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The Editor,

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Dear Editor,

We hereby submit a manuscript entitled “*Assessment of Membrane Assisted Technologies in Water Reuse Scenarios: A Group Decision-Making Tool for the Application of Membrane Technologies in Different Water Reuse Scenarios*” by Seyed M.K. Sadr, Devendra Saroj, Samaneh Kouchaki, Adeshola. Ilemobade, and Sabeha Ouki , for consideration for publication as an original research paper in the *Journal of Environmental Management*.

In this research, we have developed a fuzzy logic based group decision making framework for the selection of membrane-assisted wastewater technologies in water reuse applications. The framework has been applied to four non-potable and potable water reuse scenarios by employing a multi-criteria analysis tool. The proposed approach will open opportunities for further investigation into the application complex decision making tool in the appraisal of existing and upcoming technological developments in the area of wastewater treatment and the protection of aquatic environment.

We believe this manuscript is suitable for publication in this journal as it falls within the scope of the subject areas relevant to the journal. Our work will be of interest to the wider interdisciplinary scientific and academic community interested in emerging water and environment related research.

The novel aspects of this paper are:

- The proposed framework, which provides a powerful tool for assessing water reuse technologies, has not been applied before in wastewater treatment technology selection and environmental management.
- This method mitigates the issues related to finalising and unifying decisions of a panel of experts and decision makers, particularly in the area of wastewater management.

We affirm the originality of this manuscript which has not been published and is not being considered for publication elsewhere. We hope that you will find this manuscript having potential for publication and we thank you in advance for your consideration.

Yours sincerely,

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Conceptual representation of the interaction of urban water cycle for assessing various water reuse scenarios within a community

Highlights

- Proposed framework provides a robust tool for assessing water reuse technologies.
- Results from MCMEDM tool coincide with the existing water reuse case studies.
- Presence of NF/RO would play a major role in potable water reuse applications.
- Results show that the cost and energy were high in non-potable reuse scenarios.

A Group Decision-Making Tool for the Application of Membrane Technologies in Different Water Reuse Scenarios

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A Group Decision-Making Tool for the Application of Membrane Technologies in Different Water Reuse Scenarios

Abstract

A global challenge of increasing concern is diminishing fresh water resources. A growing practice in many communities to supplement diminishing fresh water availability has been the reuse of water. Novel methods of treating polluted waters, such as membrane assisted technologies, have recently been developed and successfully implemented in many places. Given the diversity of membrane assisted technologies available, the current challenge is how to select a reliable alternative among numerous existing and upcoming technologies for appropriate water reuse. In this research, a fuzzy logic based multi-criteria, group decision making tool has been developed. This tool has been employed in the selection of appropriate membrane treatment technologies for several non-potable and potable reuse scenarios. Robust criteria, covering technical, environmental, economic and socio-cultural aspects, were selected, while 10 different membrane assisted technologies were assessed in the tool. The results show this approach capable of facilitating systematic and rigorous analysis in the comparison and selection of membrane assisted technologies for advanced wastewater treatment and reuse.

Keywords: Water reuse, membrane assisted technologies, group decision making tool, multi-criteria analysis, fuzzy set theory.

Abbreviations¹

¹ **Abbreviations:** AnMBR, Anaerobic Membrane Bio-Reactor; CAS, Conventional Activated Sludge; CASP, Conventional Activated Sludge Process; CC bar chart, Criteria Contribution Bar Chart; CCI, Closeness Coefficient; CDPH, California Department of Public Health; CDPH-DW, California Regulations Related to Drinking Water; CDPH-RW, California Department of Public Health; Regulations Related to Recycled Water; CEPT, Chemically enhanced primary treatment; Cj, Criterion; DPWR, Direct Potable Water Reuse; EDCs, Endocrine Disruptive Compounds; FCi, Farness coefficient; FNIS, Fuzzy Negative-Ideal Solution; FPIS, Fuzzy Positive-Ideal Solution; iMBR, Immersed Membrane Bio-Reactor; IPWR, Indirect Potable Water Reuse; MBR, Membrane Bio-Reactor; MCA, Multi-Criteria Analysis; MCMEDM, Multi-Criteria Multi-Expert Decision Making; MF/UF, Microfiltration/Ultrafiltration; MLSS, Mixed Liquor Suspended Solids; NF/RO, Nanofiltration/Reverse osmosis; NPWR, Non potable water reuse; NRC, National Research Council; O&M, Operation and Maintenance; PhACs, Pharmaceuticals Active Compounds; RO, Reverse Osmosis; Si, Scenario; SOR, Surface Overflow Rate; STP, Sewage Treatment Plant; Ti, Technology; TMF, Tertiary Membrane Filtration; TOC, Total Organic Carbon; TOPSIS, Technique for Order Performance by Similarity to Ideal Solution; UNISEF, United Nations International Children's Emergency Fund; UV, Ultraviolet; WHO, World Health Organization; WHO-AWR, WHO Microbiological Guidelines for Treated Water Reuse in Agriculture; WHO-DWQ, WHO Guidelines for Drinking Water Quality; WRA, Water Reuse Application; WWTP, Wastewater Treatment Plant;

1 Introduction

Fresh water scarcity is due to many interrelated factors and is a growing concern in different parts of the world. As of 2008, about 900 million people around the world had limited access to healthy water supplies (WHO and UNICEF, 2008) and more than three and half million deaths were reported annually due to water related diseases (WHO, 2008). To meet increasing water demand and water quality standards, a diversity of water treatment technologies have been employed. Among these are membrane assisted technologies, which have been employed and proven to be suitable and reliable in different urban water reuse scenarios (Shannon et al., 2008). These technologies enable the production of high quality recycled water at reasonable costs and comparably reduced energy input (Rodriguez et al., 2009). One of the challenges has been how to select an appropriate membrane technology for a specific water reuse scenario. The plethora of membrane technology information often increases the complexity in decision making (Sadr et al., 2013). In addition, multiple water reuse scenarios require decision making tools that incorporate existing and emerging knowledge regarding novel process developments for sustainable water reuse. Since most decision making methods, e.g. multi-criteria analysis (MCA), strive to model human reasoning, and to subsequently incorporate modelled results into their procedures, the approach proposed in this paper would attempt to capture the vagueness and imprecision of information using linguistic variables (Anagnostopoulos et al., 2008). Another challenge is how to incorporate opinions of different people (e.g. stakeholders, authorities, and experts) in a panel of decision making. Kalbar et al., (2013) developed a wastewater treatment technology selection approach to integrate expert opinions by a scenario-based group decision-making process. This group decision-making (GDM) approach was based on an analytical hierarchy process (AHP). Another method which has been shown to be an efficient technique to obtain rankings from engineering experts is Multi-Criteria Multi-Expert Decision Making (MCMEDM) within a fuzzy environment (Chen, 2000; Dheena and Mohanraj, 2011).

Fuzzy logic can be used as an efficient way of modelling uncertainty, imprecision, and qualitative information (Bellman and Zadeh, 1970; Chen and Klein, 1997). In addition, Fuzzy sets provide the flexibility required to represent and handle the uncertainty and imprecision which result from lack of knowledge and ill-defined information (Yeh & Deng, 2004; Dheena and Mohanraj, 2011). In the last decade, several studies applied fuzzy logic theory to overcome uncertainty and subjectivity in multi-criteria decision making (Chen & Tzeng, 2004; Yeh & Deng, 2004; Dheena and Mohanraj, 2011). Li (1999) developed a model to overcome the problem of multi-judges and multi-criteria decision making where the performance of alternatives and the importance of criteria are imprecisely defined and represented by fuzzy sets. In conclusion, Li (1999) suggested a level weighted fuzzy relation for comparing and ranking sets of criteria and alternatives. This method can provide a precise solution for a defuzzified process since the problem is solved analytically by the algorithm of the proposed method.

Another technique for group decision making makes use of the ideal and anti-ideal points to find the most preferred alternatives. It is vital to mention that in this technique, the best alternative is the one with the shortest distance from the positive ideal point and the longest distance from the negative ideal point simultaneously (Anagnostopoulos et al., 2008; Chen & Tzeng, 2004; Kuo et al. 2007; Dheena and Mohanraj, 2011). The ideal point can be described as a point in which all the best criteria values are attainable, whereas the anti-ideal point consists of all the worst criteria values attainable. Therefore, if normalization is considered in a triangular fuzzy environment, the ideal and anti-ideal points would be (1, 1, 1) and (0, 0, 0) respectively. Chen (2000) and Chen (2001) developed two models in order to solve a group decision making problem. In another study, an extension of the method proposed by Chen (2000) was applied for facility location selection (Ertugrul, 2010). Ertugrul, (2010) stated that fuzzy numbers were effective in resolving the ambiguity of concepts that are associated with human judgments. In these studies, the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) was applied and the vertex method

was employed to calculate the distance between two triangular fuzzy numbers to find the best alternative.

The above studies show that Multi-Criteria Multi-Expert Decision Making (MCMEDM), within a fuzzy environment and while employing the TOPSIS and vertex methods, is capable of handling the challenges of group decision making in water reuse applications. Therefore, the aim of this research was to develop a fuzzy logic based multi-criteria group decision making tool for the selection of membrane treatment technologies in four different water reuse scenarios. Robust criteria covering technical, environmental, economic and socio-cultural aspects were selected in order to assess and rank the different technologies.

2 Methodology

Water treatment technology selection for a specific urban setting is challenging due to the diversity of existing treatment technologies (Sadr et al. 2013) and the vast amounts and complexity of information available on these technologies. A methodical assessment of alternatives is therefore essential to amplify the chances of success of wastewater reuse projects. Multi-Criteria Analysis (MCA) is a decision making tool which can be used in the systematic appraisal of wastewater reuse technologies (Sadr et al. 2014), Different MCA methods have been applied in various studies (e.g. Akash et al. 1997; De Marchi et al. 2000; Katukiza et al. 2010). This paper takes MCA a step further by developing and applying a tool to aid decision making among a group of experts and decision makers. Therefore, in this paper, a fuzzy logic based multi-criteria group decision making tool is proposed to facilitate the selection of the best membrane assisted treatment technologies for different water reuse scenarios. The schematic of the methodology employed herein is presented in the supplementary materials.

2.1 Development of a decision making tool for water reuse scenarios using fuzzy set theory

In the developed tool, decision making by multi-criteria analysis in a complex environment such as water reuse technology selection consists of a set of scenarios $S = \{S_1, S_2, \dots, S_l\}$, technologies $T_i = \{T_1, T_2, \dots, T_m\}$, and a set of criteria $C_j = \{C_1, C_2, \dots, C_n\}$. Rating ($\tilde{x}_{ij}$) of the technologies (T_i) with fuzzy numbers with respect to each criterion (C_j) should be applied where $i = 1, 2, \dots, m$ and $j = 1, 2, \dots, n$. The weight of each criterion is represented by a weighting vector $\tilde{W} = [\tilde{w}_1, \tilde{w}_2, \dots, \tilde{w}_n]$. The multi-criteria problem is expressed in a decision matrix $\tilde{D}$ as follows (Chen, 2000):

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix}, \quad \text{Equation 1}$$

$$\tilde{W} = [\tilde{w}_1, \tilde{w}_2, \dots, \tilde{w}_n] \quad \text{Equation 2}$$

where all the elements in the matrix are fuzzy numbers. In this research, triangular fuzzy numbers are used for the criteria weights in order to make computations simpler. The membership function of a triangular fuzzy number, which can be defined as a generalization of the indicator functions in classical sets, has the form presented in Equation 3 (Kaufmann and Gupta, 1985).

$$\tilde{\mu}(x) = \begin{cases} 0 & \text{for } x < n_1 \\ \frac{x-n_1}{n_2-n_1} & \text{for } n_1 \leq x < n_2 \\ \frac{n_3-x}{n_3-n_2} & \text{for } n_2 \leq x < n_3 \\ 0 & \text{for } x > n_3 \end{cases} \quad \text{Equation 3}$$

where n_1 , n_2 , and n_3 are real numbers that can develop a fuzzy triplet (n_1, n_2, n_3) . In a more practical view, the fuzzy set comprising the membership function ($\tilde{\mu}(x)$), the rating of technologies ($\tilde{x}_{ij}$) and weights of criteria ($\tilde{w}_j$) can be represented as:

$$\mathbf{Fuzzy\ Set} = \begin{cases} \tilde{\mu} = (n_1, n_2, n_3) \\ \tilde{x}_{ij} = (x_{1ij}, x_{2ij}, x_{3ij}) & \forall i, j, x_{kij} \in \mathbb{R}, k = 1, 2, 3, \dots \\ \tilde{w}_j = (w_{1j}, w_{2j}, w_{3j}) & \forall j, w_{kj} \in \mathbb{R}, \end{cases} \quad \text{Equation 4}$$

The importance, and therefore magnitude of the weight of each criterion as well as the performance of technologies with respect to various criteria is determined by the k experts involved in decision making. For rating the alternatives and monitoring the importance of criteria, relevant linguistic variables and fuzzy numbers have to be defined. The linguistic variables which are employed for the evaluation of the importance of the criteria and the ratings of alternatives with respect to various criteria are represented in Table 1.

Table 1: Linguistic variables and fuzzy sets: (a) Linguistic variables and fuzzy sets used for the ratings of technology alternatives with respect to various criteria, (b) Linguistic variables and fuzzy sets used for the evaluation of the importance of the criteria.

The evaluation of the importance of the criteria and the rating of alternatives with respect to each criterion by a group of K experts are computed using equations 6 and 5 respectively (Chen, 2000; Chen, 2001):

$$\tilde{x}_{ij} = \frac{1}{K} [\tilde{x}_{ij}^1 + \tilde{x}_{ij}^2 + \dots + \tilde{x}_{ij}^K] = \left(\frac{1}{K} \sum_{p=1}^K x_{1ij}^p, \frac{1}{K} \sum_{p=1}^K x_{2ij}^p, \frac{1}{K} \sum_{p=1}^K x_{3ij}^p \right) = (x_{1ij}, x_{2ij}, x_{3ij})$$

Equation 5

$$\tilde{w}_j = \frac{1}{K} [\tilde{w}_j^1 + \tilde{w}_j^2 + \dots + \tilde{w}_j^K] = \left(\frac{1}{K} \sum_{p=1}^K w_{1j}^p, \frac{1}{K} \sum_{p=1}^K w_{2j}^p, \frac{1}{K} \sum_{p=1}^K w_{3j}^p \right) = (w_{1j}, w_{2j}, w_{3j})$$

Equation 6

where $\tilde{x}_{ij}^k$ and $\tilde{w}_j^k$ are the rating and the importance of the criteria for the k^{th} decision maker.

In this step, a normalization of the fuzzy decision matrix is applied based on two rationales: (1) to ensure compatibility between the evaluations of objective criteria and the linguistic ratings of

subjective criteria (Anagnostopoulos et al., 2008), and (2) to avoid the complicated normalization formula used in the classical TOPSIS method (Chen, 2000). The normalized fuzzy decision can be symbolized by R (Equation 7):

$$R = [\tilde{r}_{ij}]_{m \times n} \quad i = 1, 2, \dots, m \quad j = 1, 2, \dots, n \quad \text{Equation 7}$$

$$\text{Where, } \tilde{r}_{ij} = \left(\frac{x_{1ij}}{c_{1j}^*}, \frac{x_{2ij}}{c_{2j}^*}, \frac{x_{3ij}}{c_{3j}^*} \right) = (r_{1ij}, r_{2ij}, r_{3ij}) \quad C_j^* = \max_i C_{ij} \quad \text{Equation 8}$$

After applying the previous step the range of triangular fuzzy numbers will belong to the closed interval of $[0, 1]$. By incorporating the fuzzy weights into the normalized fuzzy decision matrix, the weighted normalized fuzzy decision matrix ($\tilde{V}$) can be constructed and every element ($\tilde{v}_{ij}$) of $\tilde{V}$ is calculated as shown in equations 9 and 10 (Anagnostopoulos et al., 2008):

$$\tilde{V} = [\tilde{v}_{ij}]_{m \times n} \quad i = 1, 2, \dots, m \quad j = 1, 2, \dots, n \quad \text{Equation 9}$$

$$\tilde{v}_{ij} = \tilde{r}_{ij} \otimes \tilde{w}_j = (r_{1ij}, r_{2ij}, r_{3ij}) \otimes (w_{1ij}, w_{2ij}, w_{3ij}) = (r_{1ij}w_{1ij}, r_{2ij}w_{2ij}, r_{3ij}w_{3ij}), \quad r_{1ij} \geq 0, w_{1ij} \geq 0 \quad \text{Equation 10}$$

Where $\otimes$ denotes the multiplication between fuzzy numbers.

In this stage, the **Fuzzy Positive-Ideal Solution** (FPIS, A^+) and **Fuzzy Negative-Ideal Solution** (FNIS, A^-) can be defined as in equations 11 and 12 respectively:

$$A^+ = (D_1^+, D_2^+, \dots, D_n^+) \quad \text{Equation 11}$$

$$A^- = (D_1^-, D_2^-, \dots, D_n^-,) \quad \text{Equation 12}$$

where $\check{v}_j^+ = (\check{v}_{1j}^+, \check{v}_{2j}^+, \check{v}_{3j}^+) = (1, 1, 1)$ and $\check{v}_j^- = (\check{v}_{1j}^-, \check{v}_{2j}^-, \check{v}_{3j}^-) = (0, 0, 0)$ when $j = 1, 2, \dots, n$. By considering the vertex method, the distance of each water treatment technology from A^+ and A^- is calculated using equations 13 and 14:

$$D_i^+ = \sum_{j=1}^n D(\check{v}_{ij}, \check{v}_j^+) = \sqrt{\frac{1}{3}[(\check{v}_{1ij} - \check{v}_{1j}^+)^2 + (\check{v}_{2ij} - \check{v}_{2j}^+)^2 + (\check{v}_{3ij} - \check{v}_{3j}^+)^2]} \quad \text{Equation 13}$$

$$D_i^- = \sum_{j=1}^n D(\check{v}_{ij}, \check{v}_j^-) = \sqrt{\frac{1}{3}[(\check{v}_{1ij} - \check{v}_{1j}^-)^2 + (\check{v}_{2ij} - \check{v}_{2j}^-)^2 + (\check{v}_{3ij} - \check{v}_{3j}^-)^2]} \quad \text{Equation 14}$$

where $\check{v}_{ij} = (\check{v}_{1ij}, \check{v}_{2ij}, \check{v}_{3ij})$ denotes the weighted normalized element of the fuzzy decision matrix and $D(.,.)$ is the measurement of the distance between two fuzzy numbers. In this step, two coefficients are defined:

$$(1) \text{ Closeness coefficient (Chen, 2000): } CC_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad i = 1, 2, \dots, m \quad \text{Equation 15}$$

$$(2) \text{ Farness coefficient: } FC_i = \frac{D_i^+}{D_i^+ + D_i^-} \quad i = 1, 2, \dots, m \quad \text{Equation 16}$$

These coefficients have been defined to determine the ranking of all technologies. The ranking order and the final score of each technology are calculated by the closeness and farness coefficients which sum to 1. Hence, the farness coefficient can be verified by the closeness coefficient i.e.:

$$1 - CC_i \cong FC_i \quad i = 1, 2, \dots, m \quad \text{Equation 17}$$

2.2 Proposed scenarios

In this study, four water reuse scenarios (presented below) were proposed based on the necessity, viability and in some instances, popularity of water reuse in developing and developed communities. Figure 1 illustrates different possible water reuse applications within a community.

Figure 1: Conceptual representation of the interaction of urban water cycle for assessing various water reuse scenarios within a community.

2.2.1 Scenario 1: Indirect potable water reuse in a developed community

In Indirect Potable Water Reuse (IPWR), municipal wastewater is treated and discharged into environmental buffers (Asano et al. 2007; Bennett, 2011). Environmental buffers e.g. rivers, dams, lakes or aquifers play an important role in this scenario, giving the treated wastewater the opportunity to be further purified by natural physical and biological processes (NRC, 1998). In Singapore for example, the NEWater project employs IPWR via an environmental buffer prior to the treated effluent being treated to potable standards (Bennett, 2011).

A wide range of technical issues and health concerns must be addressed in IPWR and particularly when recharging groundwater with reclaimed municipal wastewater (Asano and Cotruvo, 2004). Potable water reuse applications require stringent standards compared with non-potable reuse, since potable reuse directly impacts public health. Therefore, the most critical issue in its application is health consideration (Asano et al. 2007). Health considerations result from the wide range of possible contaminants e.g. viruses, pathogens, and micro pollutants. Different countries and regions have therefore developed various standards, guidelines and approaches to guarantee the protection of human health and the environment.

In this research, the WHO guidelines for Drinking Water Quality (WHO-DWQ, 2008) and the California Department of Public Health (CDPH) water guidelines (CDPH-RW, 2009; CDPH-DW, 2013) were employed. The WHO-DWQ (2008) guidelines support the development and implementation of risk management strategies guaranteeing the safety of drinking water supplies through the control of hazardous constituents in water. The proposed strategies must include national or regional standards developed from the scientific basis provided in the guidelines. The CDPH-RW (2009) and CDPH-DW (2013) guidelines describe reasonable minimum requirements of safe practice to protect the health of consumers. This includes monitoring requirements related to nitrogen compounds, unregulated emerging chemical contaminants (e.g. endocrine disruptive compounds (EDCs) and pharmaceutical active compounds (PhACs)), and total organic carbon (TOC).

2.2.2 Scenario 2: Non potable water reuse in a water-stressed developed community

In this scenario, the evaluation is conducted according to the WHO microbiological guidelines for treated water reuse in agriculture (WHO-AWR, 1989). The guideline's limit for faecal coliform bacteria in unrestricted irrigation is less than or equal to 1×10^3 faecal coliform units per 100 ml, whereas, for restricted irrigation it is less than or equal to 1×10^5 faecal coliform units per 100 ml (WHO-AWR, 1989). The guideline recommends that for both types of irrigation, nematode eggs should be less than 0.1 eggs per litre.

2.2.3 Scenario 3: Non potable water reuse in a water-stressed developing community

The conditions discussed for Scenario 2 apply in Scenario 3, except that the reuse is proposed for a water-stressed developing community. Non Potable Water Reuse (NPWR), particularly for agricultural irrigation, is a practice that is gaining popularity in many developing communities due to water stress challenges amongst other factors (Qadir et al. 2010). This generates issues such as potential impacts on public health and the environment (Qadir et al. 2010). In addition, in developing economies, where public finances are usually stretched, financial constraints are very important whilst considering NPWR (Sadr et al 2013).

2.2.4 Scenario 4: Direct potable water reuse in a developed economy

Dishman et al. (1989) indicate that two major issues should be addressed if a community is considering the implementation of direct potable water reuse (DPWR): (1) public health concerns, and (2) public acceptance. The former has been extensively addressed by developing appropriate water reuse guidelines and standards and by implementing advanced treatment technologies (e.g. membrane assisted technologies), whereas the latter remains a major barrier to DPWR (Ilemobade et al., 2009). Dishmann et al. (1989) reported on surveys carried out during the 1970s and 1980s in developed regions and the results indicated that more than 50 per cent of respondents did not support DPWR. Since then, a handful of communities have implemented DPWR (Venkatesan et al. 2011). Of note is the Windhoek -Namibia Goreangab Water Reclamation Plant which began

operating in 1969 and whose input is the treated effluent from its upstream domestic wastewater treatment plant and any available fresh water sources (Lahnsteiner and Lempert, 2007; Asano et al., 2007).

2.3 Justification of the Evaluation Criteria employed

There are numerous criteria that merit consideration when evaluating water treatment technologies. Depending on the study, some criteria merit larger weights than others. Kangas et al. (2001) indicated that the number of criteria may be limited to nine in order to minimize the probability of rank reversal during simulation and to ease comprehension. Katukiza et al. (2010) and Sadr et al. (2013) employed five criteria in their studies. While it is important to select the least number of criteria for evaluation, it is also important to ensure that selected criteria cover the broad range of technical, environmental, economical, and socio-cultural aspects. In this research therefore, 10 criteria, satisfying the above aspects were proposed. The list of these criteria is presented in Table 2.

Table 2: Water reuse criteria employed in this study

2.4 Proposed membrane assisted technologies for water reuse

After developing appropriate criteria, different technologies should be considered. Ten different technologies were selected, based on recent developments in the advanced treatment of municipal wastewater for reuse. All alternatives are membrane assisted technologies, which have been shortlisted based on the current status of advanced wastewater treatment and reuse technologies (Sadr et al., 2014; Shannon et al., 2008). The schematic representation of each technology is illustrated in the online supplementary materials. In addition, Table 3 presents the configurations and brief highlights of these technologies. Table 3 also shows whether the technologies meet the quality threshold requirements for nonpotable and/or potable water reuse applications. Each technology has been assessed with respect to various criteria by experts. An example of the survey is presented in the online supplementary materials.

Table 3: Water reuse membrane assisted technologies

2.5 *Experts evaluation forms*

Based on various scenarios, different evaluation surveys were developed and sent to water reuse and wastewater treatment experts. These experts were selected from both academia and industry. Table 4 represents general information about the experts e.g. geographical locations and areas of expertise.

Table 4: General information about the experts who participated in this study

The responses of the experts were entered into the tool to construct evaluation matrices for each scenario. A filled survey for Scenario 1 is presented in the online supplementary materials. In addition, general responses of four experts to the survey for Scenario 1 are presented in Table 5 and Table 6.

Table 5: The fuzzy ratings of the technologies (T1 to T10) under all criteria (C1 to C10) by four experts (E1, E2, E3 and E4) for Scenario 1

Table 6: The fuzzy ratings of the criteria weights (C1 to C10) by four experts (E1, E2, E3 and E4) for Scenario 1

3 **Results and discussion**

3.1 *Scenario-based evaluation of membrane assisted water reuse technologies*

Based on the experts' opinions, the best membrane assisted treatment technologies for four scenarios of water reuse in developing and developed countries were determined using the Fuzzy based MCMEDM method. Based on the different water reuse applications and scenarios, different results were achieved:

3.1.1 Scenario 1: Indirect potable water reuse in a developed community

The preferred technology for IPWR in a developed community was identified using MCMEDM which generated treatment technology rankings (Figure 2). Closeness to the ideal point is the basis of the ranking system in this model. Therefore, the technology with the highest closeness score is the preferred alternative. For this scenario T7 obtained the highest closeness (0.3866), and is consequently the preferred option. It is followed by T1 and T2 with scores of 0.3698 and 0.3554 respectively. The least preferred technology is T4 with a score of 0.2807 followed by T5 with a closeness coefficient of 0.2931.

Figure 2: The MCMEDM ranking for Scenario 1

This ranking sequence represents the main concerns in this scenarios observed by the experts; in recent years, there has been growing concern that conventional wastewater treatment technologies do not typically satisfy the water quality requirements for IPWR and do not effectively remove a large number of emerging contaminants (Ternes et al. 2004). The preferred option (T7) is an MBR followed by NF/RO and disinfection. For IPWR purposes, the same technology was also suggested by Alturki et al. (2010). It would seem therefore that the main issue in IPWR is water quality and the removal of emerging contaminants. The second (T1) and third (T2) alternatives are also iMBRs, but without NF/RO treatment.

To analyse the results in detail, the technologies, showing the contribution of the different criteria, are shown in Figure 3. The dissimilarity of different coloured bars show that most preferred technologies generally perform very well under most criteria. In other words, if a technology receives a contribution from all or most criteria, it is most likely to perform well in that scenario and vice-versa.

Figure 3: Technologies showing the contribution of the different criteria for Scenario 1

1 It is crucial to mention that, although similar to the final ranking of each technology, the criteria
2 contribution (CC) bar chart is not the final ranking since the weights given to each criteria are not
3 applied. The CC bar chart therefore represents stage 3 in the schematic representation of the overall
4 methodology, illustrated in the supplementary materials. In the CC bar chart (Figure 3), T7 and T1
5 are also shown to be the preferred technologies while T4 and T5 perform the least. The preferred
6 technologies (T1, T2, T6 and T7) have a lower footprint due to the exclusion of clarifiers.
7 Moreover, the CEPT technologies (T8 and T9) are characterised by relatively higher surface
8 overflow rates (SOR) compared to CASP and therefore, clarifier sizes are usually relatively smaller.
9 Reduced footprint has the potential of lowering capital costs related to land acquisition and creating
10 the savings associated with the elimination and/or reduction of clarifiers or reactors. T1, T3, and T6
11 are however associated with relatively low treatment performance. Although they are potentially
12 upgradeable, they are to a large extent not flexible. On the other hand, T5, T7, T9 and T10 are
13 characterised by high O&M costs due to high energy consumption associated with the MF/UF and
14 NF/RO. These also have a large footprint and very high capital costs. The long chain of unit
15 processes significantly increases contaminant removal. Even with the low contribution of T7 in cost
16 related criteria (C1 and C2) and energy consumption (C3), this technology is the most preferred
17 alternative since it shows high contribution within the other criteria especially water quality (C10).

3.1.2 Scenario 2: Non potable water reuse in a water-stressed developed community

18 In this scenario, 10 technologies were again fed into the evaluation approach while using the 10
19 criteria input by the water reuse experts. As can be seen in Figure 4, T1 is the preferred technology
20 with a score of 0.4062, followed by T2 and T8 with scores of 0.3771 and 0.3627, respectively. T5 is
21 the least preferred technology with a score of 0.2330, closely followed by T10 with a score of
22 0.2378. T1 and T2 are both MBRs with disinfection units. This implies that the experts believe that
23 these technologies are good enough for landscape irrigation, restricted agricultural application, and

industrial reuse (e.g. cooling towers and washing). Similar technologies have successfully been applied in different studies (Norton-Brandao et al. 2013; Melin et al. 2006; Jefferson et al. 2001; Judd, 2011; Marrot et al. 2004).

Figure 4: The MCMEDM ranking for Scenario 2

A CC bar chart is illustrated in Figure 5 and can be interpreted in a similar way to Figure 3. T1, T2 and T8 perform well under most criteria such as impact on environment (C4), land requirement (C8), and water quality (C10). In the surveys, these criteria were considered important for this scenario and therefore were assigned high relative weights. The high score in these criteria contributed significantly to the overall preference ranking shown in Figure 4. The good performance of T1, T2 and T8 in these criteria may be attributed to the fact that these technologies comprise multiple unit processes and thus, conform to the multiple barrier approach and provide redundancy against failure in output quality. In addition, these technologies have lower footprint than T3, T4 and T5 (CASPs). It can also be implied that T1, T2, T6 and T7 have a capital cost saving benefit associated with land acquisition since MBRs exclude clarifiers.

Figure 5: Technologies showing the contribution of the different criteria for Scenario 2

Although T5, T7, T9 and T10 perform well under impact on environment (C4) and water quality and reliability (C10), they do not perform well in cost-related criteria (C1 and C2) and energy consumption (C3). T1, T2 and T8 are less energy intensive compared to their counterparts and more affordable. These three technologies are thus the preferred technologies to produce the required water quality for NPWR. As the results suggest, no technology perfectly satisfies all the criteria. Hence, trade-offs amongst the criteria are necessary (Sadr et al. 2014).

3.1.3 Scenario 3: Non potable water reuse in a water-stressed developing community

As shown in Figure 6, T3 attained the highest closeness score of 0.4373 and is therefore the preferred for NPWR in a water-stressed developing community. It is closely followed by T6 with a score of 0.4354. The least preferred technologies are T5 and T10 with closeness scores of 0.2712 and 0.2794, respectively. Figure 7 presents the technologies showing the contribution of the different criteria. T3 is a conventional activated sludge process (with anoxic and aerobic tanks) with MF/UF and disinfection unit and is the simplest of the three CASPs. The experts believed that these technologies have less operational expenditure in comparison with MBRs (T1, T2, T6, and T7).

Figure 6: The MCMEDM ranking for Scenario 3

Figure 7: Technologies showing the contribution of the different criteria for Scenario 3

From Figure 7, on average, T3, T6, and T8 outperform the other technologies in many criteria and are characterised by short treatment trains which result in lower footprint and associated savings in capital costs. Similar technologies were suggested in other studies (Norton-Brandao et al. 2013; Judd, 2011). These technologies are associated with relatively low energy consumption (C3) and consequently O&M costs (C2) because they comprise of single filtration systems. According to the experts who contributed to this scenario, T5, T7, T9 and T10 perform outstandingly under water quality and reliability (C10) but are the least preferred options in this scenario because they are more energy intensive (C7) and are associated with high capital and O&M costs (C1 and C2). T6, which is the second preferred technology, has low energy intensity but a high level of complexity. Thus, it would not be appropriate in specific conditions, e.g. where short retention times are required.

3.1.4 Scenario 4: Direct potable water reuse in a developed community

Direct potable water reuse is a futuristic scenario; it is not widely accepted even in the most developed countries (as reflected in C5). Asano et al. 2007 reports that there is a natural resistance of communities towards consuming any water that once contained human excreta, regardless of the extent of treatment and purification. Water quality (C10) is also of crucial importance in this scenario. Based on the experts' evaluation in the MCMEDM tool, T9 is the preferred technology with a closeness score of 0.3479, closely followed by T7 with a score of 0.3437 (Figure 8). On the other hand, T4 is the least preferred with a score of 0.2196, followed by T3 with a score of 0.2278. It can be observed from Figure 9 that T5, T7, T9 and T10 have the highest criteria scores. These technologies perform well, especially under the two high-weighted criteria - community acceptance (C5) and water quality (C10), and therefore should be the only ones to be considered for DPWR in developed communities. Consequently, although T1, T2, and T8 have relatively high closeness scores (Figure 8) and perform well under most criteria, they should not be considered in this scenario. In addition to the above motivations for T9 as the preferred technology, T9 is relatively less costly than the other technologies. T7, the second preferred, contains biological treatment which might not be always necessary and can sometimes be replaced by chemical treatment which seems to be more popular (du Pisani, 2006; Lahnsteiner and Lempert, 2007; Lauer and Rogers, 1996). It is important to mention that in DPWR applications, treated wastewater is often blended / diluted with fresh water sometimes due to psychological reasons (Asano et al. 2007; Bennett, 2011). It is also important to mention that the results of this scenario are generic and may vary due to peculiar circumstances in specific developed communities.

Figure 8: The MCMEDM ranking for Scenario 4

Figure 9: Technologies showing the contribution of the different criteria for Scenario 4

4 Conclusion

A fuzzy based multi-criteria multi-experts decision making (MCMEDM) method provides an approach for ranking competing wastewater treatment alternatives with respect to different criteria. Four different scenarios of wastewater treatment and reuse were proposed with respect to 10 criteria in order to select reliable options within a set of 10 membrane assisted technologies. The evaluation was mainly undertaken by different experts from academia and industry. The results showed that in scenarios considering potable water reuse applications (S1 and S4), the presence of nanofiltration or reverse osmosis is indispensable. Water quality (C10) and community acceptance (C4) were considered to be the most important criteria in these scenarios. The results of scenarios associated with non-potable water reuse (S2 and S3), showed that a minimum level of treatment is usually expected, since cost related criteria (C1 and C2) and energy consumption (C3) were weighed higher than most of the other criteria. The developed method showed the advantage of using fuzzy set theory to interpret linguistic variables during decision making. The result obtained with this method for the four scenarios coincides in general with existing case studies. Hence, the approach presented in this research can form the basis for the development of a tool that would allow the selection of best technologies in more futuristic wastewater reuse scenarios.

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List of tables:

Table 1: Linguistic variables and fuzzy sets: (a) Linguistic variables and fuzzy sets used for the ratings of technology alternatives with respect to various criteria, (b) Linguistic variables and fuzzy sets used for the evaluation of the importance of the criteria.

Table 2: Water reuse criteria employed in this study

Table 3: Water reuse membrane assisted technologies

Table 4: General information about the experts who participated in this study

Table 5: The fuzzy ratings of the technologies (T1 to T10) under all criteria (C1 to C10) by four experts (E1, E2, E3 and E4) for Scenario 1

Table 6: The fuzzy ratings of the criteria weights (C1 to C10) by four experts (E1, E2, E3 and E4) for Scenario 1

List of figures:

Figure 1: Conceptual representation of the interaction of urban water cycle for assessing various water reuse scenarios within a community.

Figure 2: The MCMEDM ranking for Scenario1

Figure 3: Technologies showing the contribution of the different criteria for Scenario 1

Figure 4: The MCMEDM ranking for Scenario 2

Figure 5: Technologies showing the contribution of the different criteria for Scenario 2

Figure 6: The MCMEDM ranking for Scenario 3

Figure 7: Technologies showing the contribution of the different criteria for Scenario 3

Figure 8: The MCMEDM ranking for Scenario 4

Figure 9: Technologies showing the contribution of the different criteria for Scenario 4

Figure 1
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Figure 2
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- T1: Primary treatment + iMBR (Aerobic treatment + MF/UF) + Disinfection
- T2: Primary treatment + iMBR (Anaerobic + Anoxic + Aerobic + MF/UF) + Disinfection
- T3: Primary treatment + CASP (Anoxic + Aerobic) + MF/UF + Disinfection
- T4: Primary treatment + CASP (Anaerobic + Anoxic + Aerobic) + MF/UF + Disinfection
- T5: Primary treatment + CASP (Anaerobic + Anoxic + Aerobic) + MF/UF + NF/RO + Disinfection
- T6: Primary treatment + Anaerobic treatment + MF/UF + Disinfection
- T7: Primary treatment + iMBR (Anoxic + Aerobic + MF/UF) + NF/RO + Disinfection
- T8: Primary treatment + Chemically enhanced primary treatment (CEPT) + MF/UF + Disinfection
- T9: Primary treatment + Chemically Enhanced Primary Treatment (CEPT) + MF/UF + NF/RO + Disinfection
- T10: Primary treatment + Coagulation/flocculation + sand filtration + MF/UF + NF/RO + Chlorination + UV

Figure 3
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T1	Primary treatment + MBR (Aerobic treatment + MF/UF) + Disinfection'
T2	Primary treatment + MBR (Anaerobic + Anoxic + Aerobic + MF/UF) + Disinfection'
T3	Primary treatment + CASP (Anoxic + Aerobic) + MF/UF + Disinfection'
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T7	Primary treatment + MBR (Anoxic + Aerobic + MF/UF) + NF/RO + Disinfection'
T8	Primary treatment + Chemically enhanced primary treatment (CEPT) + MF/UF + Disinfection'
T9	Primary treatment + Chemically Enhanced Primary Treatment (CEPT) + MF/UF + NF/RO + Disinfection'
T10	Primary treatment + Coagulation/flocculation + sand filtration + MF/UF + NF/RO + Disinfection (Chlorination +UV)

Figure 4

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T1: Primary treatment + iMBR (Aerobic treatment + MF/UF) + Disinfection

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Figure 6
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Figure 7
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T10	Primary treatment + Coagulation/flocculation + sand filtration + MF/UF + NF/RO + Disinfection (Chlorination +UV)

Figure 8
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T3	Primary treatment + CASP (Anoxic + Aerobic) + MF/UF + Disinfection'
T4	Primary treatment + CASP (Anaerobic + Anoxic + Aerobic) + MF/UF + Disinfection'
T5	Primary treatment + CASP (Anaerobic + Anoxic + Aerobic) + MF/UF + NF/RO + Disinfection'
T6	Primary treatment + Anaerobic treatment + MF/UF + Disinfection'
T7	Primary treatment + MBR (Anoxic + Aerobic + MF/UF) + NF/RO + Disinfection'
T8	Primary treatment + Chemically enhanced primary treatment (CEPT) + MF/UF + Disinfection'
T9	Primary treatment + Chemically Enhanced Primary Treatment (CEPT) + MF/UF + NF/RO + Disinfection'
T10	Primary treatment + Coagulation/flocculation + sand filtration + MF/UF + NF/RO + Disinfection (Chlorination +UV)

Table 1. Linguistic variables and fuzzy sets

	a. Linguistic variables and fuzzy sets used for the ratings of technology alternatives with respect to various criteria			b. Linguistic variables and fuzzy sets used for the evaluation of the importance of the criteria		
	Linguistic variables	Code	Fuzzy sets	Linguistic variables	Code	Fuzzy sets
1	Very poor	VP	(0, 0, 0.1)	Very low	VL	(0, 0, 0.1)
2	Poor	P	(0, 0.1, 0.3)	Low	L	(0, 0.1, 0.3)
3	Medium poor	MP	(0.1, 0.3, 0.5)	Medium low	ML	(0.1, 0.3, 0.5)
4	Medium	M	(0.3, 0.5, 0.7)	Fair	F	(0.3, 0.5, 0.7)
5	Medium good	MW	(0.5, 0.7, 0.9)	Medium high	MH	(0.5, 0.7, 0.9)
6	Good	W	(0.7, 0.9, 1.0)	High	H	(0.7, 0.9, 1.0)
7	Very good	VW	(0.9, 1.0, 1.0)	Very high	VH	(0.9, 1.0, 1.0)

Table 2: Water reuse criteria employed in this study.

Criteria		Description	References
C1	Capital cost	This criterion has a major influence on selection. Many regions around the world experience financial limitations including some cities unable to underwrite projects with high capital costs. The technologies associated with high capital costs are assigned low scores while those associated with lower capital costs are assigned high scores.	Hussain et al. (2002)
C2	Operation & maintenance Cost	This criterion takes account of costs associated with labour, materials (e.g. renewal of equipment and membrane replacement), energy, and chemicals. The technologies associated with high O&M costs are assigned low scores while those associated with lower O&M costs are assigned high scores.	Sohani, (1997); Katukiza et al. (2010); Sadr et al. (2013); Cornel and Krause (2008); Côté et al. (2008)
C3	Energy consumption	The amount of the energy required is determined by the treatment technology. The energy consumption criterion is important since it does not only have financial implications but also affects the environment. The technologies with lower amount of energy consumption will be assigned high scores, and vice versa.	Sadr et al. (2014)
C4	Impact on the environment	The production, distribution and use of reclaimed water may result in a number of environmental impacts. For instance, the use of chlorine compounds for disinfection of reclaimed water with high levels of organics has been associated with the formation of disinfection by-products (DBPs). Therefore, water reuse impact on the environment is considered a vital criterion in the selection process. A treatment technology with lower environmental impact is assigned a high score and vice-versa.	Metcalf and Eddy,(2003); Asano et al. (2007)
C5	Community acceptance	The community acceptance criterion gives an indication of a community's receptiveness to a given treatment technology. This criterion involves addressing complexities and uncertainties arising from the interests, cultural identities, ideologies, and goals of different stakeholders. It is critical that community receptiveness is well known, understood, and appreciated prior to the detailed planning of water reuse systems. A high score can be given to technologies with higher public appreciation, and a low score should be given to a technology which has not been publicly understood or respected.	Po et al., (2003); Sadr et al. (2014); Bixio et al. (2006); Ilemobade et al. (2009)
C6	Adaptability	Wastewater treatment technologies would need to be replaced/retrofitted as system equipment age and deteriorate. Ideally, adaptable technologies that are highly flexible and upgradeable should be assigned a high score as these are desirable properties. A high weight can also be given to flexibility because flexible technologies require less effort to adapt additional processes.	Sadr et al (2014); Bulter and Parkinson, (1997)*; Mace and Mata-Alvarez, (2002)
C7	Ease of construction and deployment	The ease of construction and deployment will influence whether a technology can be easily transported and installed. The technologies associated with high ease of construction and deployment are assigned high scores while those associated with lower ease of construction and deployment are assigned low scores.	Sadr et al (2014)
C8	Land requirement	The land requirements criterion provides an indication of the size of land that a treatment technology occupies. Under this criterion, scores are assigned based on the compactness of the technology. A high score is assigned to technology that requires a low land footprint and a low score is assigned to technology that requires a higher footprint.	Singhirunnusorn and Stenstrom, (2010); Friedler and Pisanty, (2006)
C9	Level of complexity	Baccarini (1996) defined this criterion as “ <i>consisting of many varied interrelated parts that can be operationalized in terms of differentiation and interdependency</i> ”. The level of complexity gives an indication of the level of expertise required for O&M of the treatment technology. Effort required for O&M tends to vary among technologies. Less complex technologies are assigned higher scores and vice versa.	Baccarini (1996)
C10	Water quality and reliability	Metcalf and Eddy (2003) explained reliability to be the probability of a treatment technology meeting specified effluent quality requirements at any time or over extended periods of time despite varying flow rates and influent water quality. In this study, wastewater treatment technology that is known to sustainably produce exceptional water quality and reliability is assigned a high score and vice-versa.	Metcalf and Eddy (2003) Sadr et al (2014)

* Butler, D., Parkinson, J., Towards sustainable urban drainage. *Water Sci. Technol.* 1997, 35(9), 53-63. doi: [http://dx.doi.org/10.1016/S0273-1223\(97\)00184-4](http://dx.doi.org/10.1016/S0273-1223(97)00184-4)

Table 3: Water reuse membrane assisted technologies

Code	Configuration	A	B
T1	Primary treatment + iMBR (Aerobic treatment + MF/UF) + Disinfection		
T2	Primary treatment + iMBR (Anaerobic + Anoxic + Aerobic + MF/UF) + Disinfection		
T3	Primary treatment + CASP (Anoxic + Aerobic) + MF/UF + Disinfection		
T4	Primary treatment + CASP (Anaerobic + Anoxic + Aerobic) + MF/UF + Disinfection		
T5	Primary treatment + CASP (Anaerobic + Anoxic + Aerobic) + MF/UF + NF/RO + Disinfection		
T6	Primary treatment + Anaerobic treatment + MF/UF + Disinfection		
T7	Primary treatment + iMBR (Anoxic + Aerobic + MF/UF) + NF/RO + Disinfection		
T8	Primary treatment + Chemically enhanced primary treatment (CEPT) + MF/UF + Disinfection		
T9	Primary treatment + Chemically Enhanced Primary Treatment (CEPT) + MF/UF + NF/RO + Disinfection		
T10	Primary treatment + Coagulation/flocculation + sand filtration + MF/UF + NF/RO + Disinfection (Chlorination +UV)		
A: indicates that the highlighted technology satisfies the water quality requirements for <u>only</u> non-potable water reuse applications.			
B: shows that the selected technology meets the quality threshold requirements for <u>both</u> nonpotable and potable water reuse applications			

Table 4: General information about the experts who participated in this study

S/No	Geographical location of experts	Profession (s)	Scenario
1	Australia	Advanced water treatment technologies; wastewater treatment solutions	3
2	Australia	MBR Process Optimization; Advanced Water and Wastewater Treatment; Membrane technologies	2
3	Belgium	Geologist; water and wastewater treatment	1
4	Belgium	MBR technology; wastewater treatment	3
5	Denmark	Water treatment; Mechanical and Industrial Engineering	1
6	Denmark	Renewables & Environment; membrane technologies	4
7	France	Water and wastewater treatment technologies	4
8	Germany	Project manager in wastewater treatment; membrane technologies	2
9	Iran	Membrane technologies; technology selection	2
10	Iran	Process engineering; demineralized water production systems; desalination	3
11	Iran	Process Engineering; membrane technologies; demineralized water production systems	4
12	Italy	MBR technology; environmental engineering	3
13	Netherlands	Process engineering and researcher specialised in water treatment and distribution	1
14	Netherlands	Membrane technologies; wastewater treatment and desalination	3
15	Norway	Water quality; water recourse management	1
16	Saudi Arabia	Lead R&D engineer; Desalination and water reuse	1
17	South Africa	Water quality; wastewater treatment	3
18	Spain	R&D Project Engineer; Membrane technologies	2
19	United Kingdom	Process Engineering; desalination; membrane technologies	4
20	United States	Advanced water treatment technologies; wastewater treatment solutions	3

Table 5
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Table 5: The fuzzy ratings of the technologies (T1 to T10) under all criteria (C1 to C10) by four experts (E1, E2, E3 and E4) for Scenario 1

	C1				C2				C3				C4				C5			
	E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4
T1	F	F	ML	MH	F	L	F	F	MH	L	F	F	MH	F	F	VH	L	L	L	L
T2	ML	L	L	F	F	L	ML	ML	MH	L	ML	ML	H	F	F	VH	ML	ML	ML	ML
T3	ML	F	ML	MH	ML	F	F	MH	F	H	F	MH	MH	F	F	MH	VL	VL	L	VL
T4	L	F	L	ML	L	L	ML	ML	ML	L	ML	ML	MH	F	F	MH	L	L	ML	ML
T5	VL	F	VL	VL	VL	L	L	ML	L	L	L	L	MH	F	F	MH	MH	MH	H	H
T6	L	VH	ML	MH	ML	F	F	MH	ML	F	F	H	MH	F	F	H	VL	VL	L	VL
T7	L	VH	VL	L	VL	F	L	L	L	F	L	VL	H	F	F	VH	VH	VH	H	VH
T8	F	F	ML	MH	ML	L	F	MH	ML	F	F	F	F	F	ML	F	ML	H	L	L
T9	L	L	VL	L	L	L	L	L	VL	L	L	L	F	F	ML	F	MH	H	H	MH
T10	ML	L	VL	VL	VL	F	VL	L	VL	L	VL	VL	MH	F	ML	MH	H	VH	VH	H
	C6				C7				C8				C9				C10			
	E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4
T1	MH	F	MH	MH	F	F	MH	F	F	VH	F	H	ML	F	F	MH	ML	VL	VL	VL
T2	MH	F	L	MH	MH	F	L	MH	F	VH	ML	MH	L	F	ML	F	F	ML	ML	ML
T3	ML	F	MH	ML	H	F	F	H	F	VH	VH	MH	L	F	MH	H	L	VL	VL	VL
T4	ML	F	L	ML	H	F	L	MH	F	VH	ML	L	L	L	ML	F	ML	ML	L	L
T5	ML	F	VL	ML	H	F	L	F	F	VH	L	VL	VL	VL	L	ML	MH	VH	H	H
T6	ML	VH	MH	MH	H	H	F	H	F	VH	VH	MH	L	H	MH	MH	ML	VL	VL	VL
T7	H	MH	F	H	F	H	ML	F	ML	VH	F	F	MH	ML	ML	F	VH	VH	H	VH
T8	H	F	H	MH	F	VH	H	F	ML	VH	H	MH	H	ML	H	MH	F	ML	L	L
T9	H	F	ML	MH	F	VH	L	F	L	VH	ML	F	MH	VL	ML	F	VH	H	H	H
T10	H	VH	VL	MH	F	VH	VL	ML	L	VH	VL	F	MH	VL	VL	ML	VH	H	VH	VH

Table 6: The fuzzy ratings of the criteria weights (C1 to C10) by four experts (E1, E2, E3 and E4) for Scenario 1

	S1			
	E1	E2	E3	E4
C1	F	H	MH	F
C2	H	VH	H	MH
C3	H	VH	H	MH
C4	H	F	MH	VH
C5	MH	F	VH	MH
C6	F	F	F	ML
C7	L	H	ML	L
C8	MH	VL	F	F
C9	F	H	F	ML
C10	VH	VH	VH	VH

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