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Research

Keywords: Industrial Ecology, DPSIR, Analytic Hierarchy Process (AHP), Fuzzy Theory, Iran

Posted Date: April 27th, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-22317/v1>

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Analyzing and Evaluating Industrial Ecology Development Model in Iran

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Abstract

Background: Industrial estates are one of the major centers of producing energy and industrial waste in the country. One of the important points of establishing industrial units in industrial towns and areas is to pay attention to industrial ecology; rotating economic policies with industrial ecological approach should be formed in industrial towns and the limitation of vital resources should never be neglected. The industry should be used as another industry input. Given that this trend and approach does not exist in Iran, this study seeks to investigate and analyze the factors influencing the launch of the industrial ecology perspective in Iran. Developing Industrial Ecology (IE) faces significant obstacles. However, the aim of this study is to evaluate the barriers due to a combination model, including DPSIR and Fuzzy Analytic Hierarchy Process (FAHP). To prioritize the responses (alternatives) regards to the driving forces, pressures, states, and impacts (criteria), the hierarchy of the model are established. In this research, for the purpose of identifying and prioritizing effective factors and analyzing research results, the opinions of 44 experts in the field of waste and environment, industrial engineering and industrial process were used.

Result: In the first step of the results, based on the experts' point of view and study background and the experience of the last ten years of the world's leading countries, the general framework proposed by DPSIR for IE was presented. For the comparison of two fuzzy numbers, a novel division methods using concept was used. Due to the field studies, 18 criteria and four responses are suggested. Each of the main axes of the DPSIR model was carefully analyzed and in 4 radar diagrams, the analysis of each factor was presented. The first factor (R2) Improve IE law, with Final Weight (FW) 0.251, was selected as the first priority in the IE development model in Iran. Subsequent factors, in order of final weight, included (R3) Establish IE national database (0.246), (R4) Modify industries clustering (0.249) and (R1) Industries training (0.225).

Conclusion: Industrial ecology in Iran has been failed to notices so far. The results males it crystal clear that the concepts of industrial ecology have not been implemented in Iran's industrial estates. Based on the results of the analysis and the explanations provided, the proposed action plans for developing the industrial ecology model of Iran. This action provides a legal guarantee for the development of industrial ecology. Therefore, it can be said that the proposed route is the most reliable way to succeed based on current local and regional conditions in Iran.

Keywords: Industrial Ecology; DPSIR; Analytic Hierarchy Process (AHP); Fuzzy Theory; Iran.

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Background

The development of industrial ecology mostly materialized in developed countries, and after achieving suitable results, developing countries took an interest during this topic and developing its concepts in their industries (Telesford, 2020; Morales et al., 2019; Naguyen et al., 2019; Mortensen, and Kørnøv, 2019; Pohlmann et al., 2020). In Iran, few plans are implemented within the field of industrial ecology, especially by specializing in industrial parks (Vahidi et al., 2017). Since the event of industrial ecology is related to more economic productivity, this state of the Iranian economy will be a really good reason for the utilization of economic opportunities created by the event of business ecology (Bayly, 2020; Deutz, 2020, Schröder et al., 2020; Simboli et al., 2020). However, there are obstacles during this regard, which has led to the failure of some little effort made in recent years. Therefore, this research tries to check the various policies and plan the essential infrastructure of industrial ecology development in Iran supported effective indicators. A quick overview of the method of industrial ecology formation and also the most relevant studies are presented as follows. Basic ideas resulting in industrial ecology raised in Robert Ayres's works, one among the primary scientists who worked during this field. He focused on the analysis of the flow of materials and energy (Schon et al., 2016), with a greater emphasis on energy. He suggests an industrial metabolism which by ranging the operative systems, the economic will be studied as same as food and energy in a very typical ecological system (Ayres, 1989). Later, studies aimed for reducing the dependence of the economy on materials were initiated in Japan, and "industrial ecology" was used because the official title of the planning/research group (Watanabe, 1972). Years Later, in 1983, a book published by Belgians, which debate the economy of industrial ecology as a middle rather than usual monetary flow (Billen et al., 1983). Then in 1989, an enormous change occurred after Robert Frosch and Nicholas Gallopoulos' published their article with a novelty in industrial structure. Their suggestion was a replacement aspect of production processes interconnects materials flowing (Frosch, 1995). As mentioned before, one among the important challenges within the recent decade is saving energy and first resources, and reducing the spread of pollutants, to facilitate sustainable development, taking future generations

considerations into consideration (Tyagi et al., 2020; Khan and Kabir, 2020; Khan, 2020; Dallas et al., 2020; Marques and Bassani, 2020). Industrial ecology is one among the suggested approaches during this field. Industrial ecology will be applied to several different fields, but one among the foremost integral parts of this method may well be named as ‘industrial towns’ because the centers of major energy and material consumption (Bahers et al., 2020; Mastrucci et al., 2020; Asada et al., 2020; Voskamp et al., 2020; Yu et al., 2020; Yao et al., 2020; Wu et al., 2020). that's why the concepts of industrial ecology were deployed in industrial towns and caused the formation of industrial eco-parks (Sherwood, 2020; Patel and Padhya, 2020; Gómez et al., 2020; Lahane et al., 2020; Genc et al., 2019; Le Tellier et al., 2019; Gao et al., 2019) . Some studies have expressed the event of industrial ecology as a win-win-win scenario in an economic-environmental-social trilateral relationship, and this could sure be a highlighted confirmation for the need of the presence of those concepts in industrial towns (Ho, 2020; Tothmihaly et al., 2019; Thiele, 2019; Durán and Chichava, 2017; Gibbs and Deutz, 2007). One aim which may be considered for industrial ecology is to work out whether a waste material of 1 manufacturing sector may well be employed in another sector (Mostafa and Dumrak, 2020; Bostanci, 2020; Bhushan et al., 2020; Simms et al., 2020; Royo et al., 2020) . Central industrial ecology is answerable of fixing the linear systems of human production and consumption to closed loop systems (Mohtashami et al., 2020; Fu and Meng, 2020; Ryżyński et al., 2020; Lejarza and Baldea, 2020; Lowe and Evans, 1995).

There are many advantages of using industrial ecology like environmental pollution reduction (Padash and Atae, 2019), closed material, and energy cycle, saving money and raw materials and at last achieving practical, sustainable development (Wellmer et al., 2019; Aluchna and Rok, 2019; Padash et al., 2015; Padash, 2017; Chertow, 2008). It's important to stay in mind the interacting nature of processes and industries relationship and to not consider them as separated elements of a linear flow system. this might be used as a base for discerning ways to attach plants, industries and other waste producing processes and gather them in an interconnected web which may cause a decrease of disposed and lost material within the process (Soobhany, 2019; Onwosi et al., 2020; Vu et al., 2019). The point of interest is modified from trying

to scale back facility-produced waste to abating the full waste produced by larger systems and material inflow (Stephan et al., 2020; Santagata et al., 2019; Effler et al., 2013).

Some of the recent studies on IE are discussed as follows. Bahers et al., (2020) analyzed the complexity of the strength of the relationship between IE in cities and boundary regions and the nature of these social and material links. Cecchin et al., (2020) explained Industrial Symbiosis (IS) within the framework of the Economic Cycle (CE) as a new approach to sustainability and Sustainable Development (SD), which is growing rapidly. Boons (2013), presented an outline of research on how global companies accommodate their ecological impact on the speculation of ecological modernization (Jänicke, 2020; Mastrangelo and Aguiar, 2019). Schiller et al. discussed Social-Material Network Analyses studies to classify and draw on network analyses from various disciplines (Schiller et al., 2014). Cerceau et al. presented the results of a look project between 2011 and 2012 to comprise a world inventory of innovative resource management initiatives in 18 port areas of China (Cerceau et al., 2014). Reyes-Bozo et al. studied Chilean copper mining operations thanks to the green IE strategies (Reyes-Bozo et al., 2014). Leigh & Li developed a conceptual framework because of environmental sustainable supply chain management, IE, and Industrial Symbiosis to embrace the combination and identify collaboratively work opportunities for companies (Leigh and Li, 2015).

Corder et al. focused on identifying viable options to ‘mine’ metals contained in discarded urban infrastructure, manufactured products, and goods and initial estimates of the mass and current worth of metals in end-of-life products thanks to IE (Corder et al., 2015). Smith et al. considered individual waste-to-energy or waste-to-product system synergies, evaluating the economic and environmental issues thanks to the IE system (Smith et al, 2015a, 2015b). Yune reviewed the eco-industrial development within the Shanghai Chemical parcel of land and its performance within which concluded that practice within the industrial park would facilitate green development of other chemical industrial parks in China (Yune et al., 2016). Vahidi et al. conducted a study on 38 industrial units from the full active of 220 units in Qazvin,

Iran, and concluded that 341.6 loads of 6 styles of wastes generated within the units are reusable result in 1.43 million dollars annual income (Vahidi et al., 2017).

Hao et al., proposed a model for the expansion of green chemistry beyond the boundaries of one product, combining it with the concept of the commercial ecology in an exceedingly chemical parcel of land (Hao et al., 2017). Bocken et al. in research titled “Sustainable business model experimentation by understanding ecologies of business models” contributes research on sustainable business model innovation, design and experimentation by providing a possible approach for ‘business model ecology redesign’. Bocken et al. proposed approach could help minimize symbiotic dependency on less sustainable business models; help destroy unsustainable business models by outcompeting them; and maximize contributions to favorable institutional infrastructures for more sustainable business models (Bocken et al., 2019). Baldassarre et al. (2019), design process for eco-industrial clusters by integrating the circular economy and industrial ecology perspectives and analyze the two perspectives and find they're both necessary to define Industrial Symbiosis clusters (Baldassarre et al., 2019).

Saavedra et al. conducted a study to supply theoretical help from Industrial Ecology (IE) to the Circular Economy (CE). The tactic used was supported the analysis of bibliometric within the international field. In line with bibliometric analysis, the CE evolution of CE isn't possible without the existence of concepts and tools, especially with tools like Industrial Symbiosis (IS) and ecological industrial parks (EIPs). Also, three levels of IE assistance were determined to CE, like conceptual, technical, and policy aspects. Finally, there are new CE-based research from an IE perspective with bibliometric analysis and using citation networks that include solid waste management and policies (Saavedra et al., 2018). Sullivan et al. conducted a study to ascertain a baseline for measure of the strategic benefits of IE principles. The analysis showed that while SMEs are mainly at the national level, they are also associated with business, through innovation, participation and strategic position. It's found that the mixing of IE, and business strategy is incredibly relevant for the three domains, but elements of all components are included in several degrees. IE, has special attention to innovation and its potential in new markets, products, and business

models. Internet Explorer is additionally consciously utilized in efficient use of energy and resources, ideas that are changing to attenuate, adapt and build flexibility within the future, but also to traditional concepts of business strategy and competitive advantage. This research shows that by the mix of, IE, and strategic management theory, business organizations can play a task in creating sustainable development goals in creating positive competitive advantage (Sullivan et al., 2018). In Iran, the evolution of industrial Ecology began long ago; however, this development was without thought of Environmental Problems and Industrial Ecology ideas. Industrial estates are the foremost important organizations, and every one matters identifying with them are attended by Small Industries and Industrial Parks Organization.

Park and Gupta (2015) in a related research titled “Evaluating localism within the management of post-consumer plastic bottles in Honolulu, Hawai’i: Perspectives from industrial ecology and political ecology” assessed waste management from an environmental perspective in addition as other considerations like safety and security issues affecting urban metabolic planning.

Smith (2015) considered to investigate such issues as waste streams, the particular characteristics of waste types and conversion technologies, and also the possibility of technical savers to see the economic and environmental impacts of waste and transport and processing changes in waste management system. At the half of the year 2005 "Iran Small Industries org" was integrated with "Iran Industrial Estate Co," and also the Iran Small Industries and Industrial Parks Organization (ISIPO) was formed which may be a developmental organization in association with the Ministry of Industry, Mine and Trade. The most aim designated for this organization was planning and developing industrial parks/areas (ISIPO, 2019). By the tip of 2014, a complete of 941 industrial areas were founded in Iran 754 of which are active and running, as stated within the official statistical reports of ISIPO. Establishing this, over 33000 acres of land suitable for industrial use was given to industrial units at no cost. In total, 34252 industrial units and 2429 workshops are operating in areas as mentioned earlier and have created over 700000 job opportunities, directly (ISIPO, 2019). Despite ISIOP efforts in providing the mandatory infrastructure for industrial areas, the expansion rate of those areas is above their infrastructure, which may be a worrisome issue, especially when

considering environmental infrastructures. Numerous studies and studies have been conducted on the DPSIR model and consider this model as a comprehensive and integrated model for evaluation. The European Environment Agency (EEA) has used this model for integrated environmental impact assessment studies (Kristensen, 2004). Svarstad is credited with leveraging the DPSIR model as a lens so that you can act and collect, in a cycle to reach your original goal and take precautionary action (Svarstad et al., 2008). In this study, a DPSIR model in an exceedingly Fuzzy Analytic Hierarchy Process (FAHP) is conducted supported the aim of developing industrial ecology in Iran's industrial estates. Also, thanks to the experts' judgments, the priority of responses thanks to the factors, including the driving forces, pressures, states, and impacts are calculated. Finally, due to the results, the priority responses to develop the IE are discussed. Table 1 shows the summary of related studies to industrial ecology.

Table 1 Summary of related studies to industrial ecology

Row	References	Title	Focus and Output
1	Cecchin et al., 2020	Relating Industrial Symbiosis and Circular Economy to the Sustainable Development Debate	explained Industrial Symbiosis (IS) within the framework of the Economic Cycle (CE) as a new approach to sustainability and sustainable development (SD), which is growing rapidly
2	Bahers et al., 2020	Metabolic relationships between cities and hinterland: a political-industrial ecology of energy metabolism of Saint-Nazaire metropolitan and port area	analyzed the complexity of the strength of the relationship between IE in cities and boundary regions and the nature of these social and material links.
3	Baldassarre et al., 2019	Industrial Symbiosis: towards a design process for eco-industrial clusters by integrating Circular Economy and Industrial Ecology perspectives	design process for eco-industrial clusters by integrating the circular economy and industrial ecology perspectives
4	Bocken et al., 2019	Sustainable business model experimentation by understanding ecologies of business models	contributes research on sustainable business model innovation, design by providing a possible approach for 'business model ecology redesign
5	Sullivan et al., 2018	Using industrial ecology and strategic management concepts to pursue the Sustainable Development Goals	study to ascertain a baseline for measure of the strategic benefits of IE principles
6	Saavedra et al., 2018	Theoretical contribution of industrial ecology to circular economy	conducted a study to supply theoretical help from Industrial Ecology (IE) to the Circular Economy (CE)
7	Hao et al., 2017	Using a hybrid of green chemistry and industrial ecology to make chemical production greener	proposed a model for the expansion of green chemistry beyond the boundaries of one product, combining it with the concept of the commercial ecology

Row	References	Title	Focus and Output
8	Vahidi ET AL., 2017	Analyzing material flow in Alborz industrial estate	conducted a study on 38 industrial units from the full active of 220 units
9	Yune ET AL., 2016	Greening Chinese chemical industrial park by implementing industrial ecology strategies: A case study	eco-industrial development within the Shanghai Chemical parcel of land and its performance within industrial park
10	Park and Gupta (2015)	Evaluating localism within the management of post-consumer plastic bottles in Honolulu, Hawai'i: Perspectives from industrial ecology and political ecology	assessed waste management from an environmental perspective in addition as other considerations like safety and security issues affecting urban metabolic planning
11	Smith et al., 2015	An industrial ecology approach to municipal solid waste management	considered individual waste-to-energy or waste-to-product system synergies, evaluating the economic and environmental issues
12	Corder et al., 2015	“Wealth from metal waste”: Translating global knowledge on industrial ecology to metals recycling in Australia	identifying viable options to ‘mine’ metals contained in discarded urban infrastructure, manufactured products, and goods and initial estimates
13	Cerceau et al., 2014	Implementing industrial ecology in port cities: international overview of case studies and cross-case analysis	comprise a world inventory of innovative resource management initiatives in 18 port areas of China
14	Boons, 2013	Ecological modernization and industrial ecology	research on how global companies accommodate their ecological impact on the speculation of ecological modernization

Materials and Methods

Summary of framework study

The framework of this study consists of two models. The first part uses the DPSIR model and the second part uses the FAHP model; a summary of the framework shown in Fig. 1.

Fig. 1 Summary of research methodology

The DPSIR model used to conduct the hierarchical structure of responses to develop the IE in Iran's industrial estates. However, the responses are considered as the alternatives and the driving forces, pressures, states, and impacts are considered as the criteria. In the next sections, each DPSIR, AHP, and the ranking fuzzy numbers method are explained. The hierarchical structure of decision-making is illustrated in Fig. 2.

Fig. 2 The hierarchical structure of decision-making

Due to the importance of the research and the need for accurate information, the statistical sample was collected from 44 experts with an average of 5 years of experience. The technical specifications of the experts are summarized in Table 2. Significantly, the opinion of some of the experienced factories owners and the industrial manager of some estates such as Alborz and Charmshahr and Salaries are also collected and used.

Table 2 Specifications of industry experts

Characteristics	Freq.	%
Work experiences		
12-15	10	22.72
15-20	12	27.27
20<	22	50
Relevant undergraduate degree		
Industrial Eng.	12	27.27
Safety	10	22.72
Environmental Eng.	8	18.18
Process Industry	14	31.81
Special Expert		
Operator	8	18.18

Technical inspection	7	15.90
Inspection	12	27.27
Supervisory	11	25
Manager	6	13.63
Knowledge of Industry and process		
Process knowledge	3	6.81
General knowledge	4	9.09
Industry knowledge	12	27.27
Strong knowledge	25	56.81

DPSIR Model

The Driver-Pressure-State-Impact-Response (DPSIR) is causality-based, in which human activities cause changes in the environment, which in turn triggers a management response, usually a policy. This DPSIR framework is originated from the PSR (Pressure-State-Response) model first developed by the Organization for Economic Cooperation and Development (OECD) and later modified to DPSIR by the European Environment Agency (EEA) (Mell, 2020; Shi and Tong, 2019; Hou et al., 2019; Wei et al., 2019; Sarmin et al., 2016). Although widely used, the conceptual model has been criticized for its bias towards a particular worldview that may limit its application by managers (Svarstad et al., 2008) and also for its analytical weakness. One of the approaches used in DPSIR studies is to redefine the framework for its application purposes (Anandhi et al., 2020; Han et al., 2020; Kaur et al., 2020; Scriban et al., 2019; Haque et al., 2019).

A matrix of the definitions of the five terms from the collected DPSIR model papers is compiled and used to update the definitions. Figure 2. Shows the DPSIR framework.

- Drivers: Social and economic forces that cause environmental pressures
- Pressures: Human activities caused by drivers that affect the state of the system.
- States: The condition of the system at a specific time.
- Impacts: Ecological, social and economic changes in the state caused by drivers and pressures.

- Responses: Measures taken to address impacts, rivers and pressures.

Fig. 3 The DPSIR Framework (Kristensen et al., 2004)

ANALYTIC HIERARCHY PROCESS (AHP)

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making technique which is based on the Rational Comprehensive Theory. According to Saaty, AHP's focus is on achieving the goal that will generate a rational decision, which is the best decision among any goal that will be achieved by decision makers (Saaty, 2008). In other words, the main key to a rational decision is not the alternative, the criteria, or the attribute, but also it is the goal. One of the strengths of the AHP method is its flexibility in comparisons (Kumar et al., 2020; Gaur and Ronge, 2020; Kaya et al., 2020; Nejad et al., 2013).

AHP can be conducted in seven steps which are as follows:

1. Finding Pairwise Comparison Matrix (PCM) for every decision alternative based on each criterion

2. Synthetization
3. Establishing Pairwise Comparison Matrix for each criterion
4. Establishing the Normalized Matrix
5. Establishing the Preference Vector
6. Calculating an overall value for each decision alternative
7. detecting the alternatives ranking based on the previous step acquired values

According to Saaty (Saaty, 2008), this AHP approach is suitable for decision making, which involves comparing decision-maker elements, and is difficult to measure quantitatively. This matter is based on the assumption that human beings' natural reaction when facing complex decision making, is by grouping the decision elements according to their common characteristics. This grouping process includes rank the decision elements and then comparing between each pair in each group in the form of a matrix. After that, inconsistency ratio and weight for each element will be acquired. Thus, it will provide ease in testing the data consistency.

The comparisons, according to the ratio-scale system, are used as input data in the AHP method to states the decision-making situation. The values in the ratio are then organized in a PCM. Preferably, the scale range 1–9 is chosen as the popular scaling system which sufficiently representing human beings' perception. However, the comparison scale used in the AHP method is given in Table 1.

$$CI = \frac{\text{maks. eigenvalue} - n}{n - 1} \quad (1)$$

$$\text{maks.eigenvalue} = \sum_i w_i . c_i \quad (2)$$

In the next step Consistency Ratio (CR) is calculated by using formula (3):

$$CR = \frac{CI}{RI} \quad (3)$$

Description:

n = Amount of items compared

w_i = Weight

c_i = Sum of column

CR = Consistency Ratio

CI = Consistency Index

RI = Random Consistency Index

Random Consistency Index (RI) can be used based on many references, such as Saaty's research (Saaty, 2008). The test of consistency result in the AHP method will be very useful. If $CR \geq 10\%$, the data acquired is inconsistent and If $CR < 10\%$, the data acquired is consistent (Saaty, 2008).

In order to utilize vague and uncertain information and data, fuzzy set theory can be used (Seiti et al., 2018). Fuzzy MCDM methods are applied for modeling the vagueness and uncertainty of various systems in reality (Karagoz et al., 2020; Liu and Xiao, 2020). Van Laarhoven and Pedrycz (Van Laarhoven et al., 1983) fuzzified the AHP method for the first time. In the following, a ranking fuzzy numbers method is presented in order to enhance the efficiency and precision of the fuzzy AHP approach.

Ranking fuzzy numbers method

There are many ranking fuzzy numbers methods which can use with AHP technique (Lyu et al., 2020; Tian et al., 2020; Karimi et al., 2020; Boral et al., 2020; Amini et al., 2018). The fuzzy environment and equivalent fuzzy numbers of the crisps are given in Table 3. In this research we use a new method which is described as follows:

Comparison of the two triangular fuzzy numbers, $\tilde{A} = (a, b, c)$ and $\tilde{B} = (d, e, f)$ shown in Fig. 4, is done by comparing their equivalent crisp numbers. The important question is how to save the characteristics of a fuzzy number while changing it into a crisp number. In the following, a novel method is presented.

Table 3 Fuzzy evaluation scores for the weights

Linguistic variables	Triangular fuzzy numbers	Reciprocal triangular fuzzy numbers
Equal	(1,1,1)	(1,1,1)
Moderate	(1,1,1.5)	(2/3,1,1)
Strong	(1,1.5,2)	(1/2,2/3,1)
Very strong	(1.5,2,2.5)	(2/5,1/2,2/3)
Extreme	(2,2.5,3)	(1/3,2/5,1/2)

In this method, three possible modes are considered for a triangular fuzzy number:

- i) Triangular with no vertical sides ($a \neq b \neq c$)

Fig. 4 Comparing two triangular fuzzy number with no vertical sides ($a \neq b \neq c$)

First, five vertical α – cuts with equal distances are drawn between a and b.

$$xh_i = a + i(\frac{b-a}{6}) \text{ and } i= 1, 2, 3, 4 \text{ and } 5 \quad (4)$$

Second, the places of each α – cuts to deal with the side ab are calculated.

$$yh_i = (\frac{1}{b-a}) * (xh_i - a) \text{ and } i= 1, 2, 3, 4 \text{ and } 5 \quad (5)$$

This work is also done for side bc.

$$xh_i = a + i(\frac{c-b}{6}) \text{ and } i= 6, 7, 8, 9 \text{ and } 10 \quad (6)$$

$$yh_i = (\frac{-1}{c-b}) * (xh_i - b) + 1 \text{ and } i= 6, 7, 8, 9 \text{ and } 10 \quad (7)$$

And also, $xh_{11} = b$ and $yh_{11} = 1$ are assumed. The equivalent weight of the triangular fuzzy number of $\tilde{A}$ is

$$W_{\tilde{A}} = \sum_{i=1}^{10} (xh_i * yh_i^{0.01}) + b \quad (8)$$

ii) Triangular with a vertical side ($a = b, b < c$) (Fig.5)

Fig. 5 Triangular fuzzy number with a vertical side ($a = b, b \prec c$)

First, ten vertical α -cuts with equal distances are drawn between a and c.

$$xh_i = a + i\left(\frac{c-a}{11}\right) \text{ and } i= 1, 2, 3, \dots 10 \quad (9)$$

Second, the places of each α -cuts to deal with the side bc are calculated.

$$yh_i = \left(\frac{-1}{c-b}\right) * (xh_i - b) + 1 \text{ and } i= 1, 2, 3, \dots 10 \quad (10)$$

And also, $xh_{11} = a$ and $yh_{11} = 1$ are assumed. The equivalent weight of the triangular fuzzy number of $\tilde{A}$ is

$$W_{\tilde{A}} = \sum_{i=1}^{10} (xh_i * yh_i^{0.01}) + a \quad (11)$$

iii) Triangular with a vertical side ($b = c, a \prec b$) (Fig.6)

Fig. 6 Triangular with a vertical side ($b = c, a \prec b$)

First, ten vertical α – cuts with equal distances are drawn between a and c.

$$xh_i = a + i(\frac{c-a}{11}) \text{ and } i= 1, 2, 3, \dots 10 \quad (12)$$

Second, the places of each α – cuts to deal with the side bc are calculated.

$$yh_i = (\frac{1}{b-a}) * (xh_i - a) \text{ and } i= 1, 2, 3, \dots 10 \quad (13)$$

And also, $xh_{11} = b$ and $yh_{11} = 1$ are assumed. Finally, the equivalent weight of the triangular fuzzy number of $\tilde{A}$ is

$$W_{\tilde{A}} = \sum_{i=1}^{10} (xh_i * yh_i^{0.01}) + b \quad (14)$$

Using the same method described above, the weight of $\tilde{B}$ is also calculated as $W_{\tilde{B}}$. At end, the ratio of $W_{\tilde{A}} : W_{\tilde{B}}$ are considered as the ratio of two fuzzy numbers of $\tilde{A} : \tilde{B}$.

It should be mentioned that although ten α – cuts were conducted in this method, but the use of more α – cuts will result in higher accuracy regarding the calculation of the equivalent crisp amount of a fuzzy number.

Moreover, both vertical and horizontal characteristics of a fuzzy number should be used together. However, the horizontal intensity must exceed the vertical. This is the main reason for the power 0.01 of yh_i when calculating the $W_{\tilde{A}}$ or $W_{\tilde{B}}$. The power 0.01 is a result of the many trial-and-error calculations which have led to the highest accuracy.

In the following a comparative example to validate the proposed method is presented:

Comparative example

In this comparative example, the triangular fuzzy numbers of three commonly used sets are employed for comparing the proposed ranking fuzzy numbers method with six well-known ranking fuzzy numbers

methods. These six ranking fuzzy numbers methods are as follows: (1) Nejad and Mashinchi (Nejad et al., 2011), (2) Deng et al. (Deng et al., 2006) (3) Chu and Tsao (Chu et al., 2002), (4) Abbasbandy and Asady (Sign distance method $p = 1$) (Abbasbandy & Asady, 2006), (5) Abbasbandy and Asady (Sign distance method $p = 2$) (Abbasbandy and Asady, 2006) (6) Cheng (Distance method) (Cheng and systems, 1998).

Table 3 shows the results. The three sets are as follows:

Set 1: $\tilde{A} = (1,1,3)$, $\tilde{B} = (1,1,7)$

Set 2: $\tilde{A} = (2,4,6)$, $\tilde{B} = (1,5,6)$, $\tilde{C} = (3,5,6)$

Set 3: $\tilde{A} = (2,3,8)$, $\tilde{B} = (2,3,10)$

Table 4 The results of ranking the three sets by the six mentioned methods and the suggested method.

Method	Set 1	Set 2	Set 3
1	$\tilde{A} < \tilde{B}$	$\tilde{A} < \tilde{B} < \tilde{C}$	$\tilde{A} < \tilde{B}$
2	$\tilde{A} < \tilde{B}$	$\tilde{A} < \tilde{B} < \tilde{C}$	$\tilde{A} < \tilde{B}$
3	$\tilde{A} < \tilde{B}$	$\tilde{A} < \tilde{B} < \tilde{C}$	$\tilde{A} < \tilde{B}$
4	$\tilde{A} < \tilde{B}$	$\tilde{A} < \tilde{B} < \tilde{C}$	$\tilde{A} < \tilde{B}$
5	$\tilde{A} < \tilde{B}$	$\tilde{A} < \tilde{B} < \tilde{C}$	$\tilde{A} < \tilde{B}$
6	$\tilde{A} < \tilde{B}$	$\tilde{A} < \tilde{B} < \tilde{C}$	$\tilde{A} < \tilde{B}$
The proposed method	$\tilde{A} < \tilde{B}$	$\tilde{A} < \tilde{B} < \tilde{C}$	$\tilde{A} < \tilde{B}$

The results indicate that although the suggested method is simpler than the previous methods, it accurately implements the comparisons of the three mentioned sets (Table. 4).

Result and Discussion

DPSIR is a proper technique to evaluate different factors which are affected and environmental situation. In this case, driving force, pressure factors, impacts, and state regards to the pressures and driving forces are considered based on the aim of developing industrial ecology in Iran's industrial estates. Hence,

by analyzing the some of the industrial estates and their current conditions such as their IE knowledge, waste generation, raw material, energy and water consumption and also their clustering system, the obstacles of IE development were investigated. Based on the background of studies in scientific research with the high cited related references in significant research, related to industrial ecology 43 factors were extracted based on DPSIR model. The extracted factors were consulted on the basis of expert opinion (based on questionnaire form). 22 factors were designated and ranked as effective factors in the industrial ecology model according to DPSIR criteria. The DPSIR factors are given in Table 5. Figure 7 shows the options listed in the form of the criteria and alternatives.

Table 5 DPSIR factors with the significant references and expert opinion

DPSIR/IE	Expert Ranking	References
Driving forces		
Reduce Environmental Pollution	1	Cao, 2019; Destek and Aslan, 2020; Hoang et al., 2017; Shi and Hassan, 2019; Apergis et al., 2020; Wang, 2019; Bhatia and Gakkhar, 2017
Reduce Resource Usage	2	Shaw et al., 2019; Miller and Pisani, 2018; De Stefano et al., 2016; Pujara et al., 2017; Riebsame, 2019
Reduce Waste Generating	3	Minelgaitė and Liobikienė, 2019; Pirani and Arafat, 2016; Fremstad, 2017; Adeniran et al., 2017; Ding et al., 2018; Jagtap and Rahimifard, 2019; Ding et al., 2016; Luangcharoenrat et al., 2019; Grazhdani, 2016; He et al., 2019; Chalak et al., 2016; Jamshidieini et al., 2019; Matsuda et al., 2018; Hao et al., 2019
Industries Variety	4	Law et al., 2016; Goswami et al., 2019; Balakrishnan and Gunasekaran, 2018; Aziz et al., 2017
Increase Regional Independence	5	Qisthina et al., 2019; Welch et al., 2017; Zhou et al., 2019; Hage et al., 2018; Moher et al., 2016
Pressures		
Costs	1	Ley et al., 2017; Matheson, 2019; Eriksson et al., 2016; Otto et al., 2018; Wang et al., 2018; Istrate et al., 2019; Blondin et al., 2017; Martinez-Sanchez et al., 2016; Das et al., 2016
Lack of Databases	2	Burger et al., 2018; Sacchi and Prosman, 2017; Bilal et al., 2017; Mwanza et al., 2018; de Souza et al., 2016
Lack of Industries Knowledge	3	Conke, 2018; Sodhi et al., 2020; Afroz et al., 2017; Huang et al., 2018; Leopoldino et al., 2019; Samuel et al., 2019; Resmi and Fasila, 2019
Old Technologies	4	Dobrotă and Dobrotă, 2018; Mutafela et al., 2018; Tozlu et al., 2016; Xu et al., 2018; Jani and Hogland, 2017

DPSIR/IE	Expert Ranking	References
Low Energy Prices	5	Wahlroos et al., 2017; Zhang et al., 2017; Ohnishi et al., 2018; Kumar et al., 2017; Meylan et al., 2018; Münster and Meibom, 2011
States		
Low Supervision on Pollutions	1	James, 2009; Zhang and Wang, 2019; Shen and Wang, 2018; Koo et al., 2019
Low Supervision on Energy Consuming	2	De Kok et al., 2019; Yuan and Zhao, 2016; Yang et al., 2017; Logue et al., 2018; Tang et al., 2018
Low Supervision on waste Generation	3	Abebe et al., 2017; Ramachandra et al., 2018; Ghanimeh et al., 2019; Chen and Lu, 2017; Islam et al., 2019
Impacts		
Reduce Industries Expenses	1	Zhao et al., 2016; Maiti et al., 2016; Lee and Vachon, 2016; Bufalo et al., 2018; Sellitto and de Almeida, 2019; Islam et al., 2019
Sustainable Development	2	Kacprzak et al., 2017; Rodić and Wilson, 2017; Fuldauer et al., 2019; Ferronato et al., 2018; Adeniran, 2017; Pujara et al., 2019; Kaza et al., 2018; Mishra et al., 2018
Improve Regional Human Health	3	Caballero-Anthony, 2018; World Health Organization, 2019; Feingold et al., 2019; Noormal et al., 2019; Frost et al., 2017; Padash and Rajabzadeh Ghatari, 2020; Padash et al., 2015
Improve Regional Environmental Quality	4	Park and Howard, 2018; Padash and Rajabzadeh Ghatari, 2020; Padash et al., 2016; Charfeddine et al., 2018; Chen et al., 2018; Xie and Yi, 2019
Reduce Waste Generating	5	Chalak et al., 2016; Jamshidieini et al., 2019; Matsuda et al., 2018; Hao et al., 2019; Pirani and Arafat, 2016; Fremstad, 2017; Adeniran et al., 2017; Ding et al., 2018;
Responses		
Industries Training	1	Liu et al., 2018; Peng, 2019; Lahafi et al., 2019; Liu, 2020; Hanh, 2018; Dragomir, 2020; Yu et al., 2020
Improve IE Law	2	Saavedra et al., 2018; Belaud et al., 2019; Li, 2018; Malinauskienė et al., 2018; Nguyen et al., 2019
Establish IE National Database	3	Low et al., 2018; Sullivan et al., 2018; Pauliuk ET AL., 2019; Yu and Wiedmann, 2018
Modify Industries Clustering	4	Bergman and Feser, 2020; Kanemoto et al., 2019; Sunny and Shu, 2019; Engelberg et al., 2018;

Fig. 7 Proposed generic DPSIR framework for IE

As can be seen in Table 6, the DPSIR factors are given. Moreover, due to the AHP hierarchy, driving forces, pressures, states, and impacts are assumed as the criteria, whereas the responses are considered as the alternatives.

Table 6 DPSIR factors

	Driving forces	Criteria
D1	Reduce environmental pollution	C1
D2	Reduce resource usage	C2
D3	Reduce waste generating	C3
D4	Industries variety	C4
D5	Increase regional independence	C5
	Pressures	Criteria
P1	Costs	C6
P2	Lack of Databases	C7
P3	Lack of industries knowledge	C8
P4	Old technologies	C9
P5	Low energy prices	C10
	States	Criteria
S1	Low Supervision on pollutions	C11
S2	Low Supervision on Energy consuming	C12
S3	Low Supervision on waste generation	C13

Impacts		Criteria
I1	Reduce industries expenses	C14
I2	Sustainable development	C15
I3	Improve regional human health	C16
I4	Improve regional environmental quality	C17
I5	Reduce waste generating	C18
Responses		Alternative
R1	Industries training	A1
R2	Improve IE law	A2
R3	Establish IE national database	A3
R4	Modify industries clustering	A4

Due to Table 6, there are 18 criteria and four alternatives. It should be noted that simple analysis of DPSIR usually provides responses that affect driving force and pressure factors. But, it cannot prioritize responses and clear the strategy or choose the first responses to carry out. While DPSIR combine with a FAHP method, we can have the priorities and consequently a better plan.

Table 7 FAHP final weights

Impacts		States		Pressures		Driving forces	
I1-Reduce industries expenses		S1-Low Supervision on pollutions		P1-Costs		D1 - Reduce environmental pollution	
R1	0.254	R1	0.233	R1	0.254	R1	0.25
R2	0.254	R2	0.277	R2	0.243	R2	0.25
R3	0.249	R3	0.277	R3	0.249	R3	0.25
R4	0.243	R4	0.213	R4	0.254	R4	0.25
I2-Sustainable Development		S2-Low Supervision on Energy consuming		P2-Lack of Databases		D2 - Reduce resource usage	
R1	0.228	R1	0.254	R1	0.288	R1	0.25
R2	0.27	R2	0.243	R2	0.288	R2	0.25
R3	0.27	R3	0.249	R3	0.173	R3	0.25
R4	0.232	R4	0.254	R4	0.251	R4	0.25
I3-Improve regional human health		S3-Low Supervision on waste generation		P3-Lack of industries knowledge		D3 - Reduce waste generating	
R1	0.249	R1	0.254	R1	0.272	R1	0.254
R2	0.243	R2	0.243	R2	0.237	R2	0.254
R3	0.254	R3	0.249	R3	0.219	R3	0.249
R4	0.254	R4	0.254	R4	0.272	R4	0.243
I4-Improve regional environmental quality				P4-Old Technologies		D4 - Industries Variety	
R1	0.249			R1	0.272	R1	0.254

R2	0.243	R2	0.237	R2	0.254
R3	0.254	R3	0.219	R3	0.248
R4	0.254	R4	0.272	R4	0.243
I5-Reduce waste generating		P5-Low energy prices		D5 - Increase Regional Independence	
R1	0.243	R1	0.272	R1	0.25
R2	0.254	R2	0.219	R2	0.25
R3	0.254	R3	0.272	R3	0.25
R4	0.249	R4	0.237	R4	0.25

The weighting results and the importance of the criteria to the alternatives are presented in Table 7.

This section examines the importance of each alternative to the criteria in order to evaluate the importance and prioritization of the criteria.

In Figure 8, the importance of the following Driving Forces criteria for Responses alternatives is examined. As shown by the output of the radar diagram, the D1 and D2 and D5 sub-criteria are of equal importance to the alternatives; but the D3 = Reduce Waste Generating sub-criteria, give more effectiveness and importance to the sub-criteria R1 = Industries Training and R2 = Improve IE law; In other words, industries training and improve of IE law, can have a significant impact on reduce waste generating.

This is also true of the D4 = Industries variety sub-criterion, and shows the importance of the sub-criteria R1 = Industries training and R2 = Improve IE law.

Fig. 8 Radar Diagram, Importance of Driving Forces Sub-Criteria, to Responses Alternatives

In Figure 9, the importance of the following Pressures sub criteria for Responses alternatives is examined. As can be seen, alternatives such as R1 = Industries Training and R4 = Modify Industries Clustering are most important to the P1 = Costs sub criterion. But in general, the P1 = Costs sub criteria, the importance of the effects is very close.

As can be seen from this radar diagram, the P2 = Lack of Databases sub-criterion is most relevant to R1 = Industries training and R2 = Improve IE law; and then there is the sub-criterion P3 = Lack of industries knowledge and P5 = Low energy prices. The P4 = Old technologies sub-criterion also places greater importance and equality on R1 = Industries training and R4 = Modify industries clustering.

Fig 9 Radar Diagram, Importance of Pressures Sub-Criteria, to Responses Alternatives

In Figure 10, the importance of the following States sub criteria for Responses alternatives is examined. As can be seen, Alternatives such as R2 = Improve IE law and R3 = Establish IE national database are most important to the S1 = Low Supervision on pollutions sub-criterion among all sub-criteria. This confirms that issues such as low supervision on pollutions can be due to weaknesses in IE rules and Lack of industries knowledge. Meanwhile, Sub criterion R4 = Modify industries clustering is the least important among all sub-criteria of States.

Fig. 10 Radar Diagram, Importance of States Sub-Criteria, to Responses Alternatives

In Figure 11, the importance of the Impacts sub-criteria relative to the Responses options is examined. As can be seen, Alternatives such as R2 = Improve IE law and R3 = Establish IE national database are the most important sub-criterion I2 = Sustainable development among all sub-criteria. This confirms that topics such as Sustainable development can be influenced by Improve IE and Lack of industry knowledge in industries. In this sub-criterion, the option R1 = Industries training evaluated less important.

Fig. 11 Radar Diagram, Importance of Impacts Sub-Criteria, to Responses Alternatives

In a glance at the results of the FAHP weighting evaluation across all sub criteria, the sub criterion P2 = Lack of Databases has the lowest significance level of 0.137 compared to R3 = Establish IE national database and in this sub criterion, option R1 = Industries training and R2 = Improve IE law have the highest significance of 0.288.

In this study, a new ranking fuzzy numbers method is used to reduce the human errors on decision making and flexible the results. The proof can be observed in many studies (Chang et al., 2009; Chen and Chen, 2010; Nieto-Morote and Ruz-Vila, 2012). After the pairwise questionnaires are gathered from the experts, the average value of the comparisons is calculated and transferred to the fuzzy environment based on Table 1. The inconsistency ratios are checked and sure that all of them are lower than 0.1. Then, due to the ranking fuzzy numbers method, the weights of the fuzzy matrices are gained and given in Table 6.

The numbers in Table 8 shows that there are little differences between the judgments and the effects of all four responses (alternatives) are close. However, the importance of the main criteria groups are assumed equally, and the sub-criteria are also considered equal, and just the pairwise comparison of the alternatives due to each criterion are considered. Finally, the total weights are calculated and shown in Table 8 and Figure 12.

Table 8 Final weights and the priorities

	Final Weight	Priority
R1	Industries training	0.225
R2	Improve IE law	0.251
R3	Establish IE national database	0.246
R4	Modify industries clustering	0.249

Fig. 12 Final weights of alternatives

Due to the results, it can be concluded that if we want to develop the IE efficiently, first step legal support is needed. After that, the system of industrial estate clustering needs modifications according to the

IE legal and concepts. By these two steps, a proper basis is provided to start the next steps; IE database and industrial training. However, plan it discussed in detail.

During the interviews and inspections, another important point which was observed was the lack of familiarity of workers and manager with the concepts of industrial ecology. Even with all the issues mentioned and the problems facing the development of industrial ecology, there is still considerable potential for waste flow between industrial units, but the main reason there is no such flow is the lack of information and understanding of the units about each other. Generally, industrial units in the estate work as an island and have no contact to the other units, and only some wastes such as cardboard boxes, nylon, aluminum, and plastic are collected to be recycled and are taken out of the estate. Whereas having contact between the units makes material flow possible between them. Industrial ecology brings with it the culture of recycling and reusing waste and energy and saving. The requirements for this culture are knowledge, communication, and information. The lack of these three elements and using too much energy and resources are among the major problems in Iran's industry. Considering the current economic crisis and condition in Iran, concentrating on industrial ecology plans can be a suitable approach in developing an austerity policy. Reducing costs, saving, recycling wastes with the industrial ecology approach can make the country less dependent on importing primary resources and improve the economic status in a moderate period.

Another issue worth notice is the unsuitable location selection of industrial units based on the possibility of creating an energy and waste flow with the least distance between them. Useful studies are available on correcting the clustering of industries with the industrial ecology approach, and their experiences can be used to improve this area. For example, rectifying clustering in Australia's industrial estates (Roberts, 2004) can be a suitable example to make corrections in this industrial estate.

If a complete series of information is collected on the units of the industrial estate and the potentials and missing areas of the flow network are identified in the estate, the management can massively help complete the flow network with attracting and establishing new industries. Not having a suitable, complete,

and exact database to carry out primary industrial ecology studies is one of the obstacles facing the development of industrial ecology in this estate.

Information is the base and foundation of industrial ecology studies. The studies carried out in some estates of produced waste are general waste management studies and lack the quality and accuracy to develop and material flow model. Information such as each plants production processes, waste analysis, input material analysis, energy consumption, and location data are subjects which provide the needed information for industrial ecology studies. Developing software such as websites and online databases can help improve this situation considerably. Based on the results of the analysis and the explanations provided, the proposed action plans for developing the industrial ecology model of Iran based on the resulting priorities are presented in Table 9.

Table 9 Suggested action plans for developing an Industrial ecological model based on Responses

Priority	Responses Alternatives	Action Plans	Responsible organizations
1	Improve IE law	Industrial Ecology is an integrated, operationalized vision of sustainable development, a vision that establishes an interconnected system that holds everything in the environment and sustainability; So these can be the most important suggestions in this section: 1- Developing and defining new laws and regulations; 2- Developing standards for the development of industrial estates based on industrial ecology; 3- Formulating incentives and tax exemption laws for industries subject to industrial ecology	1-Department Of Environment (DOE); 2-Ministry of Industry, Mine and Trade;
2	Modify Industries Clustering	Today, the development of industrial clusters plays a pivotal role in the economic and industrial policies of developed and developing countries. Suggested items include: 1- Implementation of industry feasibility studies in accordance with Iranian environmental laws and regulations, with emphasis on EIA and SEA; 2- Changing the definitions of the criteria for establishing industries in Iran and its tendency towards environmental and industrial ecological priorities; 3- Redefining industrial clusters with the approach of industrial ecology and renewable energies and the concepts of reuse cycles;	1-Department Of Environment (DOE); 2-Ministry of Industry, Mine and Trade; 3- Ministry of Science, Research and Technology 4- Vice

Priority	Responses Alternatives	Action Plans	Responsible organizations
		4- In addition to, Improved network communication, an emphasis on indirect support, a combination of competition and collaboration to foster learning and innovation, enhance collaboration between small and large units, and strengthen the partnership cluster of "clusters", "government" and "universities" are also suggested. .	Presidency for Science and Technology
3	Establish IE National Database	<p>The national database can be one of the most important pillars in the evaluation and updating of information on industrial ecology in Iran; for this purpose the following suggestions are offered:</p> <ul style="list-style-type: none"> - Definition of National Database of Environment and Industry; - Equipping the national database with the latest scientific software in the world with the ability to trace and locate geographically; - Defining and predicting the country's strategic needs in industry and environment with an industrial ecology approach; - Definition of different industry identifiers for all industries in the country to update their industrial and environmental information in the database. 	<p>1-Department Of Environment (DOE);</p> <p>2-Ministry of Industry, Mine and Trade;</p> <p>3- Ministry of Science, Research and Technology</p> <p>4- National mapping agency;</p> <p>5-Geographical Organization of the country;</p> <p>6-The country's data and data analysis center,</p>
4	Industries Training	<p>In the process of sustainable development, environmental education as a key lever plays a vital role in fostering public participation. Agenda 21 and the MDG goals are also in support of this; while paying attention to environmental education structures of the industry and paying particular attention to industrial ecology can advance the paths of sustainable industrial development faster based on industrial ecology approach; The following suggestions are made:</p> <ul style="list-style-type: none"> - Development of a network of industrial and environmental education with an industrial ecology approach; - Expanding the cooperation of universities with industries and industrial companies; - Definition of National Industrial Ecology Education Network; - Define the requirements of industrial ecology training for each established applicant. 	<p>1-Department Of Environment (DOE);</p> <p>2-Ministry of Industry, Mine and Trade;</p> <p>3- Ministry of Science, Research and Technology</p> <p>4- Ministry of Interior</p>

Conclusions

Industrial ecology in Iran has been failed to notices so far. The results males it crystal clear that the concepts of industrial ecology have not been implemented in Iran's industrial estates. Based on the results of the hybrid model of DPSIR and FAHP model, driving forces, pressures, impacts, states factors, and responses to developing IE in industrial estates of Iran are evaluated. Due to the results, it can be concluded that if the IE development wanted to carry out efficiently, first step legal support is essential. This action provides a legal guarantee for the development of industrial ecology. The experience of countries with a proper development state of industrial ecology shows that these basic actions must be finally carried out, and that the legislator should align with industrial ecology policies. After that, the system of industrial estate clustering needs modifications according to the IE legal and concepts. Currently, Ministry of Industries and Minerals of Iran carry out clustering with different and sometimes contradictory concepts with the industrial ecology, which in the first step, there is a need to change the perspective according to the revised rules, leads to a fundamental change in the clustering system of small and large industries in the country. According to the studies, the absence of a comprehensive database in the field of material flow (primary and waste) and energy in all industries of the country is one of the most important obstacles to the planning and management of industrial ecology in the country. Certainly, without an intelligent IT-based database, the development of industrial ecology is not feasible. The proposed action plan is intended only to achieve the fastest possible achievements of the industrial ecology of Iran in spite of the lack of background and previous actions in this regard. Therefore, it can be said that the proposed route is the most reliable way to succeed based on current local and regional conditions in Iran.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

This study did not use any financial support or credit line.

Authors' contributions

All authors - AP, HV, HN, RF - contributed to all parts of this publication. All authors read and approved the final manuscript.

Acknowledgements

The authors would like to thank Mr. Mehdi Hosseinpour for his help in field inspections and also Ms. Zahra Mohseninia and Mr. Ali Rashidi for collecting the industrial information.

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Figures

Figure 1

Summary of research methodology

Figure 2

The hierarchical structure of decision-making

Figure 3

Figure 4

Comparing two triangular fuzzy number with no vertical sides ($a \neq b \neq c$)

Figure 5

Triangular fuzzy number with a vertical side ($a = b, b \leq c$)

Figure 6

Triangular with a vertical side ($a = b$, $b \neq c$)

Figure 7

Figure 8
Radar Diagram, Importance of Driving Forces Sub-Criteria, to Responses Alternatives

Figure 9

Radar Diagram, Importance of Pressures Sub-Criteria, to Responses Alternatives

Figure 10

Radar Diagram, Importance of States Sub-Criteria, to Responses Alternatives

Figure 11

Radar Diagram, Importance of Impacts Sub-Criteria, to Responses Alternatives

Figure 12

Final weights of alternatives