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Research Article

A Fuzzy Outranking Model to Assess the Effects of Energy-Intensive Infrastructures on Wildlife Habitats (Case Study: Markazi Province)

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Abstract
Environmental impact assessment of energy-intensive infrastructure is one of the vital challenges of industrial areas in Iran. This study presents application of PROMETHEE II in combination with Fuzzy ANP, as a decision method to evaluate ecological impacts of energy-intensive infrastructures on wildlife habitat in Markazi province. To this purpose, the effects organized into four categories including quality, geomorphology, landscape, and biodiversity. The assessment carried out for three energy-intensive industry groups including metals industries (first group), chemical industries (second group), non-metallic mineral industries (third group). Analyzing the different scenarios for the proposed method drew using GAIA in Visual PROMETHEE®. The results showed that quality factors played an important role of 0.431 compared to biodiversity of 0.328, landscape of 0.152 and geomorphology of 0.089. The results also showed that chemical industries generated major impacts compared to metals and non-metallic mineral industries. Chemical industries had the most effects with a score of 0.4423. In contrast, non-metallic mineral industries had the lowest effects with a score of -0.6476. The results of GAIA curves and impacts analysis also indicated that the efficiency of the proposed tool in the rapid assessment of effects.

Keywords: Ecological Impact Assessment, Wildlife Habitat, Energy-Intensive Infrastructure, PROMETHEE II, Markazi Province.

Introduction

Currently, energy-intensive industries are one of the serious threats for wildlife habitats (Vögele et al., 2020). The impacts of energy-intensive industries on habitat include solid waste, wastewater and gases are deleterious for surface water, groundwater, soil, biodiversity, and landscapes (Sabeen et al, 2019; Ametepey and Ansah, 2014). Additionally, the impacts of them lead to the destruction of habitats and increase pollution of resources that they cause decreasing habitat qualities, increasing fragmentation and other hazards (Langlois et al, 2017; Garman, 2018; Howden et al, 2019). Assessing the effects of industries on habitat needs a powerful tool.

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The purpose of Environmental Impact Assessment (EIA) is to implement an effective assessment framework that includes identification, prediction, evaluation, and mitigation of the effects (Noble and Nwanekezie, 2017). EIA was used widely in environmental planning and engineering issues. Recently, different methods have been widely used to environmental impact assessment of industries.

Ghobadi et al. (2015) investigated a fuzzy model for environmental impact assessment of petrochemical industries as a decision support system in planning process and the development of petrochemical industry in Lorestan, Iran. The results showed that the operations stage of petrochemical industry creates more important implications than the construction stage. Bennis and Bahi (2015) proposed a methodology based on stakeholder's judgment with assistance of fuzzy Multi-Criteria Decision Analysis (MCDA) methods to assess the environmental impact. This research developed an Analytic Hierarchy Process (AHP) with outranking methodology for assessing the environmental impact.

Padash (2017) used RIAM and TOPSIS methods for environmental impact assessment of desalination and operating units in the southern of Iran. In evaluation process, positive and negative environmental impacts of Masjid-I-Sulaiman desalination and operating units were assessed based on the results of multi-disciplinary team approach and field survey data using RIAM method. Amooshahi et al. (2018) developed an outranking model of EIA for petrochemical industry using Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) approach in Arak, Iran. Their proposed system is an efficient technique to determine the impacts of petrochemical project activities.

Ghobadi and Ahmadipari (2018) presented a combination of PROMETHEE and Fuzzy MCDM methods to spatial site selection of wind power plants. In the process, the PROMETHEE method was used to prioritize the alternatives based on the weights obtained from the fuzzy AHP. The result of assessment showed that the use of PROMETHEE makes a powerful tool for the determination of weight of alternatives and criteria in the site selection.

Tian et al. (2019) analyzed an integrated decision-making method for EIA in China using Analytic Network Process (ANP) and fuzzy PROMETHEE II method. Based on the results, the fuzzy PROMETHEE method reduced the spiteful assessment in the traditional methods. Matin et al. (2019) used PROMETHEE approach to rank the financial methods in a supply chain of downstream oil industries. The results indicated that the outranking method of PROMETHEE makes flexibility and simplicity for the evaluation of data on preferences, scores, and weights.

Saffari et al. (2019) designed a fuzzy expert quantitative methodology to assess the EIA within the Folchi framework. The proposed fuzzy method had advantage of allowing consideration of uncertainties in the Folchi method in comparison with classic expert quantitative method that only unique codes were used to quantify the effect of each impacting factor on each designed environmental component.

Lu et al. (2020) developed an integrated outranking framework for determining and evaluating the impacts of industries. The results indicated that this model reduces accuracy of information and it makes EIA easy and efficient. Broniewicz and Ogrodnik (2020) used PROMETHEE and ELECTRE methods for impacts analysis of infrastructure projects. Based on the result, it was proven that the most popular method used to solve multi-criteria decision problems in the field of transport is PROMETHEE.

This study uses PROMETHEE II in combination with fuzzy ANP for environmental impact assessment of energy-intensive industries on wildlife habitats in Markazi province. This region is one of the biggest centers of strategic industries in Iran. The integration of fuzzy ANP and PROMETHEE makes a powerful tool for determination of the effects in the area. The fuzzy ANP method determines the weights of the factors while the PROMETHEE method ranks the industries based on the obtained weights from the fuzzy ANP.

Material and Methods

Characteristics of the study area

Markazi province is located in the center of Iran with bordering the provinces of Tehran, Esfahan, Semnan, and Zanjan (Figure. 1). It has an area of 29,127 km^2 and population of province is 1.41 million (Labaf and Rahimi, 2015). The province is one of the biggest centers of strategic industries in Iran. The major products of province are aluminum, aluminum products, heavy metals, under pressure tanks, power-plant and industrial boilers, agriculture and road machinery, petrochemical and refinery products, industrial colors, textile, glass, crystal, car tire, wire and cable, detergents, industrial soot, artificial fibers, building rocks, home appliances, tile, pipe and steel profile, PVC and etc. (Fatahibayat, 2016). The focus of industry in the province is located in Arak, Saveh, and Mahallat, respectively. In the study, impacts assessment carried out for three energy-intensive industry groups including metals industries (first group or G1), chemical industries (second group or G2), non-metallic mineral industries (third group or G3).

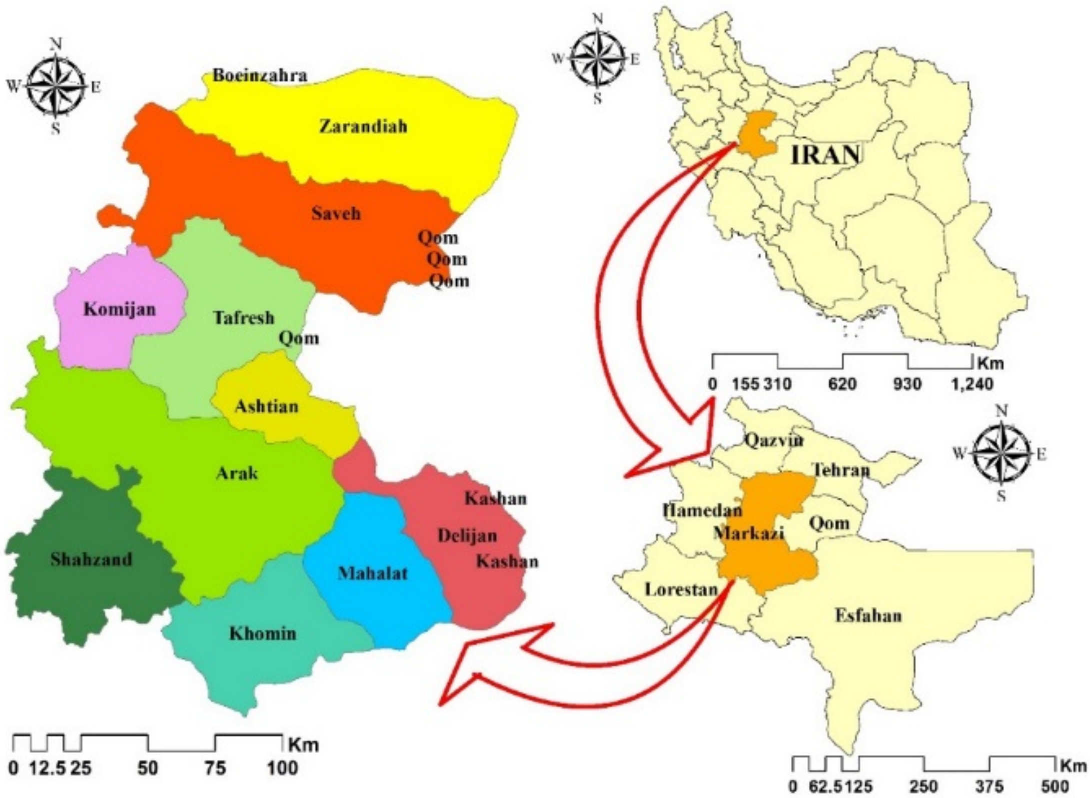

Figure 1. The study area

Identification of criteria

In the step, the main factors determined in a specific workshop based on habitat conditions of natural areas and activities of selected industries complexes. The workshop included two executive and academic groups in field of environmental planning and management. The effects organized into four categories including quality (D1), geomorphology (D2), landscape (D3) and biodiversity (D4). Table 1 shows main ecological impacts of energy-intensive industries on habitat in Markazi province. All effects selected by 30 experts based on different questionnaires. Questionnaires organized according to selected factors on a scale 1-5 to present the lowest to highest effects, and experts used them for scoring various factors. This process performed to ensure the coordination of expert's opinions.

Table 1. The key ecological impacts of energy-intensive industries on habitat

Quality(D1)	Geomorphology (D2)	Landscape(D3)	Biodiversity(D4)
Surface water (C11)	Landform (C21)	Patch area (C31)	Diversity (C41)
Groundwater (C12)	Topography (C22)	Number of patches (C32)	Richness (C42)
Soil (C13)	Hydrology (C23)	Patch shape (C33)	Distribution (C43)
Vegetation (C14)	Hydrography (C24)	Edge density (C34)	Displacement (C44)
Air (C15)	Erosion (C25)	Fragmentation (C35)	Isolation (C45)

The process of fuzzy ANP– PROMETHEE II methodology

In current study, PROMETHEE II method used in combination with fuzzy ANP to evaluate the effects of industries on natural areas. Fuzzy ANP method is one of the multi-criteria decision-making methods that overcome uncertainty due to imprecision and vagueness (Gani and Hantoro, 2018). The fuzzy ANP used to weight the ecological factors. The effects of industries ranked with PROMETHEE II. The PROMETHEE II model is an outranking technique for a fixed collection of alternatives (Abdullah et al, 2019). The method has excellent display because of its combination with the GAIA graphical method and illustrate the contradictions between the different options (Wu et al, 2020). It has a good flexibility and analyzes all quantitative and qualitative data. The steps of proposed algorithm summarized as follow:

Step 1: In this step, fuzzy ANP method used to determine the weight of factors. In this method, pairwise comparisons matrix of impacts completed using triangular fuzzy numbers. The fuzzy assessment scale in fuzzy ANP is shown in Table 2 and membership function of triangular fuzzy number presented in Figure 2.

Table 2. Fuzzy scale for weighting the impacts (Zadeh, 1996)

Linguistic terms	Fuzzy score
Extremely strong	(9,9,9)
Very strong	(6,7,8)
strong	(4,5,6)
Moderately strong	(2,3,4)
Equally strong	(1,1,1)
Intermediate	(7,8,9),(5,6,7), (3,4,5,(1,2,3)

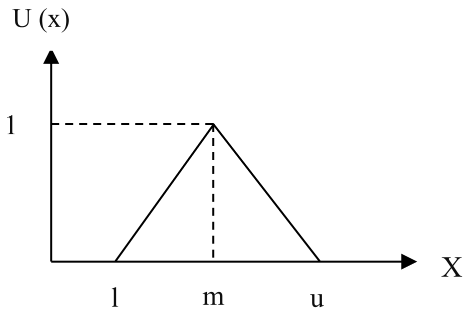

Figure 2. Membership function of triangular fuzzy number (Zadeh, 1996)

The obtained fuzzy weights introduced into initial super matrix that including total network components and their inter relationship. A general super matrix presented as follow (Gani and Hantoro, 2018):

$$W = \begin{matrix} C_1 \\ C_k \\ C_n \end{matrix} \begin{bmatrix} a_{11} & a_{1k} & a_{1n} \\ a_{k1} & a_{kk} & a_{kn} \\ a_{n1} & a_{nk} & a_{nm} \end{bmatrix}$$

C_n shows the *k* th cluster (n=1, 2, 3, n) and a_{k1} presents relative importance of cluster k regarding cluster 1.

The initial super matrix weighted with multiplying weights matrix. It formed a weighted super matrix. Finally, limit super matrix created with multiplying the weighted super matrix by itself.

Step 2: In this step, preference function determined. The functions calculate the difference between two alternatives for an impact. Their ranges are from zero to one. The decision-makers must select a preference function for each impact. Six preference functions include linear, Gaussian, normal, level, V-shape, and U-shape. Figure 3 shows types of preference functions. The degree of preference functions calculated using Eq. 1 to 3 as follow (Brans and Mareschal, 2002):

$$P_j(a,b) = F_j\left[d_j(a,b)\right] \quad (1)$$

Where Pj (a, b) shows the preference of two alternatives (a, b), as a function of dj (a, b).

$$\pi(a,b) = \Sigma\, P_j(a,b)W_j \quad (2)$$

$$\pi(b,a) = \Sigma\, P_j(b,a)W_j \quad (3)$$

Where π (a, b) of a over b defines as sum p (a, b) of each criterion, and wj represents the associated weight with *j*th criterion.

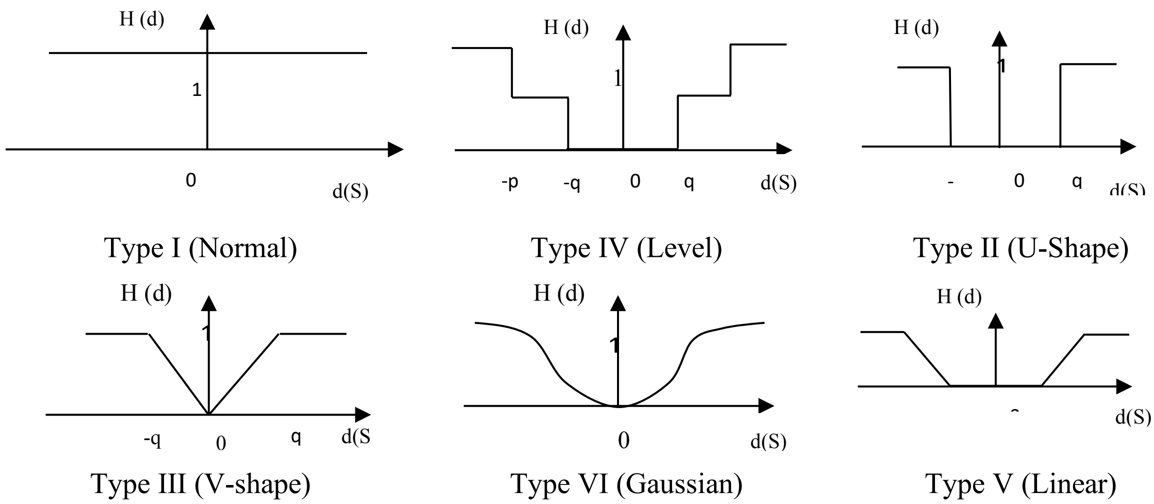

Figure 3. Preference functions in PROMETHEE method (Brans and Mareschal, 2002)

The most important part of PROMETHEE II method is to identify the type of function. In this study, V-shape function selected because it related to operational criteria and ecological issues (Brans and De Smet, 2016). In this function, if criteria value of alternative a is closer absolute preference than alternative b, then alternative a is better than alternative b. If difference of the criteria of alternative a reaches the absolute preference, then alternative a is absolutely better than alternative b.

Step 3: Finally, the flow of preference function calculated using Eq. 4 to 6 as follow (Brans and Mareschal, 2002):

$$\Phi^+(a) = \frac{1}{n-1}\,\Sigma\,\pi(a,x) \quad (4)$$

$$\Phi^-(a) = \frac{1}{n-1}\,\Sigma\,\pi(a,x) \quad (5)$$

Where Φ^+ and Φ^- are positive outranking flow and negative outranking flow for each alternative, respectively.

The positive and negative preference flows gathered into net preference flow:

$$\Phi(a) = \Phi^+(a) - \Phi^-(a) \quad (6)$$

Where Φ (a) is the net outranking flow.

Figure 4 shows overall process of fuzzy outranking method.

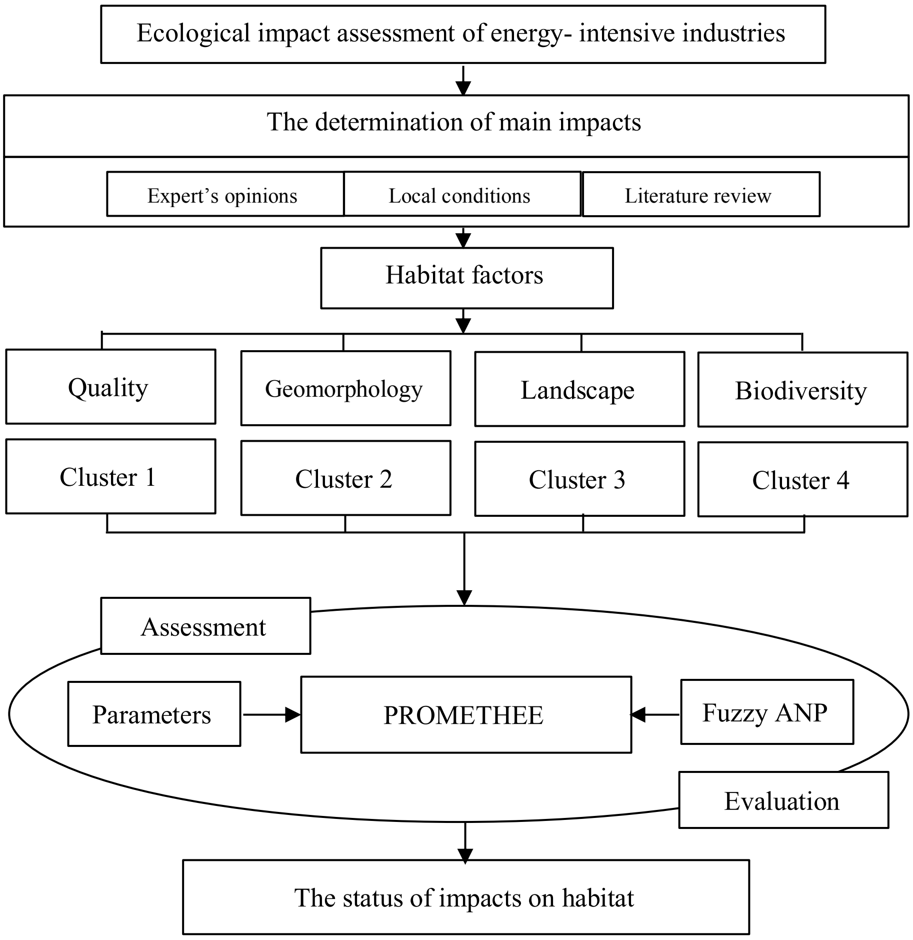

Figure 4. The process of ecological impact assessment of energy- intensive industries on habitat

Results and discussion

In this study, different factors classified into four clusters including quality, geomorphology, landscape and biodiversity. These factors integrated to determine the most effects of industries in Markazi province. Determining the weight of factors is an important step in the assessment. a slight change in weights has a considerable impact on output of evaluation. To calculate the weights of factors, we used ANP in a fuzzy environment in order to achieve reliable results. After calculating the weights of impacts, ranking of selected industry groups performed using PROMETHEE II.

Table 2 presents the initial decision matrix of effects for studied industries with regarding to the main groups of criteria. The matrix developed to determine essential parameters of the PROMETHEE method.

Table 2. Initial decision matrix of PROMETHEE

			D1		
Impact	C11	C12	C13	C14	C15
Weight	0.243	0.294	0.148	0.121	0.194
Min/Max	min	min	min	min	min
Preference Fn.	V-shape	V-shape	V-shape	V-shape	V-shape
- Q: Indifference	0	0	0	0	0
- P: Preference	2.5	2.5	2.5	2.5	2.5
First group (G1)	3.45	3.64	3.84	3.19	4.12
Second group (G2)	4.12	4.36	3.72	4.47	4.57
Third group (G3)	3.11	3.22	3.39	2.84	3.89
			D2		
Impact	C21	C22	C23	C24	C25
Weight	0.318	0.164	0.256	0.076	0.186
Min/Max	min	min	min	min	min
Preference Fn.	V-shape	V-shape	V-shape	V-shape	V-shape
- Q: Indifference	0	0	0	0	0
- P: Preference	2.5	2.5	2.5	2.5	2.5
First group (G1)	4.44	3.67	4.11	3.51	3.21
Second group (G2)	3.56	4.11	4.02	3.33	3.36
Third group (G3)	2.98	2.38	3.44	2.86	3.24
			D3		
Impact	C31	C32	C33	C34	C35
Weight	0.184	0.111	0.237	0.056	0.412
Min/Max	min	min	min	min	min
Preference Fn.	V-shape	V-shape	V-shape	V-shape	V-shape
- Q: Indifference	0	0	0	0	0
- P: Preference	2.5	2.5	2.5	2.5	2.5
First group (G1)	4.11	3.89	2.22	3.93	3.81
Second group (G2)	4.41	4.55	2.41	4.08	4.33
Third group (G3)	3.24	2.79	1.87	3.12	3.02
			D4		
Impact	C41	C42	C43	C44	C45
Weight	0.389	0.134	0.219	0.194	0.064
Min/Max	min	min	min	min	min
Preference Fn.	V-shape	V-shape	V-shape	V-shape	V-shape
- Q: Indifference	0	0	0	0	0
- P: Preference	2.5	2.5	2.5	2.5	2.5
First group (G1)	4.12	4.44	2.84	1.76	3.37
Second group (G2)	3.36	4.33	3.21	1.65	4.21
Third group (G3)	3.38	3.81	3.28	1.34	3.32

The impacts placed in matrix rows and alternatives or groups of energy-intensive industries located in columns. Based on the opinion of experts and their evaluations on impacts (Table 2), the V-shape function determined for all factors into preference degree between 0 and 2.5. It characterized for an indifference threshold Q and a preference threshold P. The highest value occured in P with a score of 2.5. In contrast, the lowest value found at Q with a score of 0.

According to the results of Table 2, groundwater (C12) has the most importance (0.294) for quality (D1) factor. Since the industries generate a large volume of wastewater, the groundwater plays the main role in the quality of habitat (Sun et al, 2019). The case of geomorphology (D2) factors present landform (C21) change has a major role (0.318) over C23 (0.256), C25 (0.186), C22 (0.164) and C24 (0.076) for impact assessment of industries in the region. The fragmentation (0.412) and diversity (0.389) recorded as important criteria for landscape (D3) and biodiversity (D4) factors, respectively.

Table 3. Initial decision matrix for main factors

Impact	D1	D2	D3	D4
Weight	0.431	0.089	0.152	0.328
Min/Max	min	min	min	min
Preference Fn.	V-shape	V-shape	V-shape	V-shape
- Q: Indifference	0	0	0	0
- P: Preference	2.5	2.5	2.5	2.5
First group (G1)	3.35	2.34	2.81	3.18
Second group (G2)	3.13	2.87	3.36	4.22
Third group (G3)	1.89	2.09	2.49	1.64

Based on the results of Table 3, the V-shape function determined for main factors into preference degree between Q (0) and P (2.5). The function generates a preference degree ratio to difference. The results also showed that quality factors played an important role of 0.431 compared to biodiversity (D4) of 0.328, landscape (D3) of 0.152 and geomorphology (D2) of 0.089. These findings supports with previous researches in Iran (Amooshahi et al, 2018), China (Tian et al, 2019) and Brazil (Boclin et al, 2006), showing the quality of environment is an important factor for EIA. The quality factors, as very effective natural criteria for EIA, have very important effects on habitat areas, health of animals and plants (Saffari et al, 2019). The high quality of habitat areas provides that species find food, water, shelter, and protection, easily (Yaqoob et al, 2019).

Table 4 shows ranking calculations extracted from Visual PROMETHEE® for different scenarios. The positive outranking flow (Φ+) indicates how an option is outranking compare to others. The negative outranking flow (Φ-) presents how an option outranked with other options (Govindan et al, 2017; Ghobadi and Ahmadipari, 2018). Highest Φ+ and lowest Φ- are the best option. The net outranking flow (Φ) balanced among positive and negative outranking flows. The highest Φ is the best alternative (Hanine et al, 2017).

Table 4. Ranking calculations extracted from Visual PROMETHEE®

Criteria	Energy-intensive industry	Φ+	Φ-	Φ	Rank
D1: Quality	First group (G1)	0.1664	0.1414	0.0250	2
	Second group (G2)	0.4264	0.0114	0.4150	1
	Third group (G3)	0.0011	0.4400	-0.4389	3
D2: Geomorphology	First group (G1)	0.2372	0.0208	0.2164	1
	Second group (G2)	0.1681	0.0532	0.1148	2
	Third group (G3)	0.0014	0.3326	-0.3312	3
D3: Landscape	First group (G1)	0.1464	0.1283	0.0181	2
	Second group (G2)	0.2241	0.1481	0.0760	1
	Third group (G3)	0.1773	0.2714	-0.0941	3
D4: Biodiversity	First group (G1)	0.1143	0.0979	0.0164	2
	Second group (G2)	0.2220	0.0113	0.2106	1
	Third group (G3)	0.0301	0.2571	-0.2270	3

Figure 5 shows Geometric Analysis for Interactive Aid (GAIA) created by Visual PROMETHEE®. GAIA is a visual tool for analyzing the results of the PROMETHEE model (Hanine et al, 2017). The results of first scenario (D1) show that the highest Φ for three industries groups of G1, G2, and G3 are 0.0250, 0.4150, and -0.4389, respectively. The ranking of the first scenario (D1) indicates that the second group of energy-intensive industries have the highest Φ (0.4150). According to first scenario, chemical industries are the worst alternative for wildlife habitats. The results of second scenario (D2) indicates that the highest Φ for three industries groups of G1, G2, and G3 are 0.2164, 0.1148, and -0.3312, respectively. The ranking of the second scenario (D2) indicates that the first group of energy-intensive industries have the highest Φ (0.2164). According to second scenario, metals industries are the worst alternative for wildlife habitats. The results of third scenario (D3) presentes that the highest Φ for three industries groups of G1, G2, and G3 are 0.0181, 0.0760, and -0.0941, respectively. The ranking of the third scenario (D3) presentes that the second group of energy-intensive industries have the highest Φ (0.0181). According to third scenario, chemical industries are the worst alternative for wildlife habitats. The results of fourth scenario (D4) show that the highest Φ for three industries groups of G1, G2, and G3 are 0.0164, 0.2106, and -0.2270, respectively. The ranking of the fourth scenario (D4) shows that the second group of energy-intensive industries have the highest Φ (0.2106). According to fourth scenario, chemical industries are the worst alternative for wildlife habitats. Generally, the results of three scenarios including D1, D3 and D4 show that the second group of energy-intensive industries are the worst alternative for wildlife habitats because the group has the highest Φ. The highest Φ for scenario 1, 3, and 4 are 0.4150, 0.0760, and 0.2106, respectively. The ranking of the second scenario (D1) indicates that the first group of energy-intensive industries have the highest Φ (0.2164).

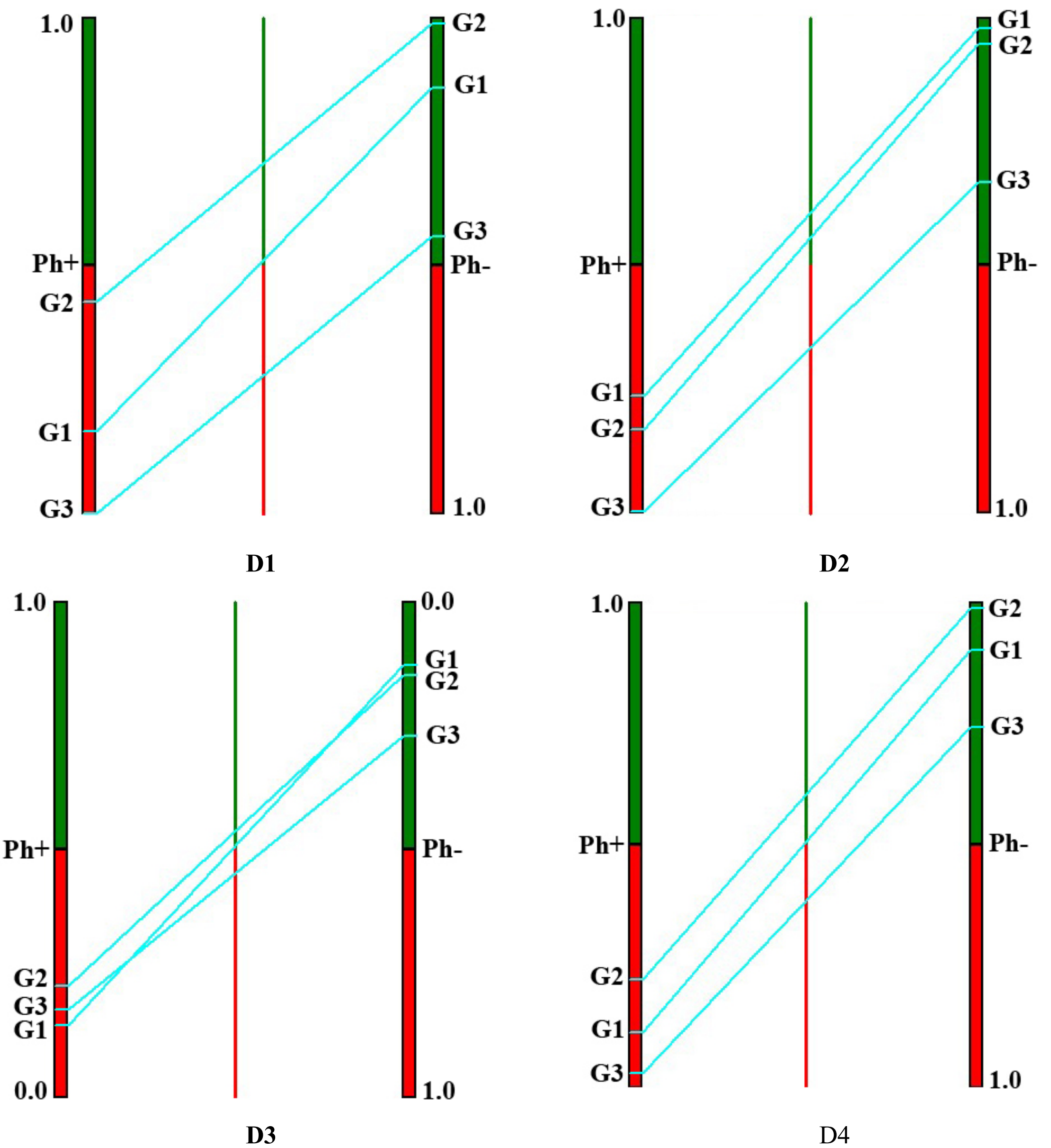

Figure 5. GAIA Plane for analyzing the different scenarios extracted from Visual PROMETHEE®

Table 5. The final ranking of energy-intensive industries

Energy-intensive industry	Φ+	Φ-	Φ	Rank
First group (G1)	0.3250	0.1180	0.2071	2
Second group(G2)	0.4660	0.0237	0.4423	1
Third group(G3)	0.0017	0.6493	-0.6476	3

The result of positive preference flow (Φ+) showed that the highest Φ+ for three industries groups of G1, G2, and G3 are 0.3250, 0.4660, and 0.0017, respectively. The ranking of the positive preference flow (Φ+) showed that the second group of energy-intensive industries have the highest Φ+ (0.4660). According to positive preference flow (Φ+), the second group is preferred to all the other groups. The result of negative preference flow (Φ-) presented that the lowest Φ- for three industries groups of G1, G2, and G3 are 0.1180, 0.0237, and 0.6493, respectively. The ranking of the negative preference flow (Φ-) showed that the second group of energy-intensive industries have the lowest Φ- (0.0237). According to negative preference flow (Φ-), the second group is preferred to all the other groups. Generally, the result of net preference flow (Φ) indicated that the highest Φ for three industries groups of G1, G2, and G3 are 0.2071, 0.4423, and -0.6476, respectively. The ranking of the net preference flow (Φ) showed that the second group of energy-intensive industries have the highest Φ (0.4423). According to net preference flow (Φ), the second group is the worst alternative for wildlife habitats.

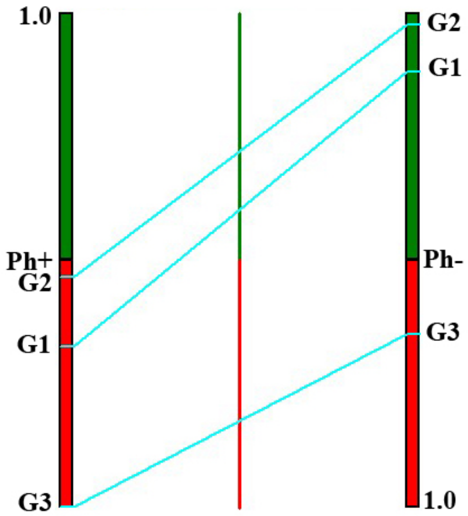

Figure 6. GAIA Plane for analyzing the final ranking extracted from Visual PROMETHEE®

According to the GAIA Plane for analyzing final ranking (Figure 6 and Table 5), chemical industries (G2) generated major impacts compared to G1 and G2. The most effects occur in G2 with a score of 0.4423. In contrast, the lowest impacts found in G3 with a score of -0.6476. These findings support by previous studies as they document that these industries release huge amounts of pollution into air, soil, water and other environmental components (Ghobadi et al, 2015; Amooshahi et al, 2018). Another study found out that chemical industries cause landscape change, habitat geomorphology and other secondary effects such as the reduction of habitat quality and biodiversity loss (Satria, 2020). Chemical industries have harmful impacts on the environment including air pollution from the release of chemical fumes and odors, noise pollution from processing plant and machinery, water pollution from contaminated discharges or accidental spills, land contamination from storing chemicals or oil (Amooshahi et al, 2018). These industries make serious health risks to the ecosystem and cause damage to the environment. Thus, it is necessary to introduce applied methods for identifying the negative impacts of the industries and reduction of impacts on natural ecosystems.

Conclusion

In this study, the integrated fuzzy ANP-PROMETHEE II approach applied in order to determine the effects of energy-intensive industries in Markazi province. To this purpose, different factors classified into four clusters including quality (D1), geomorphology (D2), landscape (D3) and biodiversity (D4). The assessment of impacts carried out for three energy-intensive industry groups include metals industries (G1), chemical industries (G2), non-metallic mineral industries (G3). Analyzing the results drew using GAIA curves in Visual PROMETHEE®. The results showed that chemical industries (G2) had the most negative impacts on wildlife habitats in the area (0.4423). The results of GAIA curves and impacts analysis also showed that the efficiency of proposed tool in the rapid assessment of effects. This finding is similar to the finding of previous studies conducted in Iran (Amooshahi et al, 2018; Ghobadi and Ahmadipari, 2018), China (Tian et al, 2019) and Poland (Broniewicz and Ogrodnik, 2020), indicating that the outranking method of PROMETHEE makes flexibility and simplicity for the evaluation of data on preferences, scores, and weights.

The present study proposes a new hybrid model for environmental impact assessment and helps environmental planners and managers with a deeper understanding of ecological criteria. These findings are supported by previous studies such as Amooshahi et al. (2018) and Bennis et al. (2015), respectively, in Iran and North African as they document that the outranking models are the best methods for the impact assessment of industries.

Considering the successful experiences of previous studies (Ghobadi et al, 2015; Bennis and Bahi, 2015; Amooshahi et al, 2018; Broniewicz and Ogrodnik, 2020; Tian et al, 2019) in application of fuzzy outranking models in combination with MCDM for EIA showed that the approach causes the reduction of uncertainty and complexity in the real assessment. The proposed approach determines the effects of industries using PROMETHEE II in combination with other models based on impact assessment studies projects in the fuzzy environment.

According to the findings from the current research, the proposed approach was able to assess the environmental impact of different alternatives for the identification of important impact sources from an outranking analysis. Many feasible alternatives can be compared by fuzzy ANP-PROMETHEE. The impacts assessed can be considered as environmental performance predictions for energy-intensive industries planning.

The findings provided by fuzzy ANP-PROMETHEE work as a pathway that support the environmental planning and managers in the development of more environmentally friendly operations. The fuzzy ANP-PROMETHEE can also support the follow-up and control of energy-intensive industries effects. The importance of different management aspects of the environmental impacts can be ranked by fuzzy ANP-PROMETHEE. In this application, the identified key aspects are valuable for environmentally conscious project management. Even though the proposed approach was able to provide an environmental assessment that considered process uncertainties and dynamic environments, there are limitations that will be addressed in the future.

The probability distributions of uncertainty and the information on dynamic environments that were used in this study are based on data from experience and assumptions. The process of information collection for assessment will provide a source of input data for the proposed method. Hence, environmental predictions of industries based on real-time information can be provided for informed environmentally friendly decisions. On the other side, the impact variations might also have a relationship with other factors, such as the number of alternatives and criteria. The proposed method could quantify these influences when their relationships to the assessment process are properly defined. In addition, this method is not limited to any specific time scale and there is no restriction in the geographical zone as well.

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