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Holistic evaluation of energy transition technology investments using an integrated recommender system and artificial intelligence-based fuzzy decision-making approach

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A R T I C L E I N F O

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A B S T R A C T

The most essential criteria should be determined in the selection of the suitable energy transition technologies due to budget deficit problem. Therefore, it is necessary to identify the most important criteria in energy transition technology selection. Therefore, a new study is needed to determine the most prominent issues in the correct selection of energy transition technologies. The purpose of this study is to identify the most appropriate energy transition technology alternative. Within this framework, a novel artificial intelligence (AI)-based fuzzy decision-making model has been presented. In the first part, the experts are prioritized by the help of AI methodology. In the next section, missing evaluations of energy transition technology investments are estimated via expert recommender system. Thirdly, the weights of the criteria for energy transition technology selection are computed by quantum picture fuzzy rough sets (QPFR) M-Stepwise Weight Assessment Ratio Analysis (SWARA). At the final stage, selected energy transition technology alternatives are ranked via QPFR-Vlse Kriterijumska Optimizacija Kompromisno Resenje (VIKOR). The main contribution of this study is the integration of AI technique to the proposed model. Similar to this issue, using M-SWARA methodology in the process of criteria weighting increases the quality of the findings. This methodology helps to consider the impact relation map of the criteria. The findings demonstrate that the most important factor is cost-effectiveness of energy transition. Similarly, it is also found that the local ecosystem is the second most significant issue. On the other side, the ranking results denote that compact renewable systems for small scale production is the most optimal solution of energy transition technology alternatives.

1. Introduction

Energy transition is the process in which renewable energy alternatives are preferred instead of fossil resources in energy production. This is a very necessary situation in terms of environmental sustainability. The main reason for this is that fossil fuels cause significant carbon emissions. This situation can lead to problems that threaten the whole world, such as global warming. On the other hand, energy transition is also of key importance for countries' national energy policies Blay-Roger et al., 2024. Thanks to renewable energy investments, countries will not have to import energy from abroad. This situation positively affects the current account balance of the countries. Technological

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development is of critical importance to ensure the successful energy transition. It is possible to increase the efficiency of energy storage processes by taking into account current technologies. This allows the costs of energy production processes to be significantly reduced Pata et al., 2024. Similarly, thanks to technological developments, energy transition processes can be implemented more successfully.

The correct selection of energy transition technologies is necessary to increase the success of this process. Local ecosystem conditions should be taken into account in this technology selection process. Since each country has different geographical conditions, natural resources may differ in these countries. Cost effectiveness is another variable to consider in this process. For the energy transition to be successful, the financial success of the projects must be ensured. To achieve this goal, it is important to manage operational costs effectively. On the other hand, the adequacy of the technological infrastructure also affects the success of the energy transition process Uche and Ngepah, 2024. If the selected energy transition technology is not compatible with the technological infrastructure of the country and the enterprises, this transition process will not be successful. Moreover, energy transition processes can be implemented more safely by having sufficient technological infrastructure. Furthermore, social acceptance is also an important factor in energy transition technology selection. This enables the projects to be accepted by the society.

To choose the right energy transition technologies, necessary improvements must be made by taking these factors into consideration. However, the most important disadvantage of these improvements is that they create high costs for businesses. Considering the budget constraint situation, too many improvements will negatively affect the financial performance of this process Rial, 2024. Therefore, it is necessary to identify the highest important criteria in energy transition technology selection. Otherwise, choosing the right energy transition technology for countries will not be possible. This situation causes this process to not be carried out successfully. In summary, a priority analysis needs to be made for the variables affecting this process. However, there are very few academic studies focusing on this issue in the literature. Therefore, a new study is needed to determine the most prominent issues in the correct selection of energy transition technologies.

Accordingly, the scientific aim of the work is to select the most suitable energy transfer technology alternative. The subject of the research was to obtain the most critical performance indicators of this process. This study extends the existing research in generating a novel fuzzy decision-making model. In this context, a new AI-based fuzzy decision-making model is proposed. Firstly, the experts are prioritized using AI methodology. Secondly, missing evaluations of energy transition technology investments are estimated with expert recommender system. Thirdly, the weights of the criteria for energy transition technology selection are calculated by QPFR M − Stepwise Weight Assessment Ratio Analysis (SWARA). At the final stage, selected energy transition technology alternatives are ranked via QPFR- Vlse Kriterijumska Optimizacija Kompromisno Resenje (VIKOR). The main motivation of this study is the necessity to make a comprehensive evaluation to identify key strategies regarding the energy transfer technology invetments. These strategies pave the way for the investors to make appropriate investment decisions. As a result, this situation has a positive contribution to both social and economic development of the countries. Within this context, the main research question is to understand which indicators should be prioritized to select the best technology in this regard. Decision-making models can be considered to reach this objective. The main reason is that these models can make a priority analysis to identifiy the most essential criteria and alternatives. However, there are lots of different criticisms for these models. Therefore, to reach appropriate results, these criticisms should be satisfied while establishing a new model. The main criticism for these models is the failure to manage uncertainties in the analysis process. The questions are becoming so complex that many different indicators can have an impact on this purpose. In addition to this issue, most of the existing fuzzy decision-making models estimate the equal weights of the expert evaluations ([1]; Biswas et al., 2024). This situation is criticized by many different scholars in the literature Sahoo et al., 2024. This condition is defined as the main motivation of making this article. To overcome these criticisms, the weights of these decision makers can be computed via AI.

The main contribution of this study is that the effective energy transfer technology alternatives are identified with a new decision making model. Because of this issue, this manuscript has both theoretical and methodologival contributions. The main theoretical contribution is that appropriate investment strategies can be determined without having too many costs. This situation provides an opportunity for the companies to increase financial performance. With the help of this issue, long-term performance improvements for these projects can be provided. In addition to them, the main superiorities of the proposed model are explained below: (*i*) Preferring M-SWARA methodology in the process of criteria weighting increase the quality of the findings. This technique is created by the help of some improvements made to the classical SWARA approach. These improvements help to consider the impact relation map of the criteria. This situation is accepted as the man superiorities in comparison with the previously generated models that considers different weighting techniques, such as AHP and ANP Lyu et al., 2024; [2]. The indicators for the selection of the most suitable energy transition technology may affect each other. Therefore, to understand which technology alternative is the most appropriate, the causality relationship between the indicators should be considered. Hence, M-SWARA methodology plays a very critical role to achieve this objective. (*ii*) The integration of the quantum theory and picture fuzzy rough sets is another contribution of this study. Quantum theory is very successful to make future estimation. Owing to this advantage, these sets are taken into consideration to handle uncertainties in the evaluation process. Picture fuzzy sets are being developed as an extension of previous fuzzy set theories such as classical fuzzy sets and intuitionistic fuzzy sets. These sets include membership, non-membership and indecision, as well as rejection. Taking these different conditions into account increases the reliability of the results. In this way, it is true that the uncertainty situation can be represented more accurately. This allows more accurate results to be obtained from classical fuzzy systems [3–5]. (*iii*) Considering expert recommender system contributes to the quality improvement of the proposed model. This methodology gives an opportunity for the experts not to answer the questions in case of the hesitancy. With the help of this situation, it can be possible to reach more appropriate findings. In models where this technique is not used, experts are required to answer all questions. These questions are derived according to the relationships between the criteria and alternatives. In this context, if the number of these factors is high, too many questions can be generated. In this case, the probability of experts encountering questions that they are not very sure about the answer increases. In cases where these people are required to answer, there is a possibility of reaching incorrect results. In cases where experts leave some questions blank, it is not possible to continue the analysis if these gaps are not filled. These gaps can be filled with the collaborative filtering technique. This situation provides the proposed model with a very important advantage over others [6,7]. *(iv)* Using AI methodology to compute the weights of the experts provides some advantages to the proposed model. In most of the previously generated models, the weights of these people are assumed as equal. However, this situation is criticized by many different scholars Eti and Yüksel, 2024; [8]. The main reason is that these people have different qualifications. For instance, the quality of these experts can be different because of educational background and working experience. To overcome this criticism, AI technique is adopted to the model to differentiate the experts. In this framework, firstly, WCSS values are computed. In the following step, cluster weights are calculated. Next, mean standard deviations are calculated. These values are taken into consideration to identify the expert weights.

Literature review is made in the second part. Hence, the main missing parts in the literature can be identified. To fill this missing part, a new model is constructed that is explained in the third section. The main results of this model are shared in the following section. These results are compared with the previous similar studies in the next part. At the end of the manuscript, the main issues of the manuscript are summarized.

2. Literature review

Briefly, this article brings a new look to the existing literature in the following areas: (I) choosing the right energy transition technology, (II) cost effectiveness, (III) adequacy of the technological infrastructure and (IV) ensuring social acceptance. The details of the literature review results are demonstrated in Table 1.

In choosing the right energy transition technology, the local ecosystem must be taken into account. The availability of natural resources may vary for each country. Ahmad et al. [9] defined that while solar energy is suitable in some countries, a significant amount of geothermal energy resources can be found in others. Therefore, these issues are important in choosing the right technology for this process Asghar et al., 2024. Considering the infrastructure of the country in which the investment will be made is also necessary for a successful energy transition. Luo et al. [10] identified that the local ecosystem must be understood to clearly determine whether the appropriate infrastructure exists. Social acceptance is another important issue in ensuring the high performance of energy transition projects. Zhang et al. [11] concluded that people living in the area where the investment will be made must accept these projects. To achieve this goal, businesses must analyze the local ecosystem correctly. Similarly, according to Yang et al. [12], the economic performance of the country to be invested in and the employment opportunities in this region also play a critical role in choosing the right technology projects.

Cost effectiveness is an important factor in choosing energy transition technology. It is necessary to ensure the continuity of investments made for the energy transition. To achieve this goal, it is important to ensure the long-term profitability of these projects Alamoush et al., 2024. In this process, cost effectiveness must be ensured. This may attract more attention from investors as it will increase the profit margin Zhdaneev and Frolov, 2024. On the other hand, ensuring cost efficiency can also increase the competitiveness of these projects. Thus, these projects will be more preferred by investors Ullah et al., 2024. Hassan et al. [16] discussed that this contributes significantly to the sustainability of these investments. Achieving cost effectiveness also helps keep prices at reasonable levels. Thus, it will be much easier to meet consumers' expectations. Mohammed et al. [17] concluded that ensuring customer satisfaction significantly enables increasing the effectiveness of energy transition technologies. Similarly, lower costs can also help increase social acceptance of these projects.

Table 1
Literature review results.

Authors	Conclusions
Ahmad et al. [9] Luo et al. [10] Zhang et al. [11] Yang et al. [12]	The local ecosystem must be taken into consideration in choosing the right energy transition technology
Alamoush et al. [13] Zhdaneev and Frolov [14] Ullah et al. [15] Hassan et al. [16] Mohammed et al. [17]	Cost effectiveness is an important factor in choosing energy transition technology.
Kyere et al. [18] Wang et al. [19] Li et al. [20] Liza et al. [21] Murshed [22]	The adequacy of the technological infrastructure should be taken into account in choosing the right energy transition technology.
Ferdoush et al. [23] Schmid-Petri and Elschner [24] Xu et al. [25] Lee et al. [26] Hou et al. [27]	Ensuring social acceptance is also necessary to determine the right technology in the energy transition process.

The adequacy of the technological infrastructure should be taken into account in choosing the right energy transition technology. In other words, the technological infrastructure of the enterprise that will invest is of critical importance in determining the technology required to ensure the correct energy transition Kyere et al., 2024. If the infrastructure of the business is not sufficient for the selected energy transition technology, the likelihood of this project being successful is very low [19]. On the other hand, Li et al. [20] defined that technological infrastructure enables energy transition technologies to be implemented efficiently. In this context, it will be possible to reduce costs if the technology infrastructure is sufficient. Liza et al. [21] underlined that it is possible for energy transition projects to be sustainable. Furthermore, for the energy transition process to be successful, energy production capacity must also be sufficient [28]. Adequate technological infrastructure also supports the achievement of this goal. In addition to them, according to Murshed [22], it is possible to ensure the security of the processes if the technological infrastructure is sufficient. This helps minimize the problems in the energy transition process.

Ensuring social acceptance is also necessary to determine the right technology in the energy transition process. It is very important for society to support the energy transition process to be successful Ferdoush et al., 2024. This supports increasing confidence in new applications. One of the most important advantages of the energy transition process is that it positively affects public health Schmid-Petri and Elschner, 2024. Choosing renewable energy sources instead of fossil fuels significantly reduces environmental pollution. This situation positively affects the health of the people living in the region. Xu et al. [25] defined that explaining this situation clearly to the public allows increasing social acceptance of the projects. On the other hand, Lee et al. [26] determined that the energy transition process can have many positive effects. According to Hou et al. [27], it is possible to increase the economic welfare of the people by reducing dependence on other countries, especially in terms of energy. Providing economic justice also allows the public to increase their acceptance of these projects.

It is possible to reach some conclusions as a result of examining similar studies in the literature. Energy transition is vital for both the social and economic development of countries. For these projects to be successful, there are some issues that need to be taken into consideration. The right choice of technology in the energy transition process is also of key importance in this process. There are many different variables that affect the right choice of this technology. Local ecosystem, cost effectiveness, adequacy of technological infrastructure and social acceptance are among the critical variables that stand out in this process. However, it is not financially possible to focus on all these variables and make improvements to choose the most appropriate technology. The main reason for this is that the actions taken also increase the costs. Therefore, it is necessary to identify the variable that is most important. There are very few similar evaluations in the literature that is the most important missing part. In this context, priority analysis for variables is carried out in this study to make a significant contribution by filling this gap in the literature.

3. Methodology

Within the scope of the research question of this article, it is aimed to rank energy transition technology alternatives. In order to rank the energy transition technology alternatives, effective criteria are determined in the selection of the transition technology to be considered. The criteria set selected as a result of the literature review is weighted with the M-SWARA method. With the weights of the criteria calculated from M-SWARA, energy transition technology alternatives are ranked by the VIKOR method. To test the consistency of the results, the ranking results are compared with the TOPSIS method.

Both the M-SWARA method, used to weight the criteria, and the TOPSIS and VIKOR methods, used to rank the alternatives, are multi-criteria decision-making techniques. The data source of these methods is the evaluations of decision makers (DMs). Fuzzy numbers are preferred when including linguistic expressions obtained from DMs evaluations in the analysis. This is because linguistic expressions contain ambiguity, and this ambiguity needs to be included in the analysis. Fuzzy set theory is recommended for computing with words in mathematics. For this reason, Quantum picture fuzzy rough set (QPFRS) is introduced and used for analysis. Multi-criteria decision-making techniques developed with this set theory are applied in analysis. Additionally, artificial intelligence-based DMs prioritization is used to determine the importance weights of DMs. The reason for using this method is that the knowledge levels of each DM are different, and it is desired to ensure that the selection of DMs is objective. In other words, the selection and weighting of DMs can be achieved with the k-means clustering algorithm. The details of the proposed model are given in Fig. 1.

3.1. DMs prioritization using AI-based decision-making

Demographic information typically includes various dimensions such as education level, years of experience, age, and salary. Each of these factors can influence a decision-maker's expertise and, consequently, the weight they should be assigned in the decision-making process. However, the challenge lies in how to quantify and combine these multidimensional factors into a single weight for each DM. For instance, should a decision-maker with higher education but less experience be given more or less weight compared to someone with extensive experience but a lower educational background? The decision-making process must consider how these different dimensions interact and influence the overall expertise of each DM. This interaction creates a complex problem because it is not straightforward to determine how much influence each demographic factor should have on the final weight.

However, the complexity of demographic data becomes even more pronounced when integrating it with AI-based decision-making models. AI models, such as the k-means clustering algorithm used in our study, require careful calibration to ensure that demographic information is correctly processed and weighted. Determining the optimal number of clusters, selecting appropriate variables, and ensuring that the algorithm accurately reflects the nuances of demographic data are all critical but challenging tasks. Accordingly, our proposed AI-based expert prioritization aims to provide more accurate results in the expert weights under the complex problem solving techniques.

To enhance the reliability of this calculation, our approach emphasizes defining expert clusters and understanding the positioning of experts within these clusters. By employing an AI-based expert prioritization model, we aim to identify the most relevant expert team for the decision-making problem. Specifically, we utilize the k-means clustering algorithm to categorize decision-makers based on their demographic information, enabling us to determine which experts fall within the clusters and which are the most prominent relative to others. This process not only provides a more structured and objective approach to weighting but also enhances the accuracy of the decision-making process by prioritizing experts who are most relevant to the criteria in question. By focusing on the most relevant expert team, we increase the calculation's reliability, thereby addressing the concerns of subjectivity and ensuring that the final decisions are well-informed and robust. So, this methodology significantly improves the reliability of determining the weights and ultimately enhances the decision-making process.

The weights of the DMs are used to obtain the decision matrix from the evaluations of the DMs. The use of unweighted arithmetic mean in this process has been criticized in recent studies and different weighted arithmetic mean are used [29,30]. Various methods are recommended to obtain these weights. Determining the importance weights of DMs based on their demographic information poses a complex problem. To address this complex problem, an artificial intelligence model is preferred. The k-means clustering algorithm, one of the artificial intelligence methods, is used for prioritizing decision makers. To apply this algorithm, the number of clusters (k) must first be determined. The optimal number of clusters can be determined using the elbow method. For this method, the Within-Cluster Sum of Squares (WCSS) value must be calculated for each number of clusters and the change of the value according to the number of clusters must be examined [31,32]. The steps of the clustering algorithm-based artificial intelligence model are given below. The equations are demonstrated in the appendix part.

Step 1 includes collecting of demographic information of the DMs. *Step 2* covers WCSS for values of differ k by Equation (1). A graph is drawn showing the WCSS calculated for each k value. In this graph, the optimal k value is determined within the scope of the elbow method.

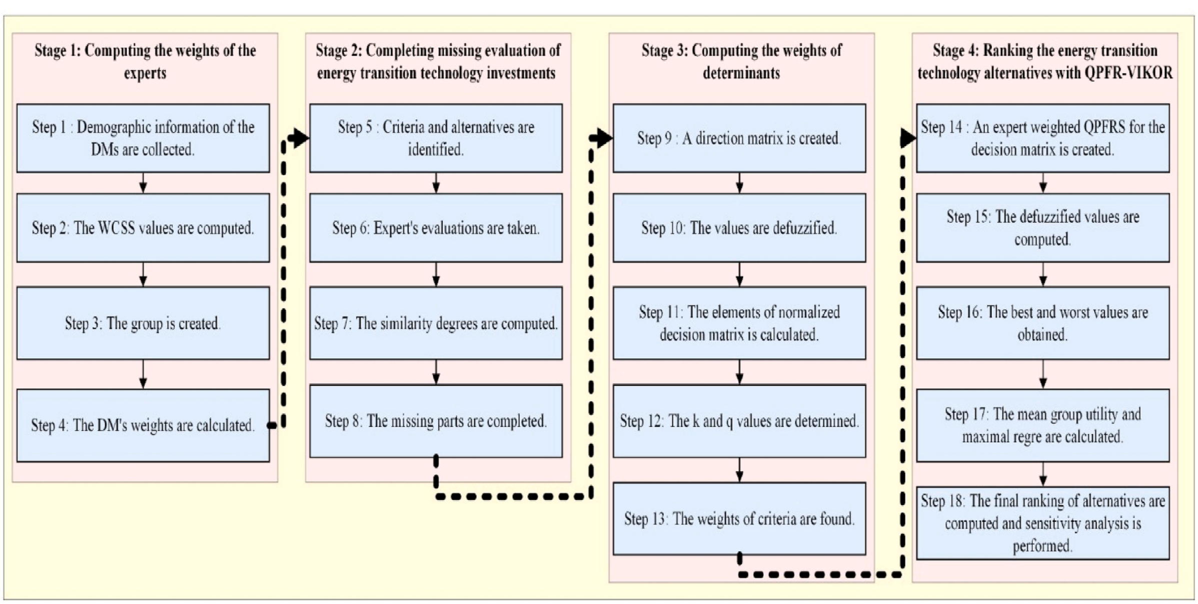

Fig. 1. The flowchart of the proposed model.

Step 3 involves group created for these people via Equations (2) and (3). In *Step 4,* DMs' weights are calculated using DMs' cluster weights. With Equations (4)–(6), the mean standard deviations (s_j) are obtained. After that, Equation (7) gives information about cluster weights (w_j). The weights of DMs (w_{tj}) are identified by Equation (8).

However, overprediction is a common issue in AI-based models, where the model might produce overly optimistic or unrealistic outcomes due to various biases or inaccuracies in the data or algorithm. To ensure that the AI-based fuzzy decision-making model does not fall into this trap, rigorous data validation process is conducted by checking missing values in the demographic data of the Decision Makers (DMs) as well as the normalization process and the use of elbow method for optimal clustering in the dataset.

3.2. Recommender system with collaborative filtering

During the process of receiving opinions from decision makers, deficiencies may occur in the decision matrix for a number of reasons. In order to eliminate these deficiencies, decision makers need to be contacted again. However, receiving feedback from decision makers for the second time negatively affects the analysis process and results. For this reason, the steps of the proposed model to complete the missing data are detailed below [33]. *Step 5* includes identified the criteria and the alternatives for energy transition technology selection. The lists of criteria and alternatives are obtained according to literature. In *Step 6,* evaluations are taken. *Step 7* computes similarity degrees by Equation (9). The rating degrees of DMs and the averaged values is indicated by $r_{u,i}/\ r_{v,i}, \overline{r_u}$ and $\overline{r_v}$. *Step 8* completes missing parts by Equation (10).

3.3. QPFRS

By Zadeh's definition, it is not possible in probability theory to computing with words. The main reason for this is that boundary of concepts or events are clear in terms of probability, but their outcome is uncertain. However, since words inherently contain uncertainty, processing such data is possible with fuzzy set theory Narang et al., 2023. Fuzzy set or fuzzy logic theory has been developing, updated and used in different fields since Zadeh's first definition [34,35]. The integration of picture rough sets from fuzzy sets with quantum mechanics using the golden ratio is described below (Kou et al., 2024). Mathematical uncertainty can be expressed using fuzzy set theory. Although these two topics have not received enough attention in the literature, recent articles show how related they are. The proposed paradigm combines quantum physics with fuzzy set theory. Equations (11)–(13) are used in this process.

Classical, intuitionistic and picture fuzzy sets are given by Equations (14)–(16). Equations (17)–(21) denote the calculations. The rough number includes lower ($\underline{Apr}(C_i)\Big)$-upper ($\overline{Apr}(C_i)$) approximation and rough boundary intervals ($Bnd(C_i)$) by Equations (22)–(24). Lower ($\underline{Lim}(C_i)$), upper ($\overline{Lim}(C_i)$) limits and the rough number ($RN(C_i)$) of C_i are shown with the help of Equations (25)–(27) Badi & Abdulshahed, 2021. Equation (28) defines membership ($C_{i\mu_A}$), neutral (C_{in_A}), non-membership (C_{iv_A}) and refusal (C_{ih_A}) functions. Lower limits are explained in Equation (29). Upper limits are determined in Equation (30). Where $N_{L\mu_A}$, N_{Ln_A}, N_{Lv_A}, N_{Lh_A} are the number of elements in $\underline{Apr}(C_{i\mu_A})$, $\underline{Apr}(C_{in_A})$, $\underline{Apr}(C_{iv_A})$, $\underline{Apr}(C_{ih_A})$ respectively while $N_{U\mu_A}$, N_{Un_A}, N_{Uv_A}, N_{Uh_A} are defined for $\overline{Apr}(C_{i\mu_A})$, $\overline{Apr}(C_{in_A})$, $\overline{Apr}(C_{iv_A})$, $\overline{Apr}(C_{ih_A})$. The components of PFRS for lower approximations are computed in Equation (31). The components of PFRS for upper approximations are computed in Equation (32). Where $\widetilde{C}_i = \left(C_{i\mu_A}, C_{in_A}, C_{iv_A}, C_{ih_A}\right)$ and $\widetilde{R}$ is the collection of $\{\widetilde{C_1}, \widetilde{C_2}, \ldots, \widetilde{C_n}\}$. $C_{i\mu_A}, C_{in_A}, C_{iv_A}, C_{ih_A}$ are the picture fuzzy sets of class $\widetilde{C}_i$. QPFRS details are stated via Equations (33) and (34). Equations (35) and (36) explain golden ratio. The amplitudes of quantum membership, neutral, non-membership, and refusal degrees, denoted by C_μ, C_n , C_v and C_h respectively, are represented in terms of phase angles α, γ, β, T. Equations (37)–(39) define phase angles.

3.4. M-SWARA with QPFRS

This type of multi-criteria decision making includes methods such as DEMATEL, AHP, SWARA. The SWARA method uses step logic in determining the weights of the criteria. Multi SWARA method, briefly M-SWARA, is the version of the SWARA method that allows multiple use. The use of M-SWARA with QPFRS is shared in Table 2 [30].

3.5. QPFRS VIKOR

VIKOR is a method based on the principle of consensus with the evaluation of decision makers. Methods such as TOPSIS, MAIRCA, VIKOR are examples of this type. Integrating QPFRS into the VIKOR method is detailed in Table 3 [36].

4. Findings of analysis

The analysis results regarding the selection of the most suitable energy transfer technology alternatives are explained.

4.1. Computing the weights of the experts

In process of *Step 1*, DM specifications are collected. By selecting and using this demographic information, the AI model is able to classify DMs into clusters that reflect their relative importance and relevance to the specific decision-making context. The k-means clustering algorithm then prioritizes these experts based on the collected data, ultimately improving the reliability and accuracy of the decision-making process. The method is designed to be objective and systematic, ensuring that the most relevant experts are prioritized, thereby enhancing the overall robustness of the decisions made. Demographic information is shown in Table 4.

In *Step 2,* k values are calculated as in Fig. 2.

Step 3 focuses on grouping of experts. Standard deviations are denoted in Table A1. *Step 4* calculates the weights in Table 5.

4.2. Completing missing evaluation of energy transition technology investments

Step 5 defines selected criteria in Table 6.

In energy transfer, the energy system used in the local region is referred to as local ecosystem. The cost efficiency of energy transfer is taken into account in the analysis as cost-effectiveness. The technological dimension of energy transfer is defined by Technological infrastructure. Social impacts and acceptance describe the social impact and social acceptability of energy transfer. Selected energy transition technology alternatives are coded in Table 7.

Energy transfer technology alternatives are widely used in practice. However, finding the appropriate one among the alternatives is a decision-making problem. Some alternatives in this problem are: Using upgraded electricity networks with smart grids can allow energy to be transported to a larger area. Since using new composite materials for efficient cell production will reduce the loss in energy transfer, efficiency in energy transfer can be achieved. Energy transfer may be possible with floating energy generation for offshore plants. Thanks to compact renewable systems for small scale production, regional energy transfers and support systems can be built. *Steps 6–8* focus on collection of the assessments, computing the degrees of similarity and finding undefines issues. In this process, the scales in Table A2 are considered. On the other hand, assessments are denoted in Table A3.

Table 2
The pseudo-code of M-SWARA with QPFRS.

Input: Criteria values $c_{ij}, i \in [1,n], j \in [1,n]$; where n equals number of criteria C, weights of DMs $w_i, k \in [1,k]$; where k is number of DMs
Output: Weight of Criteria $W_i, i \in [1,n]$

Begin
(1) Create a direction matrix
$C = [c_{ij}]_{n\times n}$
$C \leftarrow WxC$
(2) Compute defuzzified values

$$Defc_i \leftarrow \left(\begin{array}{c} \underline{Lim}(C_{\mu_i}) - \underline{Lim}(C_{n_i}) + \underline{Lim}(C_{\mu_i}).(\underline{Lim}(C_{v_i}) - \underline{Lim}(C_{h_i})) + \left(\frac{\alpha_{ij}}{2\pi}\right) - \left(\frac{\gamma_{ij}}{2\pi}\right) + \left(\frac{\alpha_{ij}}{2\pi}\right).\left(\left(\frac{\beta_{ij}}{2\pi}\right) - \left(\frac{T_{ij}}{2\pi}\right)\right) + \\ \overline{Lim}(C_{\mu_i}) - \overline{Lim}(C_{n_i}) + \overline{Lim}(C_{\mu_i}).(\overline{Lim}(C_{v_i}) - \overline{Lim}(C_{h_i})) + \left(\frac{\overline{\alpha}_{ij}}{2\pi}\right) - \left(\frac{\overline{\gamma}_{ij}}{2\pi}\right) + \left(\frac{\overline{\alpha}_{ij}}{2\pi}\right).\left(\left(\frac{\overline{\beta}_{ij}}{2\pi}\right) - \left(\frac{\overline{T}_{ij}}{2\pi}\right)\right) \end{array} \right) / 2$$

(3) Calculate elements of normalized decision matrix
(4) Determine values of k, q
$k_j \leftarrow 1 \; for \; j = 1; \; s_j + 1 \text{ for } j > 1 \; [s_{j-1} = s_j, q_{j-1} = q_j; \; s_j = 0, k_{j-1} = k_j]$
$q_j \leftarrow 1 \; for \; j = 1; \frac{q_{j-1}}{k_j} \text{ for } j > 1 \quad \forall j \in [1,2,\ldots,n]$
(5) Found weights of criteria
$W_j \leftarrow \frac{q_j}{\sum_{k=1}^{n} q_k} \quad \forall j \in [1,2,\ldots,n]$
(6) Define stable values of relation matrix with large 2t+1 value
(7) Construct impact-relation degrees of the criteria
End

Table 3
The pseudo-code of VIKOR with QPFRS.

Input: Alternative criteria values $x_{ij}, i \in [1,m], j \in [1,n]$; where m equals number of alternatives A, and n equals number of criteria C; weights of DMs $w_i, k \in [1,k]$; where k is number of DMs
Output: Rank of alternatives $A_i, i \in [1,m]$

Begin
(1) Create a expert weighted QPFRS for the decision matrix
$X = [x_{ij}]_{m\times n}$
$C \leftarrow WxX$
(2) Compute defuzzified values

$$Defc_i \leftarrow \left(\begin{array}{c} \underline{Lim}(C_{\mu_i}) - \underline{Lim}(C_{n_i}) + \underline{Lim}(C_{\mu_i}).(\underline{Lim}(C_{v_i}) - \underline{Lim}(C_{h_i})) + \left(\frac{\alpha_{ij}}{2\pi}\right) - \left(\frac{\gamma_{ij}}{2\pi}\right) + \left(\frac{\alpha_{ij}}{2\pi}\right).\left(\left(\frac{\beta_{ij}}{2\pi}\right) - \left(\frac{T_{ij}}{2\pi}\right)\right) + \\ \overline{Lim}(C_{\mu_i}) - \overline{Lim}(C_{n_i}) + \overline{Lim}(C_{\mu_i}).(\overline{Lim}(C_{v_i}) - \overline{Lim}(C_{h_i})) + \left(\frac{\overline{\alpha}_{ij}}{2\pi}\right) - \left(\frac{\overline{\gamma}_{ij}}{2\pi}\right) + \left(\frac{\overline{\alpha}_{ij}}{2\pi}\right).\left(\left(\frac{\overline{\beta}_{ij}}{2\pi}\right) - \left(\frac{\overline{T}_{ij}}{2\pi}\right)\right) \end{array} \right) / 2$$

(3) Obtain best and worst values
$\widetilde{f}_J^* \leftarrow \max_i \widetilde{x}_{ij}$
$\widetilde{f}_j^- \leftarrow \min_i \widetilde{x}_{ij}$
(4) Define criteria weight vector
$W = [w_1, w_2, .., w_j], j \in [1,2,\ldots,n], \sum_{j=1}^{n} w_j = 1$
(5) Calculate the mean group utility and maximal regre

$$\widetilde{S}_j \leftarrow \sum_{i=1}^{n} \widetilde{w}_j \frac{\left(\left|\widetilde{f}_j^* - \widetilde{x}_{ij}\right|\right)}{\left(\left|\widetilde{f}_j^* - \widetilde{f}_j^-\right|\right)}, \quad \widetilde{R}_j \leftarrow max_j \left[\widetilde{w}_j \frac{\left(\left|\widetilde{f}_j^* - \widetilde{x}_{ij}\right|\right)}{\left(\left|\widetilde{f}_j^* - \widetilde{f}_j^-\right|\right)}\right], \forall j \in [1,n]$$

(6) Compute the final ranking of alternatives
$\widetilde{Q}_i \leftarrow v(\widetilde{S}_i - \widetilde{S}^*)/(\widetilde{S}^- - \widetilde{S}^*) + (1-v)(\widetilde{R}_i - \widetilde{R}^*)/(\widetilde{R}^- - \widetilde{R}^*)$
(7) Ranking the alternatives
$A_i, i \in [1,m] \leftarrow$ rank the alternatives based on the ascending order of Q_i values
(8) Test assumptions
$Q(A^{(2)}) - Q(A^{(1)}) \geq 1/(j-1)$
(9) Compare results with sensitivity analysis
End

4.3. Computing the weights of determinants

Steps 9–12 consist of defining determinants, obtaining assessments, constructing direction matrix, and definition of expert weights-oriented sets. Opinions for the decision matrix are shown in Table A4. Completed assessments are given in Table A5. QPFN for the relation matrix and expert weighted QPFRS for the direct relation matrix are identified in Tables A6 and A7. Steps 13–16 concentrate on defuzzification, normalization, computing essential values, and creation of the relation matrix. Defuzzified, normalized and critical values are explained in Tables A8-A10. Moreover, the causal directions are demonstrated in Table A11. The weights are displayed in Table 8.

Cost-effectiveness of energy transition is defined as the most crucial item (weight:.254). The local ecosystem is found as the second most

Table 4
Demographic information of the DMs.

DMs	Education	Period of Experience	Salary (USD)	Age
DM1	Master	18	2400	42
DM2	Master	15	2450	44
DM3	Bachelor	19	2500	46
DM4	Bachelor	16	2400	42
DM5	PhD	17	2500	41
DM6	Master	20	2400	48

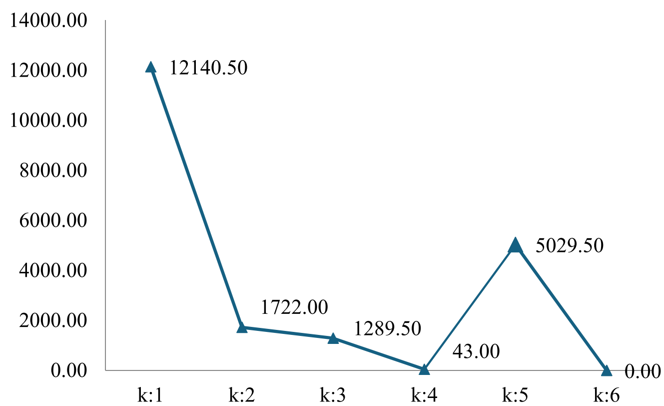

Fig. 2. The plot for elbow methods.

Table 5
Weights of experts.

DMs	Weights
DM1	.27
DM2	.00
DM3	.10
DM4	.27
DM5	.10
DM6	.27

Table 6
Criteria set for energy transition technology selection.

Criteria	Codes
Local ecosystem	LOCECO
Cost-effectiveness	COSEFF
Technological infrastructure	TECHINF
Social impacts and acceptance	SOCIMPAP

Table 7
Energy transition technology alternatives.

Alternatives	Codes
Upgraded electricity networks with smart grids	A_1
New composite materials for efficient cell production	A_2
Floating energy generation for offshore plants	A_3
Compact renewable systems for small scale production	A_4

Table 8
Stable matrix.

	LOCECO	COSEFF	TECHINF	SOCIMPAP
LOCECO	.251	.251	.251	.251
COSEFF	.254	.254	.254	.254
TECHINF	.248	.248	.248	.248
SOCIMPAP	.247	.247	.247	.247

significant issue by the weight of.251. Technological infrastructure is the last criteria with a weight of.248.

4.4. *Ranking the energy transition technology alternatives with QPFR-VIKOR*

Step 17 focuses on completed assessments of the energy transition technologies in Table 9.

Steps 18–21 identify decision matrix, expert weighted sets, defuzzified values and critical values. QPFN for the decision matrix, expert weighted QPFRS for the decision matrix and defuzzified decision values are highlighted in Tables A12-A14. Table 10 gives information about the S, R and Q values.

In our methodology, the Quantum Picture Fuzzy Rough Set (QPFRS) was introduced to handle the ambiguity in decision-makers' linguistic evaluations, particularly within the M-SWARA and VIKOR methods. While these approaches offer a robust framework for ranking alternatives and handling linguistic uncertainty, a direct comparative analysis against other control techniques, such as conventional PID controllers or neural network-based controllers, was not within the scope of our study. However, a comparative ranking results are provided by using the extended VIKOR and TOPSIS together with the sensitivity analysis to evaluate the reliability and objectivity of the decision-making process with the comprehensive understanding of its performance.

Step 22 compares the values with VIKOR. These values are taken into consideration to rank the alternatives. The highest Q values give information about the best alternatives. Compact renewable systems for small scale production is found as the most critical alternative. A comparative evaluation is also conducted with TOPSIS technique to check the relability of the findings. Fig. 3 gives information about the comparative ranking values with sensitivity analysis.

The results of the TOPSIS and VIKOR are quite similar. This situation indicates that the proposed model provides consistent results. The most

Table 9
Completed opinions regarding the energy transition technologies.

	LOCECO	COSEFF	TECHINF	SOCIMPAP
DM1				
A_1	B	F	B	G
A_2	G	P	G	F
A_3	G	G	G	G
A_4	B	B	F	G
DM3	LOCECO	COSEFF	TECHINF	SOCIMPAP
A_1	B	P	G	B
A_2	B	F	G	F
A_3	G	F	F	G
A_4	F	G	B	G
DM4	LOCECO	COSEFF	TECHINF	SOCIMPAP
A_1	B	P	B	G
A_2	G	F	B	F
A_3	B	G	B	G
A_4	F	B	F	G
DM5	LOCECO	COSEFF	TECHINF	SOCIMPAP
A_1	F	G	F	B
A_2	G	G	F	B
A_3	G	G	G	G
A_4	G	F	B	F
DM6	LOCECO	COSEFF	TECHINF	SOCIMPAP
A_1	B	G	F	B
A_2	G	G	G	B
A_3	B	F	B	G
A_4	G	F	B	F

Table 10
S, R and Q.

	Si	Ri	Q.1	Q.2	Q.3	Q.4
A_1	.587	.254	.959	.918	.878	.837
A_2	.778	.251	.690	.724	.759	.793
A_3	.666	.248	.165	.232	.298	.364
A_4	.309	.247	.000	.000	.000	.000
	Q.5	Q.6	Q.7	Q.8	Q.9	Q1
A_1	.796	.755	.714	.674	.633	.592
A_2	.828	.862	.897	.931	.966	1.000
A_3	.430	.496	.563	.629	.695	.761
A_4	.000	.000	.000	.000	.000	.000

optimal solution of energy transition technology alternatives is compact renewable systems for small scale production. The next optimal alternative is floating energy generation for offshore plants. According to these results, low-cost, high-efficiency and portable alternatives come to the fore in energy transfer technology. Renewable systems that produce small-scale production should be preferred in energy transfer technology. Additionally, the use of floating power generation can also be beneficial from a spatial perspective.

5. Discussion

Local ecosystem energy is determined to be the factor that should be taken into consideration most in selecting the appropriate technology for transition investments. In this context, the natural resources of the region where the investment will be made should be analyzed in detail. In this context, the climate of this region should be included in the scope of analysis. In this way, it is possible to determine the most accurate energy transition technology. For example, for a region where wind is abundant, it would be appropriate to choose wind turbines in energy transition. On the other hand, the environmental impacts of projects in this region must also be taken into account. Abbas et al. [37] defined that the environmental impact of renewable energy investments should be minimized. Local economic conditions should also be taken into account in choosing the most appropriate energy transition technology. Fabra and Reguant [38] identified that employment opportunities in this region are an important issue for the technology to be chosen. Moreover, Aba et al. [39] and Hersaputri et al. [40] highlighted that social support must be ensured in the selection of successful energy transition technology. To achieve this goal, people need to be informed about the positive effects of energy transition investments on the environment. This allows increasing the effectiveness of energy transition technology investments.

Cost effectiveness is another important criterion in selecting the appropriate technology for energy transition investments. In this context, it is necessary to ensure the cost effectiveness of the projects by taking many different actions. In this context, first, cost figures for different energy transition technologies should be compared. In this way, excessively high investment costs can be prevented. On the other hand, Shouwu et al. [41] concluded that a comprehensive analysis of the operational costs of businesses should be carried out. Thanks to this analysis, specific measures can be taken to reduce very high-cost figures. Belaïd and Al-Sarihi [42] defined that this significantly contributes to increasing the profit margin of the projects. Incentives applied by the state for these projects should also be taken into account in the selection of this technology. According to Huang et al. [43] and Hou et al. [27], tax deductions for energy transition technology may be available in the investor country. This significantly contributes to the cost effectiveness of projects. Providing loans with low interest rates also significantly supports the efficiency of these projects Abid et al., 2024; [44]. This allows the correct energy transition technology to be determined.

6. Conclusion

The main concluding issues are policy implications are given below.

6.1. Conclusing remarks

This study aims to select the most suitable energy transfer technology alternative. For this aim, a novel AI-based fuzzy decision-making model has been created. At the first stage, the experts are prioritized with AI methodology. Secondly, missing evaluations of energy transition technology investments are estimated by expert recommender system. In the following stage, the weights of the criteria for energy transition technology selection are calculated via QPFR M-SWARA. At the final stage, selected energy transition technology alternatives are ranked by QPFR-VIKOR. It is concluded that the most important factor is cost-effectiveness of energy transition. Similarly, it is also found that the local ecosystem is the second most significant issue. On the other side, the ranking results denote that compact renewable systems for small scale production is the most optimal solution of energy transition technology alternatives. The second most significant energy transition technology alternative is floating energy generation for offshore plants.

The main contribution of this study is the integration of AI technique to the proposed model. Owing to this issue, the evaluations of these DMs can be identified based on their demographical information. Similar to this issue, using M-SWARA methodology in the process of criteria weighting increases the quality of the findings. This methodology helps to consider the impact relation map of the criteria. It is thought that this new decision-making model has made a significant contribution to the literature. This method is especially important for making the most accurate investment decisions under complex situations. In addition to this issue, this model can also be useful for other industries. In this context,

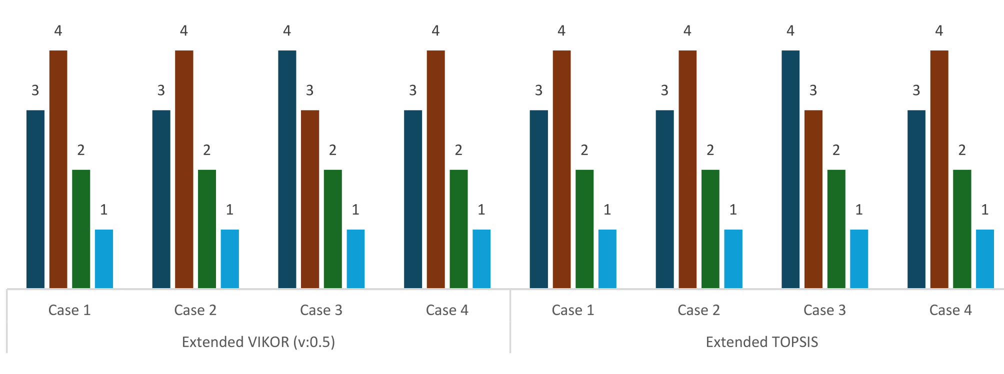

Fig. 3. Comparative ranking values with sensitivity analysis.

this developed model can also be taken into consideration in specific areas such as nuclear energy and hydrogen energy investments. Nevertheless, a specific analysis has not been conducted for renewable energy types. This situation can be accepted as the main theoretical limitation of this study. Thus, regarding the future research direction, solar energy technology can be evaluated. On the other hand, there are also some limitations with respect to the proposed model. In the following studies, a new ranking methodology can be generated to handle the criticisms related to the currently used models. The results obtained may vary under different scenarios and conditions. As a result of this comparative analysis, it is understood that the findings will not change radically according to the changing conditions. On the other hand, it may be possible for the order of importance in the criteria to change in radical situations such as war and epidemics. In future studies, more sensitive studies can be conducted for these situations. In this way, it is understood whether the results obtained in these radical situations will change or not. This situation also allows for the development of more effective strategies.

6.2. Policy implications

Some policy recommendations can be presented to increase cost-effectiveness in the energy transition process. Within this context, renewable energy producers can be given a fixed price guarantee. This situation contributes significantly to reducing costs. This condition is also a factor that increases the interest of investors. The development of flexible production capacities allows rapid responses to energy demand. This situation also allows for increased energy supply security. Therefore, it is possible for businesses to achieve cost-effectiveness. On the other hand, research studies should be increased for the development of renewable energy storage technologies. In this way, the capacity of projects to produce uninterrupted energy increases. This situation also significantly supports customer satisfaction. In order to increase these research studies, cooperation between academia and industry should be ensured. Within this framework, first of all, it should be understood what the expectations of industrial producers are. After that, universities should be integrated in order to increase academic studies on such issues. In addition to them, increasing smart grid investments is also important. The dissemination of smart grid technologies increases energy efficiency. This situation also allows for easier integration of renewable energy sources. Another policy suggestion that can be considered in this process is the implementation of a carbon tax. Applying taxes on carbon emissions increases the cost of fossil fuels. In this way, the transition to renewable energy projects is faster.

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Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent

Informed consent was obtained from all individual participants included in the study.

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CRediT authorship contribution statement

Hasan Dincer: Writing – review & editing, Validation, Resources, Project administration, Methodology. **Dragan Pamucar:** Writing – review & editing. **Serhat Yuksel:** Writing – review & editing, Supervision, Methodology, Formal analysis. **Muhammet Deveci:** Writing – review & editing, Supervision, Methodology. **Serkan Eti:** Writing – review & editing, Visualization, Validation, Supervision. **Ümit Hacioglu:** Writing – review & editing, Validation, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Nomenclature

AHP	analytical hierarchy process
AI	artificial intelligence
DEMATEL	decision making trial and evaluation laboratory
DM	decision maker
k	number of clusters
M-SWARA	multi step wise weight assessment ratio analysis
MAIRCA	multi attributive ideal-real comparative analysis
QPFR	quantum picture fuzzy rough sets
TOPSIS	technique for order of preference by similarity to ideal solution
VIKOR	Višekriterijumsko kompromisno rangiranje
WCSS	Within-Cluster Sum of Squares

Appendix A

Table A1
The Standard Deviations of Means

	Frequency	Education	Period of Experience	$	Years	Mean SD	W
C1	3	.47	1.63	.00	2.83	1.23	3.70
C2	1	.00	.00	.00	.00	.00	.00
C3	2	1.00	1.00	.00	2.50	1.13	2.25

Table A2
Scales

Criteria	Alternatives	Recommender Factors	Possibility Factors	Fuzzy Sets
little (N)	poorest (W)	1	.40	$\begin{bmatrix} \sqrt{.16}e^{j2\pi..4}, \\ \sqrt{.10}e^{j2\pi..25}, \\ \sqrt{.46}e^{j2\pi..22}, \\ \sqrt{.28}e^{j2\pi..13} \end{bmatrix}$
Somewhat (S)	Poor (P)	2	.45	$\begin{bmatrix} \sqrt{.20}e^{j2\pi..45}, \\ \sqrt{.13}e^{j2\pi..28}, \\ \sqrt{.42}e^{j2\pi..17}, \\ \sqrt{.25}e^{j2\pi..10} \end{bmatrix}$
Medium (M)	Fair (F)	3	.50	$\begin{bmatrix} \sqrt{.25}e^{j2\pi..50}, \\ \sqrt{.15}e^{j2\pi..31}, \\ \sqrt{.37}e^{j2\pi..12}, \\ \sqrt{.23}e^{j2\pi..07} \end{bmatrix}$
strong (H)	effective (G)	4	.55	$\begin{bmatrix} \sqrt{.30}e^{j2\pi..55}, \\ \sqrt{.19}e^{j2\pi..34}, \\ \sqrt{.32}e^{j2\pi..07}, \\ \sqrt{.19}e^{j2\pi..04} \end{bmatrix}$
magnificent (VH)	perfect (B)	5	.60	$\begin{bmatrix} \sqrt{.36}e^{j2\pi..6}, \\ \sqrt{.22}e^{j2\pi..37}, \\ \sqrt{.26}e^{j2\pi..02}, \\ \sqrt{.16}e^{j2\pi..01} \end{bmatrix}$

Table A3
Opinions

	DM 1	DM 3	DM 4	DM 5	DM 6
LOCECO- COSEFF	3	n/a	4	4	5
LOCECO- TECHINF	5	4	n/a	3	5
LOCECO- SOCIMPAP	4	3	3	2	4
COSEFF- LOCECO	4	5	3	3	3
COSEFF- TECHINF	4	n/a	4	4	4
COSEFF- SOCIMPAP	4	n/a	5	4	3
TECHINF- LOCECO	4	4	5	4	3
TECHINF- COSEFF	4	3	5	4	4
TECHINF- SOCIMPAP	4	2	4	4	4
SOCIMPAP- LOCECO	5	3	3	4	4
SOCIMPAP- COSEFF	5	4	4	4	4
SOCIMPAP- TECHINF	3	5	3	3	4

Table A4
Opinions for the decision matrix

	DM 1	DM 3	DM 4	DM 5	DM 6
LOCECO- A1	5	n/a	5	3	5
LOCECO- A2	4	5	4	4	4
LOCECO- A3	4	4	5	4	5
LOCECO- A4	5	3	3	4	4
COSEFF- A1	3	2	2	4	4
COSEFF- A2	2	3	3	n/a	4
COSEFF- A3	n/a	3	4	4	3
COSEFF- A4	5	4	n/a	3	3
TECHINF- A1	5	4	5	3	3
TECHINF- A2	4	4	5	3	4
TECHINF- A3	4	3	5	4	5
TECHINF- A4	3	5	n/a	5	5

(continued on next page)

Table A4 (*continued*)

	DM 1	DM 3	DM 4	DM 5	DM 6
SOCIMPAP- A1	n/a	5	4	5	5
SOCIMPAP- A2	3	n/a	3	5	5
SOCIMPAP- A3	4	4	4	4	4
SOCIMPAP- A4	4	4	4	n/a	3

Table A5
Completed assessments

DM1				
	LOCECO	COSEFF	TECHINF	SOCIMPAP
LOCECO		M	VH	H
COSEFF	H		H	H
TECHINF	H	H		H
SOCIMPAP	VH	VH	M	
DM3				
	LOCECO	**COSEFF**	**TECHINF**	**SOCIMPAP**
LOCECO		H	H	M
COSEFF	VH		H	VH
TECHINF	H	M		S
SOCIMPAP	M	H	VH	
DM4				
	LOCECO	**COSEFF**	**TECHINF**	**SOCIMPAP**
LOCECO		H	M	M
COSEFF	M		H	VH
TECHINF	VH	VH		H
SOCIMPAP	M	H	M	
DM5				
	LOCECO	**COSEFF**	**TECHINF**	**SOCIMPAP**
LOCECO		H	M	S
COSEFF	M		H	H
TECHINF	H	H		H
SOCIMPAP	H	H	M	
DM6				
	LOCECO	**COSEFF**	**TECHINF**	**SOCIMPAP**
LOCECO		VH	VH	H
COSEFF	M		H	M
TECHINF	M	H		H
SOCIMPAP	H	H	H	

Table A6
QPFN for the relation matrix

DM1				
	LOCECO	COSEFF	TECHINF	SOCIMPAP
LOCECO		$\begin{bmatrix} \sqrt{.25}e^{j2\pi..50}, \\ \sqrt{.15}e^{j2\pi..31}, \\ \sqrt{.37}e^{j2\pi..12}, \\ \sqrt{.23}e^{j2\pi..07} \end{bmatrix}$	$\begin{bmatrix} \sqrt{.36}e^{j2\pi..6}, \\ \sqrt{.22}e^{j2\pi..37}, \\ \sqrt{.26}e^{j2\pi..02}, \\ \sqrt{.16}e^{j2\pi..01} \end{bmatrix}$	$\begin{bmatrix} \sqrt{.30}e^{j2\pi..55}, \\ \sqrt{.19}e^{j2\pi..34}, \\ \sqrt{.32}e^{j2\pi..07}, \\ \sqrt{.19}e^{j2\pi..04} \end{bmatrix}$
COSEFF	$\begin{bmatrix} \sqrt{.30}e^{j2\pi..55}, \\ \sqrt{.19}e^{j2\pi..34}, \\ \sqrt{.32}e^{j2\pi..07}, \\ \sqrt{.19}e^{j2\pi..04} \end{bmatrix}$		$\begin{bmatrix} \sqrt{.30}e^{j2\pi..55}, \\ \sqrt{.19}e^{j2\pi..34}, \\ \sqrt{.32}e^{j2\pi..07}, \\ \sqrt{.19}e^{j2\pi..04} \end{bmatrix}$	$\begin{bmatrix} \sqrt{.30}e^{j2\pi..55}, \\ \sqrt{.19}e^{j2\pi..34}, \\ \sqrt{.32}e^{j2\pi..07}, \\ \sqrt{.19}e^{j2\pi..04} \end{bmatrix}$
TECHINF	$\begin{bmatrix} \sqrt{.30}e^{j2\pi..55}, \\ \sqrt{.19}e^{j2\pi..34}, \\ \sqrt{.32}e^{j2\pi..07}, \\ \sqrt{.19}e^{j2\pi..04} \end{bmatrix}$	$\begin{bmatrix} \sqrt{.30}e^{j2\pi..55}, \\ \sqrt{.19}e^{j2\pi..34}, \\ \sqrt{.32}e^{j2\pi..07}, \\ \sqrt{.19}e^{j2\pi..04} \end{bmatrix}$		$\begin{bmatrix} \sqrt{.30}e^{j2\pi..55}, \\ \sqrt{.19}e^{j2\pi..34}, \\ \sqrt{.32}e^{j2\pi..07}, \\ \sqrt{.19}e^{j2\pi..04} \end{bmatrix}$
SOCIMPAP	$\begin{bmatrix} \sqrt{.36}e^{j2\pi..6}, \\ \sqrt{.22}e^{j2\pi..37}, \\ \sqrt{.26}e^{j2\pi..02}, \\ \sqrt{.16}e^{j2\pi..01} \end{bmatrix}$	$\begin{bmatrix} \sqrt{.36}e^{j2\pi..6}, \\ \sqrt{.22}e^{j2\pi..37}, \\ \sqrt{.26}e^{j2\pi..02}, \\ \sqrt{.16}e^{j2\pi..01} \end{bmatrix}$	$\begin{bmatrix} \sqrt{.25}e^{j2\pi..50}, \\ \sqrt{.15}e^{j2\pi..31}, \\ \sqrt{.37}e^{j2\pi..12}, \\ \sqrt{.23}e^{j2\pi..07} \end{bmatrix}$	
DM3				
	LOCECO	**COSEFF**	**TECHINF**	**SOCIMPAP**

(*continued on next page*)

Table A6 (*continued*)

DM1	LOCECO	COSEFF	TECHINF	SOCIMPAP
LOCECO		$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.25}e^{j2\pi..50},\\ \sqrt{.15}e^{j2\pi..31},\\ \sqrt{.37}e^{j2\pi..12},\\ \sqrt{.23}e^{j2\pi..07}\end{bmatrix}$
COSEFF	$\begin{bmatrix}\sqrt{.36}e^{j2\pi..6},\\ \sqrt{.22}e^{j2\pi..37},\\ \sqrt{.26}e^{j2\pi..02},\\ \sqrt{.16}e^{j2\pi..01}\end{bmatrix}$		$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.36}e^{j2\pi..6},\\ \sqrt{.22}e^{j2\pi..37},\\ \sqrt{.26}e^{j2\pi..02},\\ \sqrt{.16}e^{j2\pi..01}\end{bmatrix}$
TECHINF	$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.25}e^{j2\pi..50},\\ \sqrt{.15}e^{j2\pi..31},\\ \sqrt{.37}e^{j2\pi..12},\\ \sqrt{.23}e^{j2\pi..07}\end{bmatrix}$		$\begin{bmatrix}\sqrt{.20}e^{j2\pi..45},\\ \sqrt{.13}e^{j2\pi..28},\\ \sqrt{.42}e^{j2\pi..17},\\ \sqrt{.25}e^{j2\pi..10}\end{bmatrix}$
SOCIMPAP	$\begin{bmatrix}\sqrt{.25}e^{j2\pi..50},\\ \sqrt{.15}e^{j2\pi..31},\\ \sqrt{.37}e^{j2\pi..12},\\ \sqrt{.23}e^{j2\pi..07}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.36}e^{j2\pi..6},\\ \sqrt{.22}e^{j2\pi..37},\\ \sqrt{.26}e^{j2\pi..02},\\ \sqrt{.16}e^{j2\pi..01}\end{bmatrix}$	

DM4	**LOCECO**	**COSEFF**	**TECHINF**	**SOCIMPAP**
LOCECO		$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.25}e^{j2\pi..50},\\ \sqrt{.15}e^{j2\pi..31},\\ \sqrt{.37}e^{j2\pi..12},\\ \sqrt{.23}e^{j2\pi..07}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.25}e^{j2\pi..50},\\ \sqrt{.15}e^{j2\pi..31},\\ \sqrt{.37}e^{j2\pi..12},\\ \sqrt{.23}e^{j2\pi..07}\end{bmatrix}$
COSEFF	$\begin{bmatrix}\sqrt{.25}e^{j2\pi..50},\\ \sqrt{.15}e^{j2\pi..31},\\ \sqrt{.37}e^{j2\pi..12},\\ \sqrt{.23}e^{j2\pi..07}\end{bmatrix}$		$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.36}e^{j2\pi..6},\\ \sqrt{.22}e^{j2\pi..37},\\ \sqrt{.26}e^{j2\pi..02},\\ \sqrt{.16}e^{j2\pi..01}\end{bmatrix}$
TECHINF	$\begin{bmatrix}\sqrt{.36}e^{j2\pi..6},\\ \sqrt{.22}e^{j2\pi..37},\\ \sqrt{.26}e^{j2\pi..02},\\ \sqrt{.16}e^{j2\pi..01}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.36}e^{j2\pi..6},\\ \sqrt{.22}e^{j2\pi..37},\\ \sqrt{.26}e^{j2\pi..02},\\ \sqrt{.16}e^{j2\pi..01}\end{bmatrix}$		$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$
SOCIMPAP	$\begin{bmatrix}\sqrt{.25}e^{j2\pi..50},\\ \sqrt{.15}e^{j2\pi..31},\\ \sqrt{.37}e^{j2\pi..12},\\ \sqrt{.23}e^{j2\pi..07}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.25}e^{j2\pi..50},\\ \sqrt{.15}e^{j2\pi..31},\\ \sqrt{.37}e^{j2\pi..12},\\ \sqrt{.23}e^{j2\pi..07}\end{bmatrix}$	

DM5	**LOCECO**	**COSEFF**	**TECHINF**	**SOCIMPAP**
LOCECO		$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.25}e^{j2\pi..50},\\ \sqrt{.15}e^{j2\pi..31},\\ \sqrt{.37}e^{j2\pi..12},\\ \sqrt{.23}e^{j2\pi..07}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.20}e^{j2\pi..45},\\ \sqrt{.13}e^{j2\pi..28},\\ \sqrt{.42}e^{j2\pi..17},\\ \sqrt{.25}e^{j2\pi..10}\end{bmatrix}$
COSEFF	$\begin{bmatrix}\sqrt{.25}e^{j2\pi..50},\\ \sqrt{.15}e^{j2\pi..31},\\ \sqrt{.37}e^{j2\pi..12},\\ \sqrt{.23}e^{j2\pi..07}\end{bmatrix}$		$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$
TECHINF	$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$		$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$
SOCIMPAP	$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.25}e^{j2\pi..50},\\ \sqrt{.15}e^{j2\pi..31},\\ \sqrt{.37}e^{j2\pi..12},\\ \sqrt{.23}e^{j2\pi..07}\end{bmatrix}$	

DM6	**LOCECO**	**COSEFF**	**TECHINF**	**SOCIMPAP**
LOCECO		$\begin{bmatrix}\sqrt{.36}e^{j2\pi..6},\\ \sqrt{.22}e^{j2\pi..37},\\ \sqrt{.26}e^{j2\pi..02},\\ \sqrt{.16}e^{j2\pi..01}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.36}e^{j2\pi..6},\\ \sqrt{.22}e^{j2\pi..37},\\ \sqrt{.26}e^{j2\pi..02},\\ \sqrt{.16}e^{j2\pi..01}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$
COSEFF	$\begin{bmatrix}\sqrt{.25}e^{j2\pi..50},\\ \sqrt{.15}e^{j2\pi..31},\\ \sqrt{.37}e^{j2\pi..12},\\ \sqrt{.23}e^{j2\pi..07}\end{bmatrix}$		$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.25}e^{j2\pi..50},\\ \sqrt{.15}e^{j2\pi..31},\\ \sqrt{.37}e^{j2\pi..12},\\ \sqrt{.23}e^{j2\pi..07}\end{bmatrix}$
TECHINF	$\begin{bmatrix}\sqrt{.25}e^{j2\pi..50},\\ \sqrt{.15}e^{j2\pi..31},\\ \sqrt{.37}e^{j2\pi..12},\\ \sqrt{.23}e^{j2\pi..07}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$		$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$
SOCIMPAP	$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$	

Table A7
Expert weighted QPFRS for the direct relation matrix

	LOCECO	COSEFF	TECHINF	SOCIMPAP
LOCECO		$\lceil \sqrt{.03}, \sqrt{.10} \rfloor e^{j2\pi.\lceil .05,.16 \rfloor}$, $\lceil \sqrt{.02}, \sqrt{.06} \rfloor e^{j2\pi.\lceil .03,.10 \rfloor}$, $\lceil \sqrt{.04}, \sqrt{.09} \rfloor e^{j2\pi.\lceil .01,.02 \rfloor}$, $\lceil \sqrt{.02}, \sqrt{.05} \rfloor e^{j2\pi.\lceil .01,.01 \rfloor}$	$\lceil \sqrt{.03}, \sqrt{.10} \rfloor e^{j2\pi.\lceil .05,.16 \rfloor}$, $\lceil \sqrt{.02}, \sqrt{.06} \rfloor e^{j2\pi.\lceil .03,.10 \rfloor}$, $\lceil \sqrt{.04}, \sqrt{.09} \rfloor e^{j2\pi.\lceil .01,.02 \rfloor}$, $\lceil \sqrt{.02}, \sqrt{.05} \rfloor e^{j2\pi.\lceil .01,.01 \rfloor}$	$\lceil \sqrt{.02}, \sqrt{.08} \rfloor e^{j2\pi.\lceil .05,.15 \rfloor}$, $\lceil \sqrt{.01}, \sqrt{.05} \rfloor e^{j2\pi.\lceil .03,.09 \rfloor}$, $\lceil \sqrt{.03}, \sqrt{.10} \rfloor e^{j2\pi.\lceil .01,.03 \rfloor}$, $\lceil \sqrt{.02}, \sqrt{.06} \rfloor e^{j2\pi.\lceil .00,.02 \rfloor}$
COSEFF	$\lceil \sqrt{.03}, \sqrt{.08} \rfloor e^{j2\pi.\lceil .05,.15 \rfloor}$, $\lceil \sqrt{.02}, \sqrt{.05} \rfloor e^{j2\pi.\lceil .03,.09 \rfloor}$, $\lceil \sqrt{.04}, \sqrt{.10} \rfloor e^{j2\pi.\lceil .01,.03 \rfloor}$, $\lceil \sqrt{.02}, \sqrt{.06} \rfloor e^{j2\pi.\lceil .01,.02 \rfloor}$		$\lceil \sqrt{.03}, \sqrt{.08} \rfloor e^{j2\pi.\lceil .05,.15 \rfloor}$, $\lceil \sqrt{.02}, \sqrt{.05} \rfloor e^{j2\pi.\lceil .03,.09 \rfloor}$, $\lceil \sqrt{.04}, \sqrt{.10} \rfloor e^{j2\pi.\lceil .01,.03 \rfloor}$, $\lceil \sqrt{.02}, \sqrt{.06} \rfloor e^{j2\pi.\lceil .01,.02 \rfloor}$	$\lceil \sqrt{.03}, \sqrt{.10} \rfloor e^{j2\pi.\lceil .05,.16 \rfloor}$, $\lceil \sqrt{.02}, \sqrt{.06} \rfloor e^{j2\pi.\lceil .03,.10 \rfloor}$, $\lceil \sqrt{.04}, \sqrt{.09} \rfloor e^{j2\pi.\lceil .01,.02 \rfloor}$, $\lceil \sqrt{.02}, \sqrt{.05} \rfloor e^{j2\pi.\lceil .01,.01 \rfloor}$
TECHINF	$\lceil \sqrt{.03}, \sqrt{.10} \rfloor e^{j2\pi.\lceil .05,.16 \rfloor}$, $\lceil \sqrt{.02}, \sqrt{.06} \rfloor e^{j2\pi.\lceil .03,.10 \rfloor}$, $\lceil \sqrt{.04}, \sqrt{.09} \rfloor e^{j2\pi.\lceil .01,.02 \rfloor}$, $\lceil \sqrt{.02}, \sqrt{.05} \rfloor e^{j2\pi.\lceil .01,.01 \rfloor}$	$\lceil \sqrt{.03}, \sqrt{.10} \rfloor e^{j2\pi.\lceil .05,.16 \rfloor}$, $\lceil \sqrt{.02}, \sqrt{.06} \rfloor e^{j2\pi.\lceil .03,.10 \rfloor}$, $\lceil \sqrt{.04}, \sqrt{.09} \rfloor e^{j2\pi.\lceil .01,.02 \rfloor}$, $\lceil \sqrt{.02}, \sqrt{.05} \rfloor e^{j2\pi.\lceil .01,.01 \rfloor}$		$\lceil \sqrt{.02}, \sqrt{.08} \rfloor e^{j2\pi.\lceil .05,.15 \rfloor}$, $\lceil \sqrt{.01}, \sqrt{.05} \rfloor e^{j2\pi.\lceil .03,.09 \rfloor}$, $\lceil \sqrt{.03}, \sqrt{.10} \rfloor e^{j2\pi.\lceil .01,.03 \rfloor}$, $\lceil \sqrt{.02}, \sqrt{.06} \rfloor e^{j2\pi.\lceil .00,.02 \rfloor}$
SOCIMPAP	$\lceil \sqrt{.03}, \sqrt{.10} \rfloor e^{j2\pi.\lceil .05,.16 \rfloor}$, $\lceil \sqrt{.02}, \sqrt{.06} \rfloor e^{j2\pi.\lceil .03,.10 \rfloor}$, $\lceil \sqrt{.04}, \sqrt{.09} \rfloor e^{j2\pi.\lceil .01,.02 \rfloor}$, $\lceil \sqrt{.02}, \sqrt{.05} \rfloor e^{j2\pi.\lceil .01,.01 \rfloor}$	$\lceil \sqrt{.03}, \sqrt{.10} \rfloor e^{j2\pi.\lceil .05,.16 \rfloor}$, $\lceil \sqrt{.02}, \sqrt{.06} \rfloor e^{j2\pi.\lceil .03,.10 \rfloor}$, $\lceil \sqrt{.04}, \sqrt{.09} \rfloor e^{j2\pi.\lceil .01,.02 \rfloor}$, $\lceil \sqrt{.02}, \sqrt{.05} \rfloor e^{j2\pi.\lceil .01,.01 \rfloor}$	$\lceil \sqrt{.03}, \sqrt{.08} \rfloor e^{j2\pi.\lceil .05,.15 \rfloor}$, $\lceil \sqrt{.02}, \sqrt{.05} \rfloor e^{j2\pi.\lceil .03,.09 \rfloor}$, $\lceil \sqrt{.04}, \sqrt{.10} \rfloor e^{j2\pi.\lceil .01,.03 \rfloor}$, $\lceil \sqrt{.02}, \sqrt{.06} \rfloor e^{j2\pi.\lceil .01,.02 \rfloor}$	

Table A8
The defuzzified values of QPFRSs

	LOCECO	COSEFF	TECHINF	SOCIMPAP
LOCECO	.000	.068	.066	.059
COSEFF	.060	.000	.062	.068
TECHINF	.068	.066	.000	.058
SOCIMPAP	.066	.068	.060	.000

Table A9
The normalized relation matrix

	LOCECO	COSEFF	TECHINF	SOCIMPAP
LOCECO	.000	.353	.343	.303
COSEFF	.317	.000	.325	.358
TECHINF	.356	.342	.000	.302
SOCIMPAP	.341	.348	.311	.000

Table A10
S,K,Q and W

LOCECO	Sj	kj	qj	Wj	COSEFF	Sj	Kj	qj	Wj
COSEFF	.353	1.000	1.000	.432	SOCIMPAP	.358	1.000	1.000	.430
TECHINF	.343	1.343	.745	.322	TECHINF	.325	1.325	.755	.324
SOCIMPAP	.303	1.303	.571	.247	LOCECO	.317	1.317	.573	.246
TECHINF	**Sj**	**kj**	**qj**	**Wj**	**SOCIMPAP**	**Sj**	**Kj**	**qj**	**Wj**
LOCECO	.356	1.000	1.000	.432	COSEFF	.348	1.000	1.000	.432
COSEFF	.342	1.342	.745	.322	LOCECO	.341	1.341	.746	.322
SOCIMPAP	.302	1.302	.572	.247	TECHINF	.311	1.311	.569	.246

Table A11
w and Impacts

	LOCECO	COSEFF	TECHINF	SOCIMPAP	Impact directions
LOCECO		.432	.247	.247	LOCECO→COSEFF
COSEFF	.246		.324	.430	COSEFF→SOCIMPAP
TECHINF	.432	.322		.247	TECHINF→LOCECO
SOCIMPAP	.322	.432	.246		SOCIMPAP→COSEFF

Table A12
QPFN for the decision matrix

	LOCECO	COSEFF	TECHINF	SOCIMPAP
DM1				
A1	$\left[\sqrt{.36}e^{j2\pi..6}, \sqrt{.22}e^{j2\pi..37}, \sqrt{.26}e^{j2\pi..02}, \sqrt{.16}e^{j2\pi..01}\right]$	$\left[\sqrt{.25}e^{j2\pi..50}, \sqrt{.15}e^{j2\pi..31}, \sqrt{.37}e^{j2\pi..12}, \sqrt{.23}e^{j2\pi..07}\right]$	$\left[\sqrt{.36}e^{j2\pi..6}, \sqrt{.22}e^{j2\pi..37}, \sqrt{.26}e^{j2\pi..02}, \sqrt{.16}e^{j2\pi..01}\right]$	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$
A2	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$	$\left[\sqrt{.20}e^{j2\pi..45}, \sqrt{.13}e^{j2\pi..28}, \sqrt{.42}e^{j2\pi..17}, \sqrt{.25}e^{j2\pi..10}\right]$	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$	$\left[\sqrt{.25}e^{j2\pi..50}, \sqrt{.15}e^{j2\pi..31}, \sqrt{.37}e^{j2\pi..12}, \sqrt{.23}e^{j2\pi..07}\right]$
A3	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$
A4	$\left[\sqrt{.36}e^{j2\pi..6}, \sqrt{.22}e^{j2\pi..37}, \sqrt{.26}e^{j2\pi..02}, \sqrt{.16}e^{j2\pi..01}\right]$	$\left[\sqrt{.36}e^{j2\pi..6}, \sqrt{.22}e^{j2\pi..37}, \sqrt{.26}e^{j2\pi..02}, \sqrt{.16}e^{j2\pi..01}\right]$	$\left[\sqrt{.25}e^{j2\pi..50}, \sqrt{.15}e^{j2\pi..31}, \sqrt{.37}e^{j2\pi..12}, \sqrt{.23}e^{j2\pi..07}\right]$	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$
DM3	**LOCECO**	**COSEFF**	**TECHINF**	**SOCIMPAP**
A1	$\left[\sqrt{.36}e^{j2\pi..6}, \sqrt{.22}e^{j2\pi..37}, \sqrt{.26}e^{j2\pi..02}, \sqrt{.16}e^{j2\pi..01}\right]$	$\left[\sqrt{.20}e^{j2\pi..45}, \sqrt{.13}e^{j2\pi..28}, \sqrt{.42}e^{j2\pi..17}, \sqrt{.25}e^{j2\pi..10}\right]$	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$	$\left[\sqrt{.36}e^{j2\pi..6}, \sqrt{.22}e^{j2\pi..37}, \sqrt{.26}e^{j2\pi..02}, \sqrt{.16}e^{j2\pi..01}\right]$
A2	$\left[\sqrt{.36}e^{j2\pi..6}, \sqrt{.22}e^{j2\pi..37}, \sqrt{.26}e^{j2\pi..02}, \sqrt{.16}e^{j2\pi..01}\right]$	$\left[\sqrt{.25}e^{j2\pi..50}, \sqrt{.15}e^{j2\pi..31}, \sqrt{.37}e^{j2\pi..12}, \sqrt{.23}e^{j2\pi..07}\right]$	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$	$\left[\sqrt{.25}e^{j2\pi..50}, \sqrt{.15}e^{j2\pi..31}, \sqrt{.37}e^{j2\pi..12}, \sqrt{.23}e^{j2\pi..07}\right]$
A3	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$	$\left[\sqrt{.25}e^{j2\pi..50}, \sqrt{.15}e^{j2\pi..31}, \sqrt{.37}e^{j2\pi..12}, \sqrt{.23}e^{j2\pi..07}\right]$	$\left[\sqrt{.25}e^{j2\pi..50}, \sqrt{.15}e^{j2\pi..31}, \sqrt{.37}e^{j2\pi..12}, \sqrt{.23}e^{j2\pi..07}\right]$	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$
A4	$\left[\sqrt{.25}e^{j2\pi..50}, \sqrt{.15}e^{j2\pi..31}, \sqrt{.37}e^{j2\pi..12}, \sqrt{.23}e^{j2\pi..07}\right]$	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$	$\left[\sqrt{.36}e^{j2\pi..6}, \sqrt{.22}e^{j2\pi..37}, \sqrt{.26}e^{j2\pi..02}, \sqrt{.16}e^{j2\pi..01}\right]$	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$
DM4	**LOCECO**	**COSEFF**	**TECHINF**	**SOCIMPAP**
A1	$\left[\sqrt{.36}e^{j2\pi..6}, \sqrt{.22}e^{j2\pi..37}, \sqrt{.26}e^{j2\pi..02}, \sqrt{.16}e^{j2\pi..01}\right]$	$\left[\sqrt{.20}e^{j2\pi..45}, \sqrt{.13}e^{j2\pi..28}, \sqrt{.42}e^{j2\pi..17}, \sqrt{.25}e^{j2\pi..10}\right]$	$\left[\sqrt{.36}e^{j2\pi..6}, \sqrt{.22}e^{j2\pi..37}, \sqrt{.26}e^{j2\pi..02}, \sqrt{.16}e^{j2\pi..01}\right]$	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$
A2	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$	$\left[\sqrt{.25}e^{j2\pi..50}, \sqrt{.15}e^{j2\pi..31}, \sqrt{.37}e^{j2\pi..12}, \sqrt{.23}e^{j2\pi..07}\right]$	$\left[\sqrt{.36}e^{j2\pi..6}, \sqrt{.22}e^{j2\pi..37}, \sqrt{.26}e^{j2\pi..02}, \sqrt{.16}e^{j2\pi..01}\right]$	$\left[\sqrt{.25}e^{j2\pi..50}, \sqrt{.15}e^{j2\pi..31}, \sqrt{.37}e^{j2\pi..12}, \sqrt{.23}e^{j2\pi..07}\right]$
A3	$\left[\sqrt{.36}e^{j2\pi..6}, \sqrt{.22}e^{j2\pi..37}, \sqrt{.26}e^{j2\pi..02}, \sqrt{.16}e^{j2\pi..01}\right]$	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$	$\left[\sqrt{.36}e^{j2\pi..6}, \sqrt{.22}e^{j2\pi..37}, \sqrt{.26}e^{j2\pi..02}, \sqrt{.16}e^{j2\pi..01}\right]$	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$
A4	$\left[\sqrt{.25}e^{j2\pi..50}, \sqrt{.15}e^{j2\pi..31}, \sqrt{.37}e^{j2\pi..12}, \sqrt{.23}e^{j2\pi..07}\right]$	$\left[\sqrt{.36}e^{j2\pi..6}, \sqrt{.22}e^{j2\pi..37}, \sqrt{.26}e^{j2\pi..02}, \sqrt{.16}e^{j2\pi..01}\right]$	$\left[\sqrt{.25}e^{j2\pi..50}, \sqrt{.15}e^{j2\pi..31}, \sqrt{.37}e^{j2\pi..12}, \sqrt{.23}e^{j2\pi..07}\right]$	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$
DM5	**LOCECO**	**COSEFF**	**TECHINF**	**SOCIMPAP**
A1	$\left[\sqrt{.25}e^{j2\pi..50}, \sqrt{.15}e^{j2\pi..31}, \sqrt{.37}e^{j2\pi..12}, \sqrt{.23}e^{j2\pi..07}\right]$	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$	$\left[\sqrt{.25}e^{j2\pi..50}, \sqrt{.15}e^{j2\pi..31}, \sqrt{.37}e^{j2\pi..12}, \sqrt{.23}e^{j2\pi..07}\right]$	$\left[\sqrt{.36}e^{j2\pi..6}, \sqrt{.22}e^{j2\pi..37}, \sqrt{.26}e^{j2\pi..02}, \sqrt{.16}e^{j2\pi..01}\right]$
A2	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$	$\left[\sqrt{.25}e^{j2\pi..50}, \sqrt{.15}e^{j2\pi..31}, \sqrt{.37}e^{j2\pi..12}, \sqrt{.23}e^{j2\pi..07}\right]$	$\left[\sqrt{.36}e^{j2\pi..6}, \sqrt{.22}e^{j2\pi..37}, \sqrt{.26}e^{j2\pi..02}, \sqrt{.16}e^{j2\pi..01}\right]$
A3	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$	$\left[\sqrt{.30}e^{j2\pi..55}, \sqrt{.19}e^{j2\pi..34}, \sqrt{.32}e^{j2\pi..07}, \sqrt{.19}e^{j2\pi..04}\right]$

(*continued on next page*)

Table A12 (*continued*)

DM1				
	LOCECO	COSEFF	TECHINF	SOCIMPAP
A4	$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.25}e^{j2\pi..50},\\ \sqrt{.15}e^{j2\pi..31},\\ \sqrt{.37}e^{j2\pi..12},\\ \sqrt{.23}e^{j2\pi..07}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.36}e^{j2\pi..6},\\ \sqrt{.22}e^{j2\pi..37},\\ \sqrt{.26}e^{j2\pi..02},\\ \sqrt{.16}e^{j2\pi..01}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.25}e^{j2\pi..50},\\ \sqrt{.15}e^{j2\pi..31},\\ \sqrt{.37}e^{j2\pi..12},\\ \sqrt{.23}e^{j2\pi..07}\end{bmatrix}$
DM6				
	LOCECO	**COSEFF**	**TECHINF**	**SOCIMPAP**
A1	$\begin{bmatrix}\sqrt{.36}e^{j2\pi..6},\\ \sqrt{.22}e^{j2\pi..37},\\ \sqrt{.26}e^{j2\pi..02},\\ \sqrt{.16}e^{j2\pi..01}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.25}e^{j2\pi..50},\\ \sqrt{.15}e^{j2\pi..31},\\ \sqrt{.37}e^{j2\pi..12},\\ \sqrt{.23}e^{j2\pi..07}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.36}e^{j2\pi..6},\\ \sqrt{.22}e^{j2\pi..37},\\ \sqrt{.26}e^{j2\pi..02},\\ \sqrt{.16}e^{j2\pi..01}\end{bmatrix}$
A2	$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.36}e^{j2\pi..6},\\ \sqrt{.22}e^{j2\pi..37},\\ \sqrt{.26}e^{j2\pi..02},\\ \sqrt{.16}e^{j2\pi..01}\end{bmatrix}$
A3	$\begin{bmatrix}\sqrt{.36}e^{j2\pi..6},\\ \sqrt{.22}e^{j2\pi..37},\\ \sqrt{.26}e^{j2\pi..02},\\ \sqrt{.16}e^{j2\pi..01}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.25}e^{j2\pi..50},\\ \sqrt{.15}e^{j2\pi..31},\\ \sqrt{.37}e^{j2\pi..12},\\ \sqrt{.23}e^{j2\pi..07}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.36}e^{j2\pi..6},\\ \sqrt{.22}e^{j2\pi..37},\\ \sqrt{.26}e^{j2\pi..02},\\ \sqrt{.16}e^{j2\pi..01}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$
A4	$\begin{bmatrix}\sqrt{.30}e^{j2\pi..55},\\ \sqrt{.19}e^{j2\pi..34},\\ \sqrt{.32}e^{j2\pi..07},\\ \sqrt{.19}e^{j2\pi..04}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.25}e^{j2\pi..50},\\ \sqrt{.15}e^{j2\pi..31},\\ \sqrt{.37}e^{j2\pi..12},\\ \sqrt{.23}e^{j2\pi..07}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.36}e^{j2\pi..6},\\ \sqrt{.22}e^{j2\pi..37},\\ \sqrt{.26}e^{j2\pi..02},\\ \sqrt{.16}e^{j2\pi..01}\end{bmatrix}$	$\begin{bmatrix}\sqrt{.25}e^{j2\pi..50},\\ \sqrt{.15}e^{j2\pi..31},\\ \sqrt{.37}e^{j2\pi..12},\\ \sqrt{.23}e^{j2\pi..07}\end{bmatrix}$

Table A13
Expert weighted QPFRS for the decision matrix

	LOCECO	COSEFF	TECHINF	SOCIMPAP
A1	$\lceil\sqrt{.03},\sqrt{.10}\rfloor\ e^{j2\pi.\lceil .05,.16\rfloor},\ \lceil\sqrt{.02},\sqrt{.06}\rfloor\ e^{j2\pi.\lceil .03,.10\rfloor},\ \lceil\sqrt{.04},\sqrt{.09}\rfloor\ e^{j2\pi.\lceil .01,.02\rfloor},\ \lceil\sqrt{.02},\sqrt{.05}\rfloor\ e^{j2\pi.\lceil .01,.01\rfloor}$	$\lceil\sqrt{.02},\sqrt{.08}\rfloor\ e^{j2\pi.\lceil .05,.15\rfloor},\ \lceil\sqrt{.01},\sqrt{.05}\rfloor\ e^{j2\pi.\lceil .03,.09\rfloor},\ \lceil\sqrt{.03},\sqrt{.10}\rfloor\ e^{j2\pi.\lceil .01,.03\rfloor},\ \lceil\sqrt{.02},\sqrt{.06}\rfloor\ e^{j2\pi.\lceil .00,.02\rfloor}$	$\lceil\sqrt{.03},\sqrt{.10}\rfloor\ e^{j2\pi.\lceil .05,.16\rfloor},\ \lceil\sqrt{.02},\sqrt{.06}\rfloor\ e^{j2\pi.\lceil .03,.10\rfloor},\ \lceil\sqrt{.04},\sqrt{.09}\rfloor\ e^{j2\pi.\lceil .01,.02\rfloor},\ \lceil\sqrt{.02},\sqrt{.05}\rfloor\ e^{j2\pi.\lceil .01,.01\rfloor}$	$\lceil\sqrt{.04},\sqrt{.10}\rfloor\ e^{j2\pi.\lceil .06,.16\rfloor},\ \lceil\sqrt{.02},\sqrt{.06}\rfloor\ e^{j2\pi.\lceil .04,.10\rfloor},\ \lceil\sqrt{.03},\sqrt{.09}\rfloor\ e^{j2\pi.\lceil .00,.02\rfloor},\ \lceil\sqrt{.02},\sqrt{.05}\rfloor\ e^{j2\pi.\lceil .00,.01\rfloor}$
A2	$\lceil\sqrt{.03},\sqrt{.08}\rfloor\ e^{j2\pi.\lceil .05,.15\rfloor},\ \lceil\sqrt{.02},\sqrt{.05}\rfloor\ e^{j2\pi.\lceil .03,.09\rfloor},\ \lceil\sqrt{.04},\sqrt{.10}\rfloor\ e^{j2\pi.\lceil .01,.03\rfloor},\ \lceil\sqrt{.02},\sqrt{.06}\rfloor\ e^{j2\pi.\lceil .01,.02\rfloor}$	$\lceil\sqrt{.03},\sqrt{.08}\rfloor\ e^{j2\pi.\lceil .05,.15\rfloor},\ \lceil\sqrt{.02},\sqrt{.05}\rfloor\ e^{j2\pi.\lceil .03,.09\rfloor},\ \lceil\sqrt{.04},\sqrt{.10}\rfloor\ e^{j2\pi.\lceil .01,.03\rfloor},\ \lceil\sqrt{.02},\sqrt{.06}\rfloor\ e^{j2\pi.\lceil .01,.02\rfloor}$	$\lceil\sqrt{.03},\sqrt{.10}\rfloor\ e^{j2\pi.\lceil .05,.16\rfloor},\ \lceil\sqrt{.02},\sqrt{.06}\rfloor\ e^{j2\pi.\lceil .03,.10\rfloor},\ \lceil\sqrt{.04},\sqrt{.09}\rfloor\ e^{j2\pi.\lceil .01,.02\rfloor},\ \lceil\sqrt{.02},\sqrt{.05}\rfloor\ e^{j2\pi.\lceil .01,.01\rfloor}$	$\lceil\sqrt{.03},\sqrt{.10}\rfloor\ e^{j2\pi.\lceil .05,.16\rfloor},\ \lceil\sqrt{.02},\sqrt{.06}\rfloor\ e^{j2\pi.\lceil .03,.10\rfloor},\ \lceil\sqrt{.04},\sqrt{.09}\rfloor\ e^{j2\pi.\lceil .01,.02\rfloor},\ \lceil\sqrt{.02},\sqrt{.05}\rfloor\ e^{j2\pi.\lceil .01,.01\rfloor}$
A3	$\lceil\sqrt{.03},\sqrt{.10}\rfloor\ e^{j2\pi.\lceil .05,.16\rfloor},\ \lceil\sqrt{.02},\sqrt{.06}\rfloor\ e^{j2\pi.\lceil .03,.10\rfloor},\ \lceil\sqrt{.04},\sqrt{.09}\rfloor\ e^{j2\pi.\lceil .01,.02\rfloor},\ \lceil\sqrt{.02},\sqrt{.05}\rfloor\ e^{j2\pi.\lceil .01,.01\rfloor}$	$\lceil\sqrt{.03},\sqrt{.08}\rfloor\ e^{j2\pi.\lceil .05,.15\rfloor},\ \lceil\sqrt{.02},\sqrt{.05}\rfloor\ e^{j2\pi.\lceil .03,.09\rfloor},\ \lceil\sqrt{.04},\sqrt{.10}\rfloor\ e^{j2\pi.\lceil .01,.03\rfloor},\ \lceil\sqrt{.02},\sqrt{.06}\rfloor\ e^{j2\pi.\lceil .01,.02\rfloor}$	$\lceil\sqrt{.03},\sqrt{.10}\rfloor\ e^{j2\pi.\lceil .05,.16\rfloor},\ \lceil\sqrt{.02},\sqrt{.06}\rfloor\ e^{j2\pi.\lceil .03,.10\rfloor},\ \lceil\sqrt{.04},\sqrt{.09}\rfloor\ e^{j2\pi.\lceil .01,.02\rfloor},\ \lceil\sqrt{.02},\sqrt{.05}\rfloor\ e^{j2\pi.\lceil .01,.01\rfloor}$	$\lceil\sqrt{.03},\sqrt{.08}\rfloor\ e^{j2\pi.\lceil .05,.15\rfloor},\ \lceil\sqrt{.02},\sqrt{.05}\rfloor\ e^{j2\pi.\lceil .03,.09\rfloor},\ \lceil\sqrt{.04},\sqrt{.10}\rfloor\ e^{j2\pi.\lceil .01,.03\rfloor},\ \lceil\sqrt{.02},\sqrt{.06}\rfloor\ e^{j2\pi.\lceil .01,.02\rfloor}$
A4	$\lceil\sqrt{.03},\sqrt{.10}\rfloor\ e^{j2\pi.\lceil .05,.16\rfloor},\ \lceil\sqrt{.02},\sqrt{.06}\rfloor\ e^{j2\pi.\lceil .03,.10\rfloor},\ \lceil\sqrt{.04},\sqrt{.09}\rfloor\ e^{j2\pi.\lceil .01,.02\rfloor},\ \lceil\sqrt{.02},\sqrt{.05}\rfloor\ e^{j2\pi.\lceil .01,.01\rfloor}$	$\lceil\sqrt{.03},\sqrt{.10}\rfloor\ e^{j2\pi.\lceil .05,.16\rfloor},\ \lceil\sqrt{.02},\sqrt{.06}\rfloor\ e^{j2\pi.\lceil .03,.10\rfloor},\ \lceil\sqrt{.04},\sqrt{.09}\rfloor\ e^{j2\pi.\lceil .01,.02\rfloor},\ \lceil\sqrt{.02},\sqrt{.05}\rfloor\ e^{j2\pi.\lceil .01,.01\rfloor}$	$\lceil\sqrt{.04},\sqrt{.10}\rfloor\ e^{j2\pi.\lceil .06,.16\rfloor},\ \lceil\sqrt{.02},\sqrt{.06}\rfloor\ e^{j2\pi.\lceil .04,.10\rfloor},\ \lceil\sqrt{.03},\sqrt{.09}\rfloor\ e^{j2\pi.\lceil .00,.02\rfloor},\ \lceil\sqrt{.02},\sqrt{.05}\rfloor\ e^{j2\pi.\lceil .00,.01\rfloor}$	$\lceil\sqrt{.03},\sqrt{.08}\rfloor\ e^{j2\pi.\lceil .05,.15\rfloor},\ \lceil\sqrt{.02},\sqrt{.05}\rfloor\ e^{j2\pi.\lceil .03,.09\rfloor},\ \lceil\sqrt{.04},\sqrt{.10}\rfloor\ e^{j2\pi.\lceil .01,.03\rfloor},\ \lceil\sqrt{.02},\sqrt{.06}\rfloor\ e^{j2\pi.\lceil .01,.02\rfloor}$

Table A14
The defuzzified decision values

Criteria/Alternatives	LOCECO	COSEFF	TECHINF	SOCIMPAP
A1	.065	.059	.066	.070
A2	.062	.061	.066	.066
A3	.068	.060	.066	.062
A4	.066	.066	.070	.060

Appendix B

$$WCSS = \sum_{j=1}^{k} \sum_{x_i \in C_j} d(x_i, c_j)^2 \tag{1}$$

$$d(x_i, x_j) = \sqrt{\sum_{l=1}^{n} (x_{il} - x_{jl})^2} \tag{2}$$

$$c_j = \frac{1}{|C_j|}\sum_{x_i \in C_j} x_i \tag{3}$$

$$s_j = \frac{1}{n}\sum_{l=1}^{n}\sigma_{jl} \tag{4}$$

$$\sigma_{jl} = \sqrt{\frac{1}{|C_j|}\sum_{x_i \in C_j}\left(x_{il} - \overline{x}_{jl}\right)^2} \tag{5}$$

$$\overline{x}_{jl} = \frac{1}{|C_j|}\sum_{x_i \in C_j} x_{il} \tag{6}$$

$$w_j = |C_j| \times s_j \tag{7}$$

$$w_{tj} = \frac{1}{|C_j|}\frac{w_j}{\sum\limits_{w_j \in C_j} w_j} \tag{8}$$

$$sim(u,v) = \frac{\sum_{i \in I}\left(r_{u,i} - \overline{r_u}\right)\left(r_{v,i} - \overline{r_v}\right)}{\sqrt{\sum_{i \in I}\left(r_{u,i} - \overline{r_u}\right)^2}\sqrt{\sum_{i \in I}\left(r_{v,i} - \overline{r_v}\right)^2}} \tag{9}$$

$$p_{u,i} = \frac{\sum_{j \in S} sim(u,v) r_{u,j}}{\sum_{j \in S}|sim(u,v)|} \tag{10}$$

$$Q(|u>) = \varphi e^{j\theta} \tag{11}$$

$$|C> = \{|u_1>, |u_2>, \ldots, |u_n>\} \tag{12}$$

$$\sum_{|u> \subseteq |C>} |Q(|u>)| = 1 \tag{13}$$

$$A = \{\langle x, \mu_A(x)\rangle | x \in X\} \tag{14}$$

$$A = \{\langle x, \mu_A(x), v_A(x)\rangle | x \in X\} \tag{15}$$

$$A = \{\langle x, \mu_A(x), n_A(x), v_A(x), h_A(x)\rangle | x \in X\} \tag{16}$$

$$A \subseteq B \text{ if } \mu_A(x) \leq \mu_B(x) \text{ and } n_A(x) \leq n_B(x) \text{ and } v_A(x) \geq v_B(x), \forall x \in X\ ) \tag{17}$$

$$A = B \text{ if } A \subseteq B \text{ and } B \subseteq A \tag{18}$$

$$A \cup B = \{(x, max(\mu_A(x), \mu_B(x)), min(n_A(x), n_B(x)), min(v_A(x), v_B(x))) | x \in X\} \tag{19}$$

$$A \cap B = \{(x, min(\mu_A(x), \mu_B(x)), min(n_A(x), n_B(x)), max(v_A(x), v_B(x))) | x \in X\} \tag{20}$$

$$coA = \overline{A} = \{(x, v_A(x), n_A(x), \mu_A(x)) | x \in X\} \tag{21}$$

$$\underline{Apr}(C_i) = \cup\left\{Y \in \frac{X}{R(Y)} \leq C_i\right\} \tag{22}$$

$$\overline{Apr}(C_i) = \cup\left\{Y \in \frac{X}{R(Y)} \geq C_i\right\} \tag{23}$$

$$Bnd(C_i) = \cup\left\{Y \in \frac{X}{R(Y)} \neq C_i\right\} \tag{24}$$

$$\underline{Lim}(C_i) = \sqrt[N_L]{\prod\nolimits_{i=1}^{N_L} Y} \in \underline{Apr}(C_i) \tag{25}$$

$$\overline{Lim}(C_i) = \sqrt[N_U]{\prod\nolimits_{i=1}^{N_U} Y} \in \overline{Apr}(C_i) \tag{26}$$

$$RN(C_i) = \left\lceil \underline{Lim}(C_i), \overline{Lim}(C_i) \right\rfloor \tag{27}$$

$$|C_A> = \left\{ \begin{array}{c} \langle u, \left(\left\lceil \underline{Lim}\left(C_{i\mu_A}\right), \overline{Lim}\left(C_{i\mu_A}\right)\right\rfloor (u), \left\lceil \underline{Lim}\left(C_{in_A}\right), \overline{Lim}\left(C_{in_A}\right)\right\rfloor (u), \\ \left\lceil \underline{Lim}\left(C_{iv_A}\right), \overline{Lim}\left(C_{iv_A}\right)\right\rfloor (u), \left\lceil \underline{Lim}\left(C_{ih_A}\right), \overline{Lim}\left(C_{ih_A}\right)\right\rfloor (u)\right) | u \in 2^{|C_A>} \end{array} \right\} \tag{28}$$

$$\begin{aligned}
&\underline{Lim}\left(C_{i\mu_A}\right)=\frac{1}{N_{L\mu_A}}\sum_{i=1}^{N_{L\mu_A}}Y\in\underline{Apr}\left(C_{i\mu_A}\right)\\
&\underline{Lim}\left(C_{in_A}\right)=\frac{1}{N_{Ln_A}}\sum_{i=1}^{N_{Ln_A}}Y\in\underline{Apr}\left(C_{in_A}\right)\\
&\underline{Lim}\left(C_{iv_A}\right)=\frac{1}{N_{Lv_A}}\sum_{i=1}^{N_{Lv_A}}Y\in\underline{Apr}\left(C_{iv_A}\right)\\
&\underline{Lim}\left(C_{ih_A}\right)=\frac{1}{N_{L\pi_A}}\sum_{i=1}^{N_{L\pi_A}}Y\in\underline{Apr}\left(C_{ih_A}\right)
\end{aligned}\tag{29}$$

$$\begin{aligned}
&\overline{Lim}\left(C_{i\mu_A}\right)=\frac{1}{N_{U\mu_A}}\sum_{i=1}^{N_{U\mu_A}}Y\in\overline{Apr}\left(C_{i\mu_A}\right)\\
&\overline{Lim}\left(C_{in_A}\right)=\frac{1}{N_{Un_A}}\sum_{i=1}^{N_{Un_A}}Y\in\overline{Apr}\left(C_{in_A}\right)\\
&\overline{Lim}\left(C_{iv_A}\right)=\frac{1}{N_{Uv_A}}\sum_{i=1}^{N_{Uv_A}}Y\in\overline{Apr}\left(C_{iv_A}\right)\\
&\overline{Lim}\left(C_{ih_A}\right)=\frac{1}{N_{U\pi_A}}\sum_{i=1}^{N_{U\pi_A}}Y\in\overline{Apr}\left(C_{ih_A}\right)
\end{aligned}\tag{30}$$

$$\begin{aligned}
&\underline{Apr}\left(C_{i\mu_A}\right)=\cup\left\{Y\in\frac{X}{\widetilde{R}(Y)}\le C_{i\mu_A}\right\}\\
&\underline{Apr}\left(C_{in_A}\right)=\cup\left\{Y\in\frac{X}{\widetilde{R}(Y)}\le C_{in_A}\right\}\\
&\underline{Apr}\left(C_{iv_A}\right)=\cup\left\{Y\in\frac{X}{\widetilde{R}(Y)}\le C_{iv_A}\right\}\\
&\underline{Apr}\left(C_{ih_A}\right)=\cup\left\{Y\in\frac{X}{\widetilde{R}(Y)}\le C_{ih_A}\right\}
\end{aligned}\tag{31}$$

$$\begin{aligned}
&\overline{Apr}\left(C_{i\mu_A}\right)=\cup\left\{Y\in\frac{X}{\widetilde{R}(Y)}\le C_{i\mu_A}\right\}\\
&\overline{Apr}\left(C_{in_A}\right)=\cup\left\{Y\in\frac{X}{\widetilde{R}(Y)}\le C_{in_A}\right\}\\
&\overline{Apr}\left(C_{iv_A}\right)=\cup\left\{Y\in\frac{X}{\widetilde{R}(Y)}\le C_{iv_A}\right\}\\
&\overline{Apr}\left(C_{ih_A}\right)=\cup\left\{Y\in\frac{X}{\widetilde{R}(Y)}\le C_{ih_A}\right\}
\end{aligned}\tag{32}$$

$$C=\left[C_{\mu}.e^{j2\pi.\alpha},C_{n}.e^{j2\pi.\gamma},C_{v}.e^{j2\pi.\beta},C_{h}.e^{j2\pi.T}\right]\tag{33}$$

$$\varphi^2=\left|C_{\mu}(|u_i>)\right|\tag{34}$$

$$C_n=\frac{C_\mu}{G}\tag{35}$$

$$C_h=\frac{C_v}{G}\tag{36}$$

$$\alpha=\left|C_{\mu}(|u_i>)\right|\tag{37}$$

$$\gamma=\frac{\alpha}{G}\tag{38}$$

$$T=\frac{\beta}{G}\tag{39}$$

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