15}, {[0.10, 0.20],0.15}}	0.7813
Γ_6	VHI	{{[0.70, 0.80],0.75}, {[0.10, 0.20],0.15}, {[0.10, 0.20],0.15}}	0.7813
Γ_7	HI	{{[0.60, 0.70],0.65}, {[0.20, 0.30],0.25}, {[0.20, 0.30],0.25}}	0.7113
Γ_8	SHI	{{[0.50, 0.60],0.55}, {[0.30, 0.40],0.35}, {[0.30, 0.40],0.35}}	0.6513
Γ_9	HI	{{[0.60, 0.70],0.65}, {[0.20, 0.30],0.25}, {[0.20, 0.30],0.25}}	0.7113
Γ_{10}	VHI	{{[0.70, 0.80],0.75}, {[0.10, 0.20],0.15}, {[0.10, 0.20],0.15}}	0.7813

Table A.2

Expert evaluations

	Ω_b	Λ_1	Λ_2	Λ_3	Λ_4	Λ_5	Λ_6	Λ_7	Λ_8	Λ_9	Λ_{10}	Λ_{11}
Γ_1	Ω_1	VHI	VHI	HI	SHI	SHI	VHI	VHI	MI	HI	LI	VLI
	Ω_2	VHI	HI	MI	VHI	SHI	HI	VHI	MI	SHI	LI	VLI
	Ω_3	SHI	SHI	MI	HI	SHI	HI	VHI	MI	MI	VLI	VLI
	Ω_4	HI	HI	MI	HI	SHI	SHI	VHI	MI	MI	VLI	VLI
	Ω_5	HI	VHI	SHI	HI	SHI	HI	VHI	MI	SLI	VLI	VLI
	Ω_6	SHI	SHI	MI	HI	SHI	SLI	VHI	MI	MI	VLI	VLI
	Ω_7	MI	MI	MI	SHI	SHI	MI	VHI	MI	MI	VLI	VLI
	Ω_8	VHI	HI	SHI	HI	SHI	SHI	VHI	MI	HI	VLI	VLI
Γ_2	Ω_1	VHI	HI	HI	SHI	MI	HI	MI	SHI	HI	HI	SHI
	Ω_2	HI	SHI	SHI	SLI	SHI	HI	HI	MI	HI	VHI	SHI
	Ω_3	HI	SHI	VHI	SHI	MI	VHI	HI	SHI	SHI	HI	MI
	Ω_4	HI	HI	VHI	MI	HI	SHI	SHI	HI	VHI	MI	HI
	Ω_5	SHI	HI	SHI	HI	SHI	HI	SHI	SHI	HI	SHI	MI
	Ω_6	SHI	HI	HI	SHI	SHI	HI	HI	SHI	HI	MI	SHI
	Ω_7	HI	MI	SHI	HI	SHI	HI	SLI	VHI	SHI	HI	MI
	Ω_8	MI	HI	SHI	SLI	HI	SHI	SHI	VHI	HI	HI	HI
Γ_{10}												
	Ω_1	HI	VHI	SLI	MI	HI	VHI	VHI	LI	VHI	VLI	VLI
	Ω_2	VHI	VHI	SHI	HI	HI	MI	VHI	SHI	VHI	LI	VLI
	Ω_3	VHI	SHI	VHI	VHI	HI	SLI	VHI	HI	SHI	MI	VLI
	Ω_4	VHI	SHI	SLI	SHI	VHI	VHI	VHI	MI	HI	LI	VLI
	Ω_5	HI	SHI	VHI	VHI	SHI	MI	VHI	SLI	MI	LI	VLI
	Ω_6	VHI	SLI	VHI	HI	SHI	VLI	VHI	LI	LI	VLI	VLI
	Ω_7	HI	SLI	HI	VHI	SHI	VLI	VHI	LI	LI	LI	VLI
	Ω_8	VHI	HI	VHI	VHI	HI	VHI	VHI	MI	HI	VLI	VLI

Table A.3
Corresponding decision matrix*

	Ω_b	Λ_1								
		κ^-	κ^+	κ	$\hbar^-$	$\hbar^+$	$\hbar$	σ^-	σ^+	σ
Γ_1	Ω_1	0.70	0.80	0.75	0.10	0.20	0.15	0.10	0.20	0.15
	Ω_2	0.70	0.80	0.75	0.10	0.20	0.15	0.10	0.20	0.15
	Ω_3	0.50	0.60	0.55	0.30	0.40	0.35	0.30	0.40	0.35
	Ω_4	0.60	0.70	0.65	0.20	0.30	0.25	0.20	0.30	0.25
	Ω_5	0.60	0.70	0.65	0.20	0.30	0.25	0.20	0.30	0.25
	Ω_6	0.50	0.60	0.55	0.30	0.40	0.35	0.30	0.40	0.35
	Ω_7	0.40	0.50	0.45	0.40	0.50	0.45	0.40	0.50	0.45
	Ω_8	0.70	0.80	0.75	0.10	0.20	0.15	0.10	0.20	0.15

*SCF numbers are shown only for the first expert depending on the first criterion. The same transformation is applied to the other experts and criteria

Table A.4
Aczel-Alsina-SCF-based aggregated evaluation matrix

Ω_b	Λ_1								
	κ^-	κ^+	κ	$\hbar^-$	$\hbar^+$	$\hbar$	σ^-	σ^+	σ
Ω_1	0.6569	0.7582	0.7074	0.9901	0.9696	0.9812	0.9901	0.9696	0.9812
Ω_2	0.6786	0.7795	0.7289	0.9929	0.9750	0.9852	0.9929	0.9750	0.9852
Ω_3	0.5985	0.7004	0.6490	0.9798	0.9508	0.9666	0.9798	0.9508	0.9666
Ω_4	0.6710	0.7721	0.7213	0.9920	0.9731	0.9839	0.9920	0.9731	0.9839
Ω_5	0.6294	0.7311	0.6800	0.9859	0.9618	0.9752	0.9859	0.9618	0.9752
Ω_6	0.6219	0.7248	0.6728	0.9848	0.9585	0.9730	0.9848	0.9585	0.9730
Ω_7	0.6272	0.7290	0.6777	0.9855	0.9607	0.9744	0.9855	0.9607	0.9744
Ω_8	0.6303	0.7333	0.6811	0.9867	0.9615	0.9755	0.9861	0.9598	0.9744
$\vdots$									
Ω_b	Λ_2								
	κ^-	κ^+	κ	$\hbar^-$	$\hbar^+$	$\hbar$	σ^-	σ^+	σ
Ω_1	0.6478	0.7491	0.6982	0.9888	0.9672	0.9794	0.9888	0.9672	0.9794
Ω_2	0.6254	0.7273	0.6760	0.9852	0.9604	0.9741	0.9852	0.9604	0.9741
Ω_3	0.6135	0.7159	0.6643	0.9832	0.9563	0.9710	0.9832	0.9563	0.9710
Ω_4	0.6077	0.7085	0.6579	0.9816	0.9557	0.9700	0.9816	0.9557	0.9700
Ω_5	0.6108	0.7132	0.6615	0.9825	0.9551	0.9701	0.9825	0.9551	0.9701
Ω_6	0.5739	0.6744	0.6236	0.9787	0.9508	0.9661	0.9772	0.9407	0.9582
Ω_7	0.4234	0.5199	0.4711	0.9488	0.9078	0.9298	0.9377	0.8672	0.8947
Ω_8	0.6031	0.7045	0.6534	0.9858	0.9616	0.9750	0.9858	0.9518	0.9674
$\vdots$									
Ω_b	Λ_{11}								
	κ^-	κ^+	κ	$\hbar^-$	$\hbar^+$	$\hbar$	σ^-	σ^+	σ
Ω_1	0.4885	0.5829	0.5350	0.9880	0.9653	0.9780	0.9880	0.8898	0.9149
Ω_2	0.4248	0.5162	0.4700	0.9875	0.9634	0.9768	0.9875	0.8540	0.8825
Ω_3	0.4564	0.5494	0.5021	0.9841	0.9579	0.9723	0.9841	0.8708	0.8983
Ω_4	0.5153	0.6105	0.5622	0.9906	0.9705	0.9819	0.9906	0.9035	0.9269
Ω_5	0.3381	0.4284	0.3827	0.9829	0.9539	0.9698	0.9829	0.8008	0.8351
Ω_6	0.3795	0.4697	0.4240	0.9839	0.9563	0.9715	0.9839	0.8257	0.8574
Ω_7	0.3381	0.4284	0.3827	0.9829	0.9539	0.9698	0.9829	0.8008	0.8351
Ω_8	0.4843	0.5788	0.5308	0.9857	0.9613	0.9748	0.9857	0.8887	0.9139

Table A.5

Crisp-aggregated evaluation matrix

Ω_b	Λ_1	Λ_2	Λ_3	Λ_4	Λ_5	Λ_6	Λ_7	Λ_8	Λ_9	Λ_{10}	Λ_{11}
Ω_1	0.7503	0.7439	0.6922	0.6469	0.6815	0.7452	0.7055	0.6553	0.7065	0.6926	0.6874
Ω_2	0.7657	0.7286	0.7162	0.6931	0.6895	0.7134	0.7322	0.6408	0.7314	0.7176	0.6746
Ω_3	0.7108	0.7208	0.7606	0.7214	0.7113	0.7384	0.7427	0.6352	0.7206	0.6875	0.6771
Ω_4	0.7603	0.7165	0.7625	0.7212	0.7512	0.7426	0.7293	0.6822	0.7297	0.6635	0.6973
Ω_5	0.7313	0.7190	0.7233	0.7305	0.6887	0.6952	0.7257	0.6505	0.6778	0.6692	0.6617
Ω_6	0.7266	0.7009	0.7351	0.7100	0.6893	0.6635	0.7459	0.6623	0.7009	0.6497	0.6659
Ω_7	0.7298	0.6376	0.7038	0.7512	0.6507	0.6680	0.7241	0.6993	0.6811	0.7176	0.6617
Ω_8	0.7334	0.7193	0.7068	0.7080	0.7271	0.6772	0.7155	0.7107	0.7100	0.6798	0.6835

Table A.6

Normalized evaluation matrix, criterion class vector, slope vector, envelope vector, and ratio vector

Ω_b	Λ_1	Λ_2	Λ_3	Λ_4	Λ_5	Λ_6	Λ_7	Λ_8	Λ_9	Λ_{10}	Λ_{11}
Ω_1	0.1270	0.1308	0.1193	0.1138	0.1219	0.1320	0.1212	0.1228	0.1249	0.1265	0.1271
Ω_2	0.1296	0.1281	0.1235	0.1220	0.1234	0.1264	0.1258	0.1201	0.1293	0.1310	0.1247
Ω_3	0.1203	0.1268	0.1311	0.1270	0.1273	0.1308	0.1276	0.1190	0.1274	0.1255	0.1252
Ω_4	0.1287	0.1260	0.1315	0.1269	0.1344	0.1316	0.1253	0.1278	0.1290	0.1211	0.1289
Ω_5	0.1238	0.1264	0.1247	0.1286	0.1232	0.1232	0.1247	0.1219	0.1198	0.1222	0.1223
Ω_6	0.1230	0.1233	0.1267	0.1249	0.1233	0.1176	0.1281	0.1241	0.1239	0.1186	0.1231
Ω_7	0.1235	0.1121	0.1213	0.1322	0.1164	0.1184	0.1244	0.1310	0.1204	0.1310	0.1223
Ω_8	0.1241	0.1265	0.1219	0.1246	0.1301	0.1200	0.1229	0.1332	0.1255	0.1241	0.1264
$\mathcal{D}_f$	0.0023	0.0047	0.0030	0.0046	0.0045	0.0036	0.0017	0.0035	0.0024	0.0031	0.0016
$\mathcal{W}_f$	0.0344	0.0525	0.0367	0.0489	0.0583	0.0396	0.0224	0.0407	0.0349	0.0455	0.0235
$\mathcal{C}_f$	61.4631	30.5705	47.1635	31.1344	31.7856	39.4806	82.3416	40.3727	60.4061	46.0924	86.6977
$\mathcal{B}_f$	0.0006	0.0017	0.0008	0.0016	0.0018	0.0010	0.0003	0.0010	0.0006	0.0010	0.0003

Table A.7

Maximum proportion matrix

Ω_b	Λ_1	Λ_2	Λ_3	Λ_4	Λ_5	Λ_6	Λ_7	Λ_8	Λ_9	Λ_{10}	Λ_{11}
Ω_1	0.4916	0.4615	0.5242	0.5373	0.5128	0.4710	0.5139	0.5125	0.4983	0.5072	0.5059
Ω_2	0.4814	0.4718	0.5071	0.5029	0.5069	0.4927	0.4954	0.5237	0.4810	0.5248	0.4965
Ω_3	0.5186	0.4772	0.4771	0.4829	0.4914	0.4756	0.4882	0.5281	0.4884	0.5034	0.4984
Ω_4	0.4850	0.4802	0.4758	0.4831	0.4642	0.4727	0.4973	0.4923	0.4822	0.4857	0.5131
Ω_5	0.5044	0.4785	0.5022	0.4766	0.5075	0.5057	0.4998	0.5162	0.5190	0.4899	0.4869
Ω_6	0.5076	0.4912	0.4941	0.4909	0.5071	0.5290	0.4861	0.5072	0.5023	0.4752	0.4901
Ω_7	0.5054	0.5385	0.5159	0.4627	0.5358	0.5256	0.5009	0.4800	0.5166	0.5248	0.4869
Ω_8	0.5030	0.4783	0.5137	0.4922	0.4804	0.5188	0.5068	0.4719	0.4958	0.4978	0.5031

Table A.8

Minimum proportion matrix

Ω_b	Λ_1	Λ_2	Λ_3	Λ_4	Λ_5	Λ_6	Λ_7	Λ_8	Λ_9	Λ_{10}	Λ_{11}
Ω_1	0.5084	0.5385	0.4758	0.4627	0.4872	0.5290	0.4861	0.4875	0.5017	0.4928	0.4941
Ω_2	0.5186	0.5282	0.4929	0.4971	0.4931	0.5073	0.5046	0.4763	0.5190	0.4752	0.5035
Ω_3	0.4814	0.5228	0.5229	0.5171	0.5086	0.5244	0.5118	0.4719	0.5116	0.4966	0.5016
Ω_4	0.5150	0.5198	0.5242	0.5169	0.5358	0.5273	0.5027	0.5077	0.5178	0.5143	0.4869
Ω_5	0.4956	0.5215	0.4978	0.5234	0.4925	0.4943	0.5002	0.4838	0.4810	0.5101	0.5131
Ω_6	0.4924	0.5088	0.5059	0.5091	0.4929	0.4710	0.5139	0.4928	0.4977	0.5248	0.5099
Ω_7	0.4946	0.4615	0.4841	0.5373	0.4642	0.4744	0.4991	0.5200	0.4834	0.4752	0.5131
Ω_8	0.4970	0.5217	0.4863	0.5078	0.5196	0.4812	0.4932	0.5281	0.5042	0.5022	0.4969

Table A.9

Empty range matrix

Ω_h	Λ_1	Λ_2	Λ_3	Λ_4	Λ_5	Λ_6	Λ_7	Λ_8	Λ_9	Λ_{10}	Λ_{11}
Ω_1	0.0168	0.0769	0.0483	0.0746	0.0255	0.0580	0.0278	0.0250	0.0034	0.0143	0.0119
Ω_2	0.0372	0.0564	0.0143	0.0058	0.0139	0.0145	0.0093	0.0473	0.0380	0.0496	0.0070
Ω_3	0.0372	0.0456	0.0458	0.0342	0.0172	0.0488	0.0235	0.0561	0.0232	0.0069	0.0033
Ω_4	0.0300	0.0396	0.0483	0.0339	0.0717	0.0546	0.0054	0.0153	0.0357	0.0287	0.0262
Ω_5	0.0087	0.0431	0.0045	0.0468	0.0150	0.0114	0.0004	0.0323	0.0380	0.0201	0.0262
Ω_6	0.0153	0.0177	0.0118	0.0183	0.0142	0.0580	0.0278	0.0144	0.0046	0.0497	0.0198
Ω_7	0.0108	0.0769	0.0317	0.0746	0.0717	0.0512	0.0018	0.0400	0.0331	0.0497	0.0262
Ω_8	0.0059	0.0435	0.0275	0.0155	0.0392	0.0375	0.0137	0.0561	0.0084	0.0044	0.0062

Table A.10

Relative relationship matrix

Ω_h	Λ_1	Λ_2	Λ_3	Λ_4	Λ_5	Λ_6	Λ_7	Λ_8	Λ_9	Λ_{10}	Λ_{11}
Ω_1	0.9359	0.7499	1.0000	1.0000	1.0000	0.8024	1.0000	1.0000	0.9866	1.0000	1.0000
Ω_2	0.8661	0.8071	1.0000	1.0000	1.0000	0.9444	0.9638	1.0000	0.8636	1.0000	0.9727
Ω_3	1.0000	0.8396	0.8389	0.8760	0.9346	0.8296	0.9121	1.0000	0.9131	1.0000	0.9871
Ω_4	0.8897	0.8584	0.8312	0.8770	0.7640	0.8124	0.9789	0.9415	0.8711	0.8945	1.0000
Ω_5	1.0000	0.8474	1.0000	0.8360	1.0000	1.0000	0.9984	1.0000	1.0000	0.9240	0.9027
Ω_6	1.0000	0.9329	0.9546	0.9307	1.0000	1.0000	0.8972	1.0000	1.0000	0.8271	0.9251
Ω_7	1.0000	1.0000	1.0000	0.7562	1.0000	1.0000	1.0000	0.8572	1.0000	1.0000	0.9027
Ω_8	1.0000	0.8461	1.0000	0.9406	0.8599	1.0000	1.0000	0.8079	0.9674	0.9825	1.0000

Table A.11

Weighted relative relationship matrix

Ω_h	Λ_1	Λ_2	Λ_3	Λ_4	Λ_5	Λ_6	Λ_7	Λ_8	Λ_9	Λ_{10}	Λ_{11}
Ω_1	0.0496	0.1218	0.0736	0.1484	0.1733	0.0761	0.0257	0.0952	0.0539	0.0933	0.0256
Ω_2	0.0459	0.1311	0.0736	0.1484	0.1733	0.0896	0.0248	0.0952	0.0471	0.0933	0.0249
Ω_3	0.0530	0.1364	0.0618	0.1300	0.1619	0.0787	0.0235	0.0952	0.0499	0.0933	0.0253
Ω_4	0.0471	0.1394	0.0612	0.1301	0.1324	0.0770	0.0252	0.0897	0.0476	0.0835	0.0256
Ω_5	0.0530	0.1377	0.0736	0.1240	0.1733	0.0948	0.0257	0.0952	0.0546	0.0862	0.0231
Ω_6	0.0530	0.1515	0.0703	0.1381	0.1733	0.0948	0.0231	0.0952	0.0546	0.0772	0.0237
Ω_7	0.0530	0.1624	0.0736	0.1122	0.1733	0.0948	0.0257	0.0816	0.0546	0.0933	0.0231
Ω_8	0.0530	0.1374	0.0736	0.1396	0.1490	0.0948	0.0257	0.0769	0.0528	0.0917	0.0256

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