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Research Article

Multi-Criteria Decision-Making Analysis for the Selection of Desalination Technologies

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Abstract

Accessible fresh water resources for drinking and usage are very limited in our world. Furthermore, these limited fresh water resources are gradually decreasing due to climate change, industrialization, and population growth. Despite the ever-increasing need for water, the inadequacies in our resources have made it critical to develop alternative drinking and utility water production methods. Desalination, one of the most important alternatives for fresh water supply, is on the rise on a global scale. Desalination facilities use various thermal and membrane techniques to separate water and salt. Concentrated brine, which contains desalination chemicals and significant amounts of salt, and is formed in high volumes from desalination processes, is also a concern. This article compares various desalination techniques using a multi-criteria decision-making method. The findings show that the Reverse Osmosis & Membrane Crystallization process is the most preferred technology due to its cost advantages as well as operational efficiency. Similarly, Multistage flash &Electrodialysis, the least preferred alternative, has been criticized for its low cost-effectiveness. These results suggest that cost and operational efficiency will continue to be the main drivers in the evaluation of desalination technologies in the near future.

Keywords: Multi-Criteria Decision-Making, Oceanography, Desalination, TOPSIS, PROMETHEE

Introduction

According to common estimates, only 1% of freshwater worldwide is easily accessible. As a result, when the growing global population is taken into consideration, the conservation of these water supplies becomes an increasingly critical issue. There are several alternatives to conventional water supply systems, yet the availability of clean drinking water remains a global issue. According to Savun-Hekimoğlu et al. (2021), alternatives include desalination, irrigation with recycled water, water transfer from regions with sufficient water to regions with a shortage, and rainwater harvesting. Demand for freshwater has increased as a result of increasing population and climate change, and as a result, the seawater desalination sector has experienced exponential growth, with an ongoing rise in the number of reverse osmosis-based plants. (Grossowicz, et al., 2020). Desalination, which involves utilizing available seawater resources, stands out among these and other recently developed alternatives. More than 16,000 desalination facilities are in use worldwide, and practically all are located in high-income nations. Today, it is seen that there is a rise in the generation of fresh water from seawater, particularly in Middle Eastern nations with arid regions. Although it may be an energy-expensive solution, desalination is even considered for the restoration of ancient freshwater resources by Middle Eastern countries. In a 2022 climate treaty between Jordan, Israel, and the United Arab Emirates, countries agreed upon the installation of 600-Megawatt capacity solar power plants in the desert and use the generated clean electricity to pump desalinated seawater to the Sea of Galilee and Jordan River (Friedman, 2022). These two bodies of freshwater, which are used to be the main source of life and irrigation in the region, are facing the threat of severe water loss and drying (Burak et al., 2004; Wine et al., 2019).

Seawater is inappropriate for use in industry, agriculture, or human consumption (Ohya et al., 2001). By removing salt from the nearly infinite supply of seawater, desalination has emerged as a substantial source of fresh water (Khawaji et al., 2008). A growing number of countries depend on desalination technology to provide their fresh water demands. Around 20 000 desalination facilities of various capacities can produce 86.55 million cubic meters of potable water each day by the year 2020. Using energy, desalination operations convert seawater to fresh water. These procedures' costs and viability generally depend on the cost of energy. Desalination plants produce hazardous sludge with high salt content in addition to fresh water. Therefore, the management of this byproduct, known as brine, should be taken into account while designing the desalination plant. Socio-economic and ecological impact of desalination is revealed in a causal loop diagram in Figure 1.

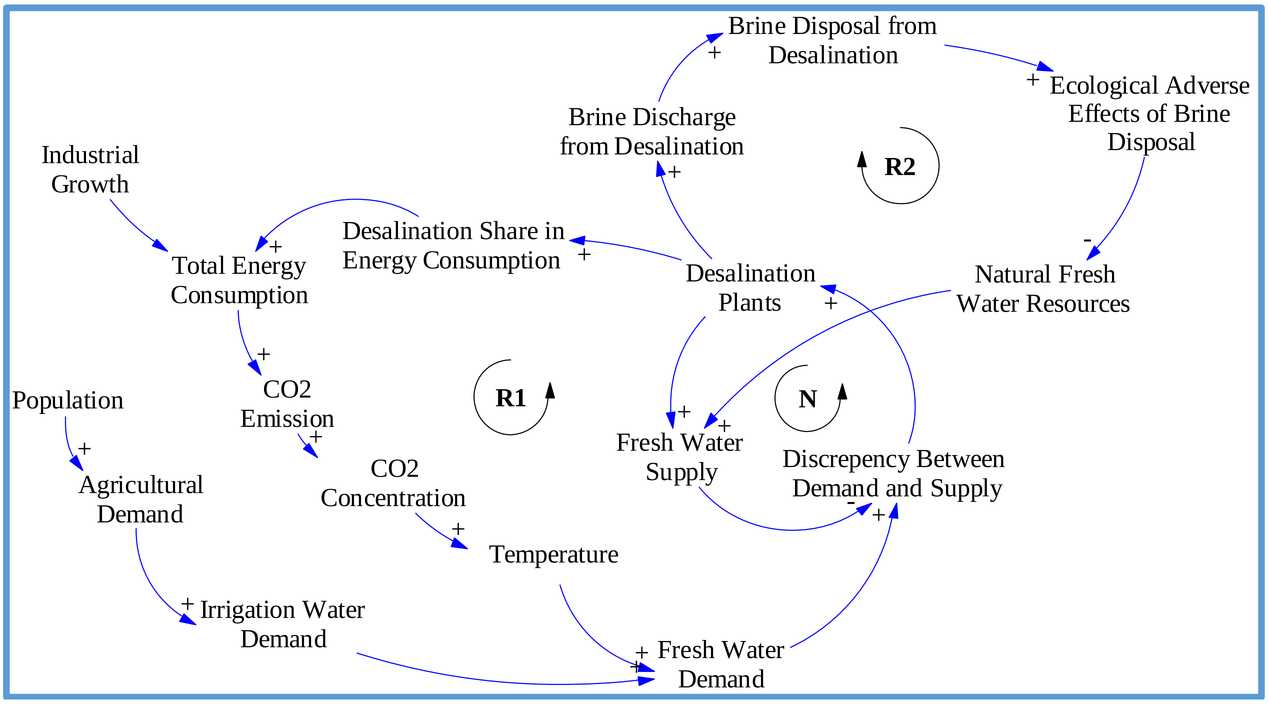

Fig. 1. A simple causal loop diagram for desalination technology

As an energy-consuming solution to water scarcity problem, desalination triggers two respective positive feedback loops that increases global need for desalination technology over time. First positive feedback loop (R1) works through energy consumption of desalination and its share in national and global energy consumption. Increased energy consumption stimulates CO_2 emissions and temperature due to greenhouse effect. Increased climate temperature lead fresh water demand of people (and agriculture) to surge which increases need for desalination plants. The second positive feedback loop (R2) goes through brine disposal of desalination plants. Effluent brine creates pressure on natural fresh water resources and this pressure increases need for desalination technology. These two powerful positive feedback loops are only balanced with a single negative feedback loop (N) of desalination plants' water supply. As N1 is not powerful enough to balance R1 and R2, desalination is considered to be a controversial solution to water scarcity problem.

In general, each desalination technology has a different set of pros and cons. Before making an investment decision, decision-makers need to evaluate all alternatives with respect to a set of qualitative and quantitative criteria. For instance, the investment and operational costs of desalination plants and the amount of effluent salt per unit volume of water are quantitative criteria that can effectively be measured. The price of manufacturing 1 cubic meter of purified water ranges from 50 to 100 cents, though it differs based on technological advancement and investment cost structure (Papaetrou et al., 2017). However, qualitative factors, e.g. public acceptance or environmental friendliness, are usually hard to measure. Therefore, choosing the right desalination technology requires the utilization of Multi-Criteria Decision Making (MCDM) methods that can incorporate qualitative and quantitative methods into the decision-making process effectively.

In this paper, we considered seven different evaluation criteria to evaluate desalination alternatives with two MCDM methods. Our results indicate that RO & Membrane Crystallization process dominates the other alternative desalination technologies due to its lower (investment and operational) costs and high efficiency. Similarly, high-cost rates lead the ion exchange process to the least favorable option for desalination plants. These results indicate that the cost rates and operational efficiency are the main drivers for the selection of desalination technologies which stands for one of the main contributions of our study. In addition, our work contributes to the literature with the joint usage of Fuzzy TOPSIS and Fuzzy PROMETHEE methods for the desalination technology selection.

This paper consists of five sections. The second section briefly reviews the relevant literature. Section 3 considers viable desalination options as well as decision criteria for the investment problem. Section 4 presents resulting rankings from the two MCDM methods whereas Section 5 concludes the paper.

Literature Review

In many environmental problems, MCDM is a common decision-support system as environmental problems require the evaluation of multiple alternatives with respect to a set of criteria in qualitative and quantitative scales. Some exemplary ecological problems that are approached with MCDM are reservoir management and water allocation (Zamani et al., 2020; Mahmoud and Garcia, 2000; Srdjevic et al., 2004; Flug et al., 2000), wastewater treatment (Kholghi, 2001; Piadeh et al., 2018a; Khalil et al., 2005), urban water management (Joubert et al., 2003; Zarghami et al., 2008; De Marchi et al., 2000; Savun-Hekimoğlu et al., 2021), urban landfill management (Sharma et al., 2020; Shah et al., 2021; Coban et al., 2018), groundwater management (Pietersen, 2006; Okello et al., 2015), river bank management and flood control (Ebrahimian et al., 2019; Wu et al., 2019; Shariat et al., 2019), and design and control of irrigation systems (Karleuša et al., 2019; Gonçalves et al., 2020; Tiwari et al., 1999).

From the methodological perspective, MCDM studies focusing on environmental problems utilize Multi Attribute Utility Theory (MAUT) (Schuwirth et al., 2012; Monte and de Almeida-Filho, 2016; Zheng et al., 2016), compromise programming (Chang et al., 1995; Shiau and Lee, 2005; Fattahi and Fayyaz, 2010; Tzeng et al., 1991), Analytical Hierarchy Procedure (AHP) (Salas and Yepes, 2018; Zyoud et al., 2016; Ramanathan, 2001; Sharifipour and Mahmodi, 2012; Freitas and Magrini, 2013; Piadeh et al., 2018b), PROMETHEE and TOPSIS. TOPSIS is a popular method that takes each alternatives' distance to the best and worst alternatives into account respectively (Savun-Hekimoğlu et al., 2021; Noureddine and Ristic, 2019). It is appropriate for environmental problems including criteria that are not necessarily mutually exclusive (Blanco-Mesa et al., 2017). In our study, we modified TOPSIS with fuzzification to be able incorporate randomness in expert judgements.

PROMETHEE is another popular method that ranks alternatives based on a criteria set. Environmental applications of the method, such as waste management, life cycle assessment (Hermoso-Orzáez et al., 2019), and water management (Savun-Hekimoğlu et al., 2021) are well known in the literature. Furthermore, Raju et al. (2000) consider PROMETHEE to compare various irrigation technologies in the agricultural production. Behzadian et al. (2010) review the environmental publications on PROMETHEE, which we extended with fuzzification addressing variability in expert judgements.

A review of the existing body of knowledge shows that some research has been done on water purification and desalination using MCDM in recent years (Anqi and Mohammed, 2021). Chamblas and Pradenas investigated the selection of the most suitable seawater desalination technology using three MCDM techniques and TOPSIS. Al Araidah et al. (2020) investigated the most important factors for choosing a reverse osmosis membrane using Fuzzy-AHP. Talaeipour et al. (2018) compared a hybrid process of nanofiltration, reverse osmosis and both to desalinate groundwater using AHP. Hajeeh and Al-Othman (2005) addressed four desalination plants using a two-stage AHP process and determined the most suitable desalination technology based on 7 selected criteria. Hajeeh (2010) has developed a hierarchy model based on fuzzy set theory taking into account 6 factors and 3 technologies for the selection of desalination technology (Hajeeh, 2010; Ghassemi and Danesh, 2013). Huang (2022) consider a decision-making framework for renewable-powered desalination plants using a hybrid methodology consisting of four different multi-criteria decision-making methods. They evaluated nine different desalination technologies using nine evaluation criteria. Dweiri et al. (2018) utilize AHP for the location selection problem for a desalination plant. In their work, 5 main criteria and 40 respective sub-criteria are considered for selecting a location for a desalination plant. Location of a desalination plant is also considered by Badi et al. (2018) using a combination of AHP and Combinative Distance-based Assessment (CODAS) method. They applied this method to a desalination plant in Libya.

The findings obtained when the word "desalination" is searched using the web of science database shows that the studies on this subject have increased considerably over the years (Figure 2).

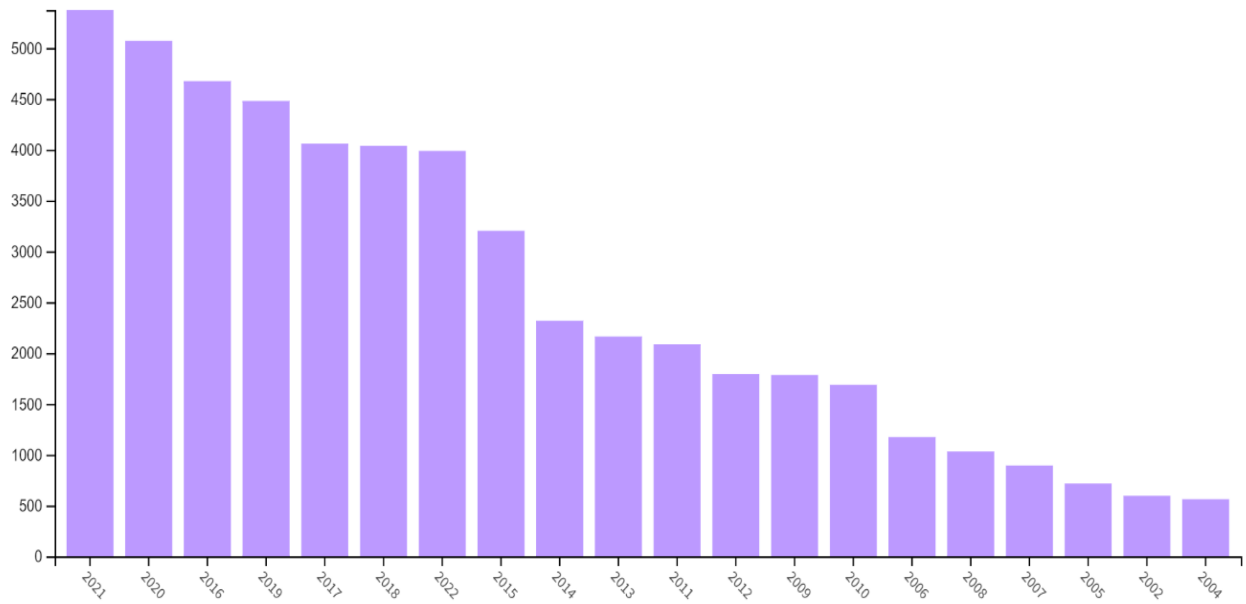

Fig. 2. The number of studies over the years obtained when the word "desalination" is searched using the web of science database (Barchart derived from Clarivate *Web of Science*, Copyright Clarivate 2022. All rights reserved).

3. Model

The MCDM methodology consists of multiple phases shown in Figure 3: development of alternatives and criteria, data collection, data processing and interpretation of results. This section presents a detailed description of each stage in the relevant subsections.

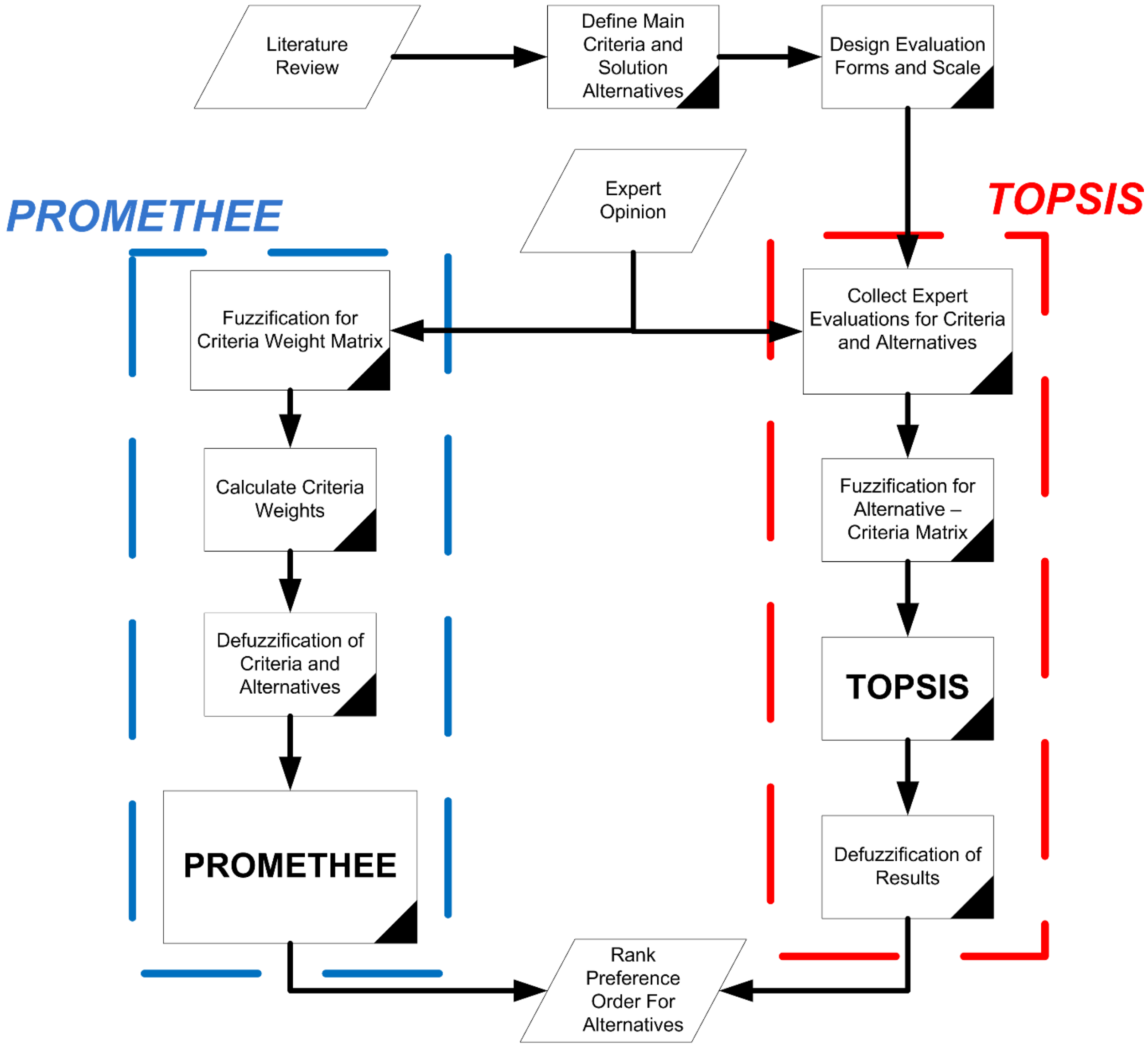

Fig. 3. Flowchart of the study.

Development of Alternatives

Although there are numerous technologies on desalination and new technologies are being developed, the three main methods are membrane, thermal and chemical processes. In desalination with membrane technologies, salt and water are physically separated from each other by using various semi-permeable membranes. In thermal technologies, water is evaporated and then condensed, leaving only salt. Chemical technologies, on the other hand, separate salt from water using various chemicals. Some common desalination technologies are briefly described below.

Multi-stage flash (MSF) is a thermal process based on the principle of shock evaporation (Bulut, 2021; Khawaji et al., 2008). They are processes consisting of many stages at low pressure, where the temperature drops by 2°C at each stage (Kalogirou, 2005). Although the performance of MSF plants is not very high and the total desalination capacity is 40-45% and requires pressure, it is the most widely used process worldwide due to its advantages such as easy operation (Bulut, 2021; Compain, 2012). This process is especially widely used in the Middle East and accounts for 34% of worldwide seawater desalination (Bulut, 2021; He and Yan, 2009; El-Ghonemy, 2018). The electrodialysis system is used not only for desalination but also for the recovery of the desired substances from wastewater (Sadrzadeh and Mohammadi, 2008). It is also a method used to obtain high purity salt (Sadrzadeh and Mohammadi, 2009). In the electrodialysis process, the electrical potential difference between the electrodes immersed in the solution and the ions in seawater is used (Bulut, 2021; Kalogirou, 2009). The cations in the brine feed water are directed towards the negative electrode and the anions towards the positive electrode and are retained in the ion exchange membranes (Bulut, 2021; Kalogirou, 2009). Nanofiltration (NF) is a membrane process that works with pressure to separate particles according to their size and electrostatic interactions (Faridirad et al., 2014; Bulut, 2021). Although the most known disadvantage of the process is membrane contamination, which leads to the shortening of the membrane life, it stands out among other membrane processes due to its high separation ability and lower pressure requirement compared to the reverse osmosis process (Faridirad et al., 2014; Bulut, 2021). Membrane crystallization can be expressed as the percolation of a solution with a crystallizable and non-volatile solute through a porous membrane. A temperature differential between the two membrane surfaces typically acts as the driving force (Koyuncu, 2018). Since the membrane is hydrophobic, liquid cannot enter the pores. Only volatile substances, then, pass through the membrane and condense at the permeate area (Quist-Jensen et al., 2016).

The reverse osmosis (RO) membrane system is based on the separation of water from the saline solution and obtaining fresh water by exceeding the applied osmotic pressure (Compain, 2012; Kalogirou, 2005). RO systems have many advantages, which can be listed as being easy to operate, high separation efficiency, low energy consumption (Kalogirou, 2005; Bulut, 2021). This process does not require heating but does require pressure (Compain, 2012; Bulut, 2021). In addition, pre-treatment is required to prevent membrane clogging (Kalogirou, 2005). Ion exchange is an extremely effective chemical procedure for desalination. The displacement of ions with the same charge from the liquid phase to the solid phase is the basic mechanism used in this technique (Bulut, 2021). Using a strong acid cation exchanger to turn the salt into acid and a weak anion exchanger to absorb the weak acid to remove it are the two steps in the ion exchange desalination process (Dube and Tzoneva, 2007). The mechanical vapor compression (MVC) process uses mechanical compression and thermal compression to generate heat for evaporation and then to condense water vapor (Aly and El-Fiqi, 2003; Ahmed et al., 2019; Bulut, 2021). Mechanical vapor compression systems use a mechanical compressor that uses electricity to compress the vapor, while thermal vapor compression systems use a steam injection compressor (Bulut, 2021; Compain, 2012). Kim (2011), which uses the same set of alternatives with us, reviewed some of the processes that can produce both potable quality water and salable salt. Therefore, the comparative cost evaluation of our alternatives can be found in Kim (2011). These processes, most of which are hybrid processes, were chosen as alternatives in this study. Expert academics and private sector employees evaluated the alternatives according to the various criteria shown in Table 1. Figure 3 shows the overview of the study.

Table 1. Development of Alternatives and Criteria

Alternatives	Criteria
A1: Multistage flash (MSF) and Electrodialysis (ED)	• **C1**: Initial investment cost
A2: Nanofiltration (NF) and Membrane Crystallization (MCr)	• **C2**: Operation and Maintenance Cost
A3: Reverse osmosis (RO) and Ion Exchange (IE)	• **C3**: Efficiency (The proportion of the fresh water generation to the seawater consumption)
A4: Mechanical vapor compression (MVC) and Electrodialysis (ED)	• **C4**: Land Requirement
A5: Reverse osmosis (RO) and Membrane Crystallization (MCr)	• **C5**: Carbon dioxide emissions generated
	• **C6**: Acceptation by the public/end users
	• **C7**: Salt Recovery Potential

Calculation of Criteria Weights

After the development of criteria and solution alternatives, we collect evaluations of experts from academia, public, and private sectors. In the data collection phase, we asked experts to judge the relative importance of criteria and alternatives by selecting from the following set linguistic rating set.

$$LR = (very\ high\ , high, medium\ high, medium, medium\ low, low, very\ low).$$

Criteria weights are calculated with the F-TOPSIS method. Fuzzification is used to obtain the parameters of the triangular distribution, which is utilized to obtain criteria weights and alternatives' score of importance in both MCDM methods. For criteria weight calculation, we utilize FUCOM method, which is recognized to be better than BWM and AHP (Mukhametzyanov and Pamucar, 2018). Our method is a modified version of the FUCOM method as it requires less amount of data. This method has been suggested by Savun-Hekimoğlu et al. (2021) for evaluation of criteria weights for the first time. In the rest of the section, we present summaries of F-TOPSIS and F-PROMETHEE methods for alternative scoring. A detailed mathematical exposition of our methodology is presented in Appendix D of Savun-Hekimoğlu et al. (2021).

Fuzzy TOPSIS

F-TOPSIS method begins with the enumeration of linguistic ratings and the estimation of the parameters of the triangular distribution (Chen et al., 2006). The parameters of the triangular distribution are extended to ratings for each criterion in Table 2. Similarly, evaluation data from experts for alternatives are mapped onto the integers given in Table 2. Also, the normalization of weighted average of the parameters is conducted. Using the normalized parameters values, the best and the worst ideal solutions are obtained for each criterion. These ideal solutions are utilized to calculate the closeness coefficient of each alternative leading to preference score.

Table 2. Linguistic Evaluation Scale for Criteria and Alternatives (Cinar and Ahiska, 2010)

Linguistic Rating	Criteria n_1	Criteria n_2	Criteria n_3	Alternatives n_1	Alternatives n_2	Alternatives n_3
Very Good (VG)	0.80	1.00	1.00	8	10	10
Good (G)	0.70	0.80	0.90	7	8	9
Medium Good (MG)	0.50	0.65	0.80	5	6.5	8
Medium (M)	0.40	0.50	0.60	4	5	6
Medium Low (ML)	0.20	0.35	0.50	2	3.5	5
Low (L)	0.10	0.20	0.30	1	2	3
Very Low (VL)	0.00	0.00	0.20	0	0	2

Fuzzy PROMETHEE

F-PROMETHEE begins with the expected value of the triangular distribution for the evaluation of each expert. It proceeds with the preference score of each alternative pair based on each criterion. In this calculation, Gaussian preference function is utilized to map differences of alternatives onto [0,1] interval (Behzadian et al., 2010; Dagdeviren, 2008). Next, we obtain a global preference index using weighted averages. In the last two phases of F-PROMETHEE, we obtain ranking flows (Dagdeviren, 2008, Eq.8). The net outranking flow, denoted by ϕ, is calculated using the difference between positive and negative ranking flows, that are denoted with ϕ^+ and ϕ^- in Table 5. In the following section, we present our results of F-PROMETHEE and F-TOPSIS methods for the desalination technology selection problem.

Results

In our analyses, we calculated the importance index of each criteria using AHP method. According to our numerical results given in Table 3, the two most important criteria are initial investment cost (C1) and efficiency (C3). These results are consistent with the current distribution of the desalination technology. Desalination requires significantly higher investment cost compared to other supply alternatives. Furthermore, almost all desalination technologies consume energy to remove sea salt from water which rises costs of those facilities for the economies. The least important evaluation criterion is found to be public acceptance (C6 in Table 3). This is probably becuase desalination facilities are installed to coastal regions and seawater is an endless water source in public perception.

Table 3. Criteria Weights from AHP Method.

Criteria	Code	Lower Bound	Median	Upper Bound
Initial investment cost	**C1**	0.70	0.87	1.00
Operation and Maintenance Cost	**C2**	0.40	0.60	0.80
Efficiency (The proportion of the freshwater generation to the seawater consumption)	**C3**	0.70	0.93	1.00
Land Requirement	**C4**	0.20	0.55	0.90
Carbon dioxide emissions generated	**C5**	0.20	0.50	0.80
Acceptation by the public/end users	**C6**	0.10	0.35	0.60
Salt Recovery Potential	**C7**	0.20	0.55	0.90

Table 4. Average Alternative and Criteria Weights for PROMETHEE Method

Alternatives	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**
Criteria Weights	**0.856**	**0.600**	**0.878**	**0.550**	**0.500**	**0.350**	**0.550**
A1	1.556	1.111	8.889	1.611	3.556	8.444	8.889
A2	1.556	2.556	8.444	3.000	4.556	7.944	7.944
A3	2.056	2.056	6.500	5.000	4.500	6.500	6.500
A4	1.556	1.111	9.333	3.556	5.000	8.444	7.889
A5	4.000	3.000	6.500	4.000	4.500	7.000	7.000
std deviation	*1.060*	*0.849*	*1.346*	*1.255*	*0.528*	*0.879*	*0.925*

Table 5. Alternative Rankings from PROMETHEE

Alternatives	Q+	Q-	Q	Description
A5	1.426	0.990	0.436	RO& Membrane Crystallization
A4	1.106	0.679	0.427	MVC & ED
A2	0.962	0.564	0.399	NF and Membrane Crystallization
A1	0.887	1.388	-0.501	MSF & ED
A3	0.642	1.404	-0.761	RO & Ion Exchange

Using calculated criteria and alternative weights in Table 4, we obtain positive and negative ranking flows (Q+ and Q- in Table 5) using Fuzzy-PROMETHEE method. The differences between positive and negative flows of each alternative is used as the ranking metric in Table 5. According to PROMETHEE calculations, we find RO&

Membrane Crystallization process is the most preferred desalination alternative whereas RO & Ion Exchange is the least preferred one. Good score of RO& Membrane Crystallization process is mainly due to its high evaluations of experts for investment cost and efficiency that can be observed from Table 3. Similarly, we also find that the low ranking of RO and Ion exchange process is attributed to its cost inefficiency.

To compare and vlidate our results from PROMETHEE, we also apply a combination of AHP and TOPSIS methods for the desalinatiion technology selection problem. For the weights of evaluation criteria, we applied Analytical Hierarchy Process (AHP) to calculate weights. For each criteria, we obtain data and calculated lower bound, median and upper bounds of ratings in Table 3. Median values are used as the criteria weights in the TOPSIS method.

TOPSIS utilizes the distance of each alternative to the hypothetical best possible and worst possible alternatives. The distance difference to the best and worst possible alternatives are considered as the alternative score in Table 6. In this part of the study, the results indicate that RO & Membrane Crystallization process is the most desired alternative whereas MSF &ED are least desirable one.

Conclusion

Water scarcity is a pressing issue for all nations of our World and desalination is projected to be an important part of the solution. Especially in arid regions, energy-expensive desalination plants are powered with solar panels to alleviate the severity of climate change's socio-economic impacts and reverse negative environmental feedbacks that further exacerbate water scarcity.

To make an investment for such an unconventional technology, policymakers need to consider different factors and compare various alternatives with respect to a wide range of criteria set. These decision-making criteria might be in qualitative or quantitative form and might conflict with each other. Multicriteria decision making models are suggested to deal with such decision problems as they allow analysts to take all relevant factors into account in the same model.

In this study, we consider two different MCDM models to rank different desalination technologies. Specifically, five different technology alternatives, Reverse Osmosis&Membrane Crystallization, Nanofiltration&Membrane Crystallization, Mechanical vapor compression & Electrodialysis, Reverse Osmosis&Ion Exchange and Multistage flash & Electrodialysis, are evaluated with respect to seven distinct decision criteria, including investment and operational costs, public acceptance, efficiency, salt recovery, and CO_2 emission rate. The results indicate that RO& Membrane Crystallization process is considered the most promising desalination technology mainly due to its low investment, operational costs, and high efficiency. This result also indicates the importance of future technological developments that may lead to efficiency gains and cost reductions of the desalination technology for its sustained and widespread usage to battle the effects of climate change.

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References

Abrishamchi, A., Ebrahimian, A., Tajrishi, M., Mariño, M.A. (2005). Case study: application of multicriteria decision making to urban water supply. *J. water Resour. Plan. Manag.* 131, 326–335.

Ahmed, F. E., Hashaikeh, R., Hilal, N. (2019). Solar powered desalination- technology, energy and future Outlook. *Desalination* 453: 54-76.

Al-Araidah, O., Hayajneh, M.T., Al-Rwabdah, R.A. (2020). Desalination membrane selection using group fuzzy analytical hierarchy process. *Desalin. WATER Treat*. 2020, 174, 79–89.

Aly, N. H., El-Fiqi, A. K. (2003). Thermal performance of seawater desalination systems. *Desalination* 158: 127-142.

Anqi, A. E., Mohammed, A. A. (2021). Evaluating Critical Influencing Factors of Desalination by Membrane Distillation Process—Using Multi-Criteria Decision-Making. *Membranes*, 11(3), 164.

Badi, I., Ballem, M., Shetwan, A. (2018). Site selection of desalination plant in libya by using combinative distance-based assessment (codas) method. *International Journal for Quality Research,* 12(3).

Behzadian, M., Kazemzadeh, R. B., Albadvi, A., Aghdasi, M. (2010). PROMETHEE: A comprehensive literature review on methodologies and applications. *European Journal of Operational Research*, 200 (1), 198-215.

Benitez, J., Delgado-Galván, X., Izquierdo, J., Pérez-Garcia, R. (2011). Achieving matrix consistency in AHP through linearization. *Appl. Math. Model.* 35, 4449–4457.

Bulut, Ayben Polat. (2021). "Artan Su İhtiyaci İçin Deniz Suyu Kullanimi Ve Aritma Teknolojileri." *Türk Bilimsel Derlemeler Dergisi* 14, no. 2: 124-137.

Burak, S., Doğan, E., Gazioğlu, C. (2004). Impact of urbanization and tourism on coastal environment. *Ocean Coast. Manag.* 47, 515–527.

Cabrera Jr, E., Cobacho, R., Estruch, V., Aznar, J. (2011). Analytical hierarchical process (AHP) as a decision support tool in water resources management. *J. Water Supply Res. Technol.* 60, 343–351.

Chamblás, O., Pradeñas, L.(2018). Multi-criteria optimization for seawater desalination. *Tecnol. y Ciencias del Agua*, 9, 198–213.

Chang, N. B., Wen, C. G., Wu, S. L. (1995). Optimal management of environmental and land resources in a reservoir watershed by multiobjective programming. *Journal of environmental management*, 44(2), 144-161.

Chen, C.-T., Lin, C.-T., Huang, S.-F. (2006). A fuzzy approach for supplier evaluation and selection in supply chain management. *Int. J. Prod. Econ*. 102, 289–301.

Cinar, N., Ahiska, S.S. (2010). A decision support model for bank branch location selection. *Int. J. Hum. Soc. Sci.* 5, 846–851.

Clarivate Analytics. (2022). Web of Science databases. Retrieved November, 2022, from https://clarivate.com/products/web-of science/databases/

Compain, P. (2012). Solar energy for water desalination. *Procedia Engineering* 46: 220-22.

Dağdeviren, M. (2008). Decision making in equipment selection: an integrated approach with AHP and PROMETHEE. *Journal of intelligent manufacturing*, 19(4), 397-406.

De Marchi, B., Funtowicz, S.O., Cascio, S. Lo, Munda, G. (2000). Combining participative and institutional approaches with multicriteria evaluation. An empirical study for water issues in Troina, Sicily. *Ecol. Econ*. 34, 267–282.

Dube, N. M., Tzoneva, R. (2007). Optimal closed-loop controller design for an ion exchange process used for desalination of water," *IFAC Proceedings Volumes*, 40: 970-975.

Dweiri, F., Khan, S. A., Almulla, A. (2018). A multi-criteria decision support system to rank sustainable desalination plant location criteria. *Desalination*, 444, 26-34.

Ebrahimian, A., Wadzuk, B., Traver, R. (2019). Evapotranspiration in green stormwater infrastructure systems. *Science of the total environment*, 688, 797-810.

El-Ghonemy, A. M. K. (2018). Performance test of a sea water multi-stagef lash distillation plant: Case study. *Alexandria Engineering Journal*, 57: 2401-2413.

Faridirad, F., Zourmand, Z., Kasiri, N., Moghaddam, M. K., Mohammadi, T. (2014). Modeling of suspension fouling in nanofiltration. *Desalination*, 346: 80-90.

Fattahi, P., Fayyaz, S. (2010). A compromise programming model to integrated urban water management. *Water Resour. Manag*. 24, 1211–1227.

Flug, M., Seitz, H.L.H., Scott, J.F. (2000). Multicriteria decision analysis applied to Glen Canyon Dam. *J. Water Resour. Plan. Manag*. 126, 270–276.

Freitas, A.H.A., Magrini, A. (2013). Multi-criteria decision-making to support sustainable water management in a mining complex in Brazil. *J. Clean. Prod*. 47, 118–128.

Friedman, T. (2022) Climate Change Will Destroy Arabs and Israelis Before They Destroy Each Other. *The New York Times*. https://www.nytimes.com/2022/12/06/opinion/how-biden-can-help-save-the-middle-east.html

Golfam, P., Ashofteh, P.-S., Loáiciga, H.A., (2019a). Evaluation of the VIKOR and FOWA Multi-Criteria Decision Making Methods for Climate-Change Adaptation of Agricultural Water Supply. *Water Resour. Manag*. 33, 2867–2884.

Golfam, P., Ashofteh, P.-S., Rajaee, T., Chu, X. (2019b). Prioritization of water allocation for adaptation to climate change using multi-criteria decision making (MCDM). *Water Resour. Manag*. 33, 3401–3416.

Gonçalves, J. M., Ferreira, S., Nunes, M., Eugénio, R., Amador, P., Filipe, O., Damásio, H. (2020). Developing irrigation management at district scale based on water monitoring: study on Lis valley, Portugal. *AgriEngineering*, 2(1), 78-95.

Grossowicz, M.; Ofir, E.; Shabtay, A.; Wood, J.; Biton, E.; Belkin, N.; Frid, O.; Sisma-Ventura, G.; Kress, N.; Berman-Frank, I.; et al. (2020). Modeling the Effects of Brine Outflow from Desalination Plants on Coastal Food-Webs of the Levantine Basin (Eastern Mediterranean Sea). *Desalination, 496*, 114757.

Hajeeh, M., Al-Othman, A. (2005). Application of the analytical hierarchy process in the selection of desalination plants. *Desalination*, 174(1), 97-108.

Hajeeh,M., Fuzzy approach for water desalination plants selection, (2010), 4th IASME/WSEAS *International Conference on Geology and Seismology, University of Cambridge*, UK, pp. 53–61.

He, T., Yan, L. (2009). Application of alternative energy integration technology in seawater desalination. *Desalination* 249, 104-108.

Hermoso-Orzáez, M. J., Lozano-Miralles, J. A., Lopez-Garcia, R., Brito, P. (2019). Environmental criteria for assessing the competitiveness of public tenders with the replacement of large-scale LEDs in the outdoor lighting of cities as a key element for sustainable development: Case study applied with PROMETHEE methodology. *Sustainability*, 11(21), 5982.

Huang, Q. (2022). Selecting sustainable renewable energy-powered desalination: an MCDM framework under uncertain and incomplete information. *Clean Technologies and Environmental Policy*, 1-18.

Joubert, A., Stewart, T.J., Eberhard, R. (2003). Evaluation of water supply augmentation and water demand management options for the City of Cape Town. *J. Multi-Criteria Decis. Anal.* 12, 17–25.

Kalogirou, S. A. (2005). Seawater desalination using renewable energy sources. *Progress in Energy and Combustion Science* 31: 242-281.

Karleuša, B., Hajdinger, A., Tadić, L. (2019). The application of multi-criteria analysis methods for the determination of priorities in the implementation of irrigation plans. *Water* 11, 501.

Khalil, M.I., Schmidhalter, U., Gutser, R. (2005). Turnover of chicken manure in some upland soils of Asia: Agricultural and Environmental Perspective, *Hamburger Berichte*. pp. 275–292.

Khawaji, A. D., Kutubkhanah, I. K., Wie, J. M. (2008). Advances in seawater desalination technologies. *Desalination*, 221(1-3), 47-69.

Kholghi, M. (2001). Multi-criterion decision-making tools for wastewater planning management. *Journal Of Agrıcultural Scıence And Technology*, 281-286.

Kim, D. H. (2011). A review of desalting process techniques and economic analysis of the recovery of salts from retentates. *Desalination*, 270(1-3), 1-8.

Koyuncu, İ. (2018). Su/Atıksu Arıtılması ve Geri Kazanılmasında Membran Teknolojileri ve Uygulamaları. TC Çevre ve Şehircilik Bakanlığı, 554s, Ankara.

Mahmoud, M.R., Garcia, L.A. (2000). Comparison of different multicriteria evaluation methods for the Red

Bluff diversion dam. *Environ. Model. Softw*. 15, 471–478.

Monte, M.B.S., de Almeida-Filho, A.T. (2016). A multicriteria approach using MAUT to assist the maintenance of a water supply system located in a low-income community. *Water Resour. Manag*. 30, 3093–3106.

Mukhametzyanov, I., Pamucar, D. (2018). A sensitivity analysis in MCDM problems: A statistical approach. *Decis. Mak. Appl. Manag. Eng*. 1, 51–80.

Noureddine, M., Ristic, M. (2019). Route planning for hazardous materials transportation: Multicriteria decision making approach. *Decis. Mak. Appl. Manag. Eng.* 2, 66–85.

Ohya, H., Suzuki, T., Nakao, S. (2001). Integrated system for complete usage of components in seawater: A proposal of inorganic chemical combinat on seawater. *Desalination*, 134(1-3), 29-36.

Okello, C., Tomasello, B., Greggio, N., Wambiji, N., Antonellini, M. (2015). Impact of population growth and climate change on the freshwater resources of Lamu Island, Kenya. *Water*, 7(3), 1264-1290.

Papapetrou, M., Cipollina, A., Commare, U.L., Micale, G., Zaragoza, G., Kosmadakis, G. (2017). Assessment of methodologies and data used to calculate desalination costs, *Desalination*,Volume 419, 8-19.

Petrovic, I., Kankaras, M. (2020). A hybridized IT2FS-DEMATEL-AHP-TOPSIS multicriteria decision making approach: Case study of selection and evaluation of criteria for determination of air traffic control radar position. *Decis. Mak. Appl. Manag. Eng.* 3, 146–164.

Piadeh, F., Ahmadi, M., Behzadian, K. (2018a). Reliability assessment for hybrid systems of advanced treatment units of industrial wastewater reuse using combined event tree and fuzzy fault tree analyses. *J. Clean. Prod.* 201, 958–973.

Piadeh, F., Alavi-Moghaddam, M.R., Mardan, S. (2018b). Assessment of sustainability of a hybrid of advanced treatment technologies for recycling industrial wastewater in developing countries: Case study of Iranian industrial parks. *J. Clean. Prod.* 170, 1136–1150.

Pietersen, K. (2006). Multiple criteria decision analysis (MCDA): A tool to support sustainable management of groundwater resources in South Africa. *Water SA* 32, 119–128.

Quist-Jensen, C. A., Macedonio, F., Drioli, E. (2016). Membrane crystallization for salts recovery from brine—an experimental and theoretical analysis. *Desalination and Water Treatment*, 57(16), 7593-7603.

Raju, K.S., Duckstein, L., Arondel, C. (2000). Multicriterion analysis for sustainable water resources planning: a case study in Spain. *Water Resour. Manag.* 14, 435–456.

Ramanathan, R. (2001). A note on the use of the analytic hierarchy process for environmental impact assessment. Journal of environmental management, 63(1), 27-35.

Sadrzadeh, M., Mohammadi, T. (2008). Sea water desalination using electrodialysis. *Desalination,* 221: 440-447.

Sadrzadeh, M., Mohammadi, T. (2009). Treatment of sea water using elecrodialysis: current efficiency evaulation. *Desalination*, 249: 279-285.

Salas, J., Yepes, V. (2018). A discursive, many-objective approach for selecting more-evolved urban vulnerability assessment models. *Journal of Cleaner Production*, 176, 1231-1244.

Savun-Hekimoğlu, B., Erbay, B., Hekimoğlu, M., Burak, S. (2021). Evaluation of water supply alternatives for Istanbul using forecasting and multi-criteria decision making methods. *Journal of Cleaner Production*, 287, 125080.

Scholten, L., Schuwirth, N., Reichert, P., Lienert, J., (2015). Tackling uncertainty in multi-criteria decision analysis--An application to water supply infrastructure planning. *Eur. J. Oper. Res.* 242, 243–260.

Schuwirth, N., Reichert, P., Lienert, J. (2012). Methodological aspects of multi-criteria decision analysis for policy support: A case study on pharmaceutical removal from hospital wastewater. *European Journal of Operational Research*, 220(2), 472-483.

Shah, A. V., Srivastava, V. K., Mohanty, S. S., Varjani, S. (2021). Municipal solid waste as a sustainable resource for energy production: State-of-the-art review. Journal of Environmental Chemical Engineering, 9(4), 105717.

Shariat, R., Roozbahani, A., Ebrahimian, A. (2019). Risk analysis of urban stormwater infrastructure systems using fuzzy spatial multi-criteria decision making. *Sci. Total Environ*. 647, 1468–1477.

Sharifipour, R., Mahmodi, B. (2012). Presentation of coastal environmental management plan by using swot/ahp methods. *Journal of Applied Sciences and Environmental Management*, 16(1), 157-163.

Sharma, M., Joshi, S., Kumar, A. (2020). Assessing enablers of e-waste management in circular economy using DEMATEL method: An Indian perspective. *Environmental Science and Pollution Research*, 27(12), 13325-13338.

Shiau, J.T., Lee, H.C. (2005). Derivation of optimal hedging rules for a water-supply reservoir through compromise programming. *Water Resour. Manag*. 19, 111–132.

Shourian, M., Raoufi, Y., Attari, J. (2017). Interbasin water transfer capacity design by two approaches of simulation-optimization and multicriteria decision making. *J. Water Resour. Plan. Manag.* 143, 4017054.

Srdjevic, B., Medeiros, Y.D.P., Faria, A.S., (2004). An objective multi-criteria evaluation of water management scenarios. *Water Resour. Manag*. 18, 35–54.

Talaeipour, M., Mahvi, A.H., Nouri, J., Hassani, A. (2018). Comprehensive Evaluation Optimal Ground Water Desalination Process with Membranes and Integrated Process Using AHP Method in Qom Province, Iran. *Arch. Hyg. Sci.*, 7, 216–224.

Thinh, N. X., Hedel, R. (2004). A fuzzy compromise programming environment for the ecological evaluation of land use options. *EnviroInfo* (1) pp. 614-623.

Tiwari, D.N., Loof, R., Paudyal, G.N. (1999). Environmental--economic decision-making in lowland irrigated agriculture using multi-criteria analysis techniques. *Agric. Syst.* 60, 99–112.

Tzeng, G. H., Teng, J. Y., Hu, C. P. (1991). Urban environmental evaluation and improvement: application of multiattribute utility and compromise programming. *Behaviormetrika,* 18(29), 83-98.

Weng, S.Q., Huang, G.H., Li, Y.P. (2010). An integrated scenario-based multi-criteria decision support system for water resources management and planning--A case study in the Haihe River Basin. *Expert Syst. Appl*. 37, 8242–8254.

Wine, M. L., Rimmer, A., Laronne, J. B. (2019). Agriculture, diversions, and drought shrinking Galilee Sea. *Science of the Total Environment*, 651, 70-83.

Wu, Z., Shen, Y., Wang, H. (2019). Assessing urban areas' vulnerability to flood disaster based on text data: A case study in Zhengzhou city. *Sustainability*, 11(17), 4548.

Zamani, R., Ali, A. M. A., Roozbahani, A. (2020). Evaluation of adaptation scenarios for climate change impacts on agricultural water allocation using fuzzy MCDM methods. *Water Resources Management*, 34(3), 1093-1110.

Zamarrón-Mieza, I., Yepes, V., Moreno-Jiménez, J.M., (2017). A systematic review of application of multi-criteria decision analysis for aging-dam management. *J. Clean. Prod*. 147, 217–230.

Zarghami, M., Abrishamchi, A., Ardakanian, R. (2008). Multi-criteria decision making for integrated urban water management. *Water Resour. Manag*. 22, 1017–1029.

Zheng, J., Egger, C., Lienert, J. (2016). A scenario-based MCDA framework for wastewater infrastructure planning under uncertainty. *Journal of environmental management*, 183, 895-908.

Zyoud, S.H., Kaufmann, L.G., Shaheen, H., Samhan, S., Fuchs-Hanusch, D. (2016). A framework for water loss management in developing countries under fuzzy environment: Integration of Fuzzy AHP with Fuzzy TOPSIS. *Expert Syst. Appl.* 61, 86–10.