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Research Article

Identifying Criteria and Indicators and Determining the Alternative Scenario for Transforming Industrial Towns into Eco-industrial Parks

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Abstract
Manufacturing waste in that industry is dominant and attracts the attention of the town waste management system. The present study aims to identify the best alternative for managing environmental problems and waste in Ahvaz industrial towns. The criteria and indicators of transforming industrial towns into EIPs are collected and analyzed from different aspects and, then, prioritized using fuzzy and TOPSIS fuzzy techniques. Accordingly, four main criteria (environmental, economic, social/legal, and specialized/technical) are considered, for each of which some sub-criteria are considered. According to the criteria and sub-criteria as well as library and field studies, six alternatives are considered. Results of the questionnaire distributed among experts and employees in Ahvaz industrial towns are collected. The items in each criterion are scored 1-10. Calculations performed in fuzzy and real environments reveal compiling executive guidelines and standards (0.591) is the most appropriate alternative, followed by tertiary education and infrastructural culture building (0.557), modifying and updating laws and regulations (0.535), developing industrial research, development and training units (0.462), providing financial support for knowledge-based activities of industries (0.419) and developing industry monitoring and evaluation units (0.371) as the first to sixth priorities. The results indicated executive guidelines and standards should be compiled to manage environmental problems in industrial towns and transform towns into echo-industrial parks. It is hoped that decision-makers in this field will take an important step to transform industrial towns into echo-industrial parks, minimize environmental problems and manage waste by developing executive guidelines and updated and advanced standards.
Keywords: Echo-Industrial Park, Ahvaz, TOPSIS, Fuzzy Theory, Waste Management

Introduction

With the development of industries in recent years, governments have realized that they are more capable of providing services, controlling and managing manufacturing pollutants, and reducing service costs by gathering industries in one place. Agglomeration of industries in a limited area has

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advantages and disadvantages, e.g., the cumulative effects of pollutants and manufacturing waste are among the most important disadvantages of these towns.

High agglomeration of a specific industry in industrial towns is among the problems of industrial towns in Iran. Therefore, manufacturing waste in that industry is dominant and attracts the attention of the town waste management system. Industrialized countries have used various solutions to improve the general condition of industrial towns. Investigating industrial ecology, upgrading town management systems, and transforming towns into eco-industrial parks are among the most efficient techniques. Changing the system has provided achievements such as reducing pollutants, manufacturing waste, and raw materials entering the town and increasing production. In eco-industrial parks, the existing industries in the town are combined in a way that the waste of some plants could be used as raw materials and input of another plant. Thus, manufacturing waste is minimized and less raw materials are consumed, resulting in significant economic savings.

Industrial ecology considers technological dynamics as an important element to move from an unsustainable industrial system to a sustainable industrial ecosystem (Lambert & Boons, 2002).

The idea of EIP was developed in the 1960s as a locally collaborative set of strategies that industrial facilities could follow to use materials more efficiently and reduce and recycle waste (Tudor et al., 2007). Following the renewed attention since the 1992 Earth Summit, academic research, as well as policy measures on EIPs, has increased (Gibbs & Deutz, 2004). Five years after the energizing Rio Earth Summit, research began to examine methods for moving society and industry away from linear throughput toward closed-loop materials and energy strategies to reduce waste and pollution (Ehrenfeld & Gertler, 1997). Only a year later, the idea of eco-industrial parks was recognized as the infant of a field in the research world, as it had just emerged as an approach towards environmentally sustainable socio-economic development (Côté & Cohen-Rosenthal, 1998). Given that no specific definition of an eco-industrial park was provided due to the multitude of objectives, productivity timeframes, and capital costs, it was agreed in 2000 that eco-industrial networks have not been viable (Chertow, 2000). An early definition that remained relevant was the one federally accepted by the U.S. Environmental Protection Agency (EPA) field book, which defines EIP as "a community consisting of manufacturing and service businesses that seek to improve environmental and economic performance through collaboration in managing environmental and resource problems including energy, water, and materials." The community of businesses seeks a collective benefit using the collaboration that is greater than the sum of the individual benefits that each company would realize in case of optimizing its performance." As research progressed, definitions of EIP such as the U.S. EPA was narrowed down to the networking ability of companies to reduce waste, recover value and achieve demand (Tudor et al., 2007). As these modern definitions became empowered, researchers began to question the concept of EIPs and whether this theoretical concept has truly entered the professional industry (Gibbs & Deutz, 2007). Efforts to implement industrial symbiosis and EIPs were renewed. A case study (2015) revealed the real impact of industrial production on global emissions, reporting that 62% of the global greenhouse gas emissions in 2012 were derived from industrial production emissions (Lu et al., 2015; . International Energy Agency, 2014). These applied research and initiatives for industrial sustainability and reduction of greenhouse gas emissions through EIPs continued until the end of the 2010s (Martin & Harris, 2018; Guo et al., 2018; Farooque et al., 2021). In the late 2010s and early 2020s, researchers acknowledged the importance of material exchanges to counter the effects of resource depletion. Currently, they are conducting innovative research on industrial symbiosis concerning EIPs.

Recent studies have focused on using loop diagrams to understand social impacts on material interdependencies, utilizing scenario-based approaches to analyze value chains during disruptive

events, and analyzing ecological food webs to understand echo-industrial trade-offs (Morales & Diemer, 2019; Morales et al., 2022; Layton et al., 2016a; Layton et al., 2016b). Madanhire and Mbohwa (2016) investigated how the EIP concept could be implemented in a city with a developing economy to reduce the large amount of industrial waste disposed of in landfills and improve the current unsustainable use of resources, energy, and water in the study area (Harare, Zimbabwe).

Ribeiro et al. (2017) described an integrated approach to transform an industrial park into an echo-industrial park by combining three interconnected objectives, namely, consolidating industrial symbiosis, promoting sustainable accessibility, and developing multi-functionalities. Susur et al. (2019) systematically examined 104 industrial eco-parks in 24 countries mentioned in 66 papers considering the perspective of strategic management in the transition to developing EIPs. Paying attention to social approaches is of particular importance for improving industrial zones toward EIPs (Genc et al., 2019). In addition to social approaches, evaluating the environmental performance of eco-industrial development in industrial towns should also be investigated (Fan & Fang, 2020).

Numerous good studies have been conducted on EIPs in China. Honga and Gasparatosb (2020) presented a critical approach based on the available evidence on key institutional aspects, sustainability impacts, and implementation challenges related to the development and operation of EIPs in China through institutional analysis of key policy documents and broad narrative-based literature. Qing Hu et al. (2021) studied Nanchang High-tech Development Zone in China to evaluate the ecological impact of land use in EIP based on life cycle assessment.

Recent articles have focused on identifying criteria and indicators for transforming industrial towns into eco-industrial parks. The aim is to create sustainable industrial zones that balance economic growth with environmental protection and social responsibility.

A study identified nine criteria and 21 indicators for assessing the sustainability of industrial parks. The criteria included resource efficiency, pollution prevention, and social responsibility, while the indicators included energy consumption, water use, and waste generation (Tang et al., 2021).

Another study proposed a framework for transforming industrial towns into eco-industrial parks. The framework focused on three stages: analysis, planning, and implementation. The analysis stage involved identifying the strengths, weaknesses, opportunities, and threats of the industrial town. The planning stage involved developing alternative scenarios for transforming the town into an eco-industrial park. The implementation stage involved selecting the best scenario and implementing it (Alavi et al., 2021).

The other article discussed the importance of stakeholder engagement in the transformation of industrial towns into eco-industrial parks. The article emphasized the need for collaboration among stakeholders, including government agencies, industry, and local communities. The authors suggested that stakeholder engagement could help identify opportunities and challenges, build trust, and develop a shared vision for the transformation (Wang et al., 2021).

It could be said that no serious action has been taken on implementing and developing EIPs in Iran. Therefore, there is no EIP, which causes a large amount of energy and resources to be wasted. Developing a local model for expanding EIPs is of great importance so this could be considered the most important step towards sustainable development.

The present research aims to collect and examine the criteria and indicators of transforming industrial towns into EIPs from different aspects and prioritize them using fuzzy and TOPSIS fuzzy techniques.

Material and Methods

TOPSIS fuzzy multi-criteria decision-making model

TOPSIS model, proposed by Hwang and Yoon (1981), is among the most widely used multi-criteria decision-making models. In this decision-making method, it is assumed that k decision-makers evaluate m decision-making alternatives by n criteria. In this research, triangular fuzzy numbers are used, in which a triangular fuzzy number $\tilde{A}$ could be defined as (a, b, c) (Figure 1).

Linguistic variables represent values as literal expressions. The concept of a linguistic variable is useful in well or complex undefined situations (Chen & Hwang, 1992) (Table 1).

$$\mu_{\tilde{A}(x)} = \begin{cases} 0, & x < a \\ \frac{x-a}{b-a} & a \le x \le b \\ \frac{c-x}{c-b} & b \le x \le c \\ 0 & x > a \end{cases}$$

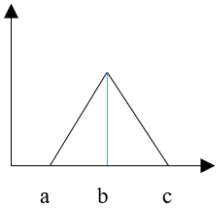

Figure 1. Triangular fuzzy number (Chen & Hwang, 1992)

Table 1. Verbal variables of importance weight and ranking of each criterion in the used fuzzy space

Verbal variables of ranking (Wang Tien & Chang, 2007; Yong, 2006)		Verbal variables of importance weight of each criterion (Chu, 2002; Chu & Lin, 2003)	
(0,0,0.1)	(VL) Very low	(0,0,0.1)	(VL) Very low
(0,0.1,0.3)	(L) low	(0,0.1,0.3)	(L) low
(0.1,0.3,0.5)	(ML) Medium low	(0.1,0.3,0.5)	(ML) Medium low
(0.3,0.5,0.7)	(M) Medium	(0.3,0.5,0.7)	(M) Medium
(0.5,0.7,0.9)	(MH) Medium High	(0.5,0.7,0.9)	(MH) Medium High
(0.7,0.9,1)	(H) High	(0.7,0.9,1)	(H) High
(0.9,1,1)	(VH) Very High	(0.9,1,1)	(VH) Very High

TOPSIS fuzzy approach is presented as follows:

I) Denotes a set consisting of *k* decision-makers $E=\{D_1, D_2, ..., D_k\}$

II) Represents a set consisting of m alternatives $A=\{A_1, A_2, ..., A_m\}$

III) A set is consisting of *n* criteria $C=\{C_1, C_2, ..., C_m\}$ that measures the performance of alternatives.

IV) Indicates the performance ranking *Ai* (*i= 1, 2, ..., m*) considering *Ci* (*j= 1, 2, ..., n*) as $X=\{Xij, i= 1, 2, ..., m, j= 1, 2, ..., n\}$

It is assumed that there are *K* decision makers and the fuzzy rating of each decision maker D_k (*k=1, 2 ,..., K*) could be represented as triangular fuzzy numbers (*k= 1, 2, ..., K*)$\tilde{R}_k$ by membership function $\mu_{\tilde{R}_k}(x)$. (1)

The fuzzy rating of all decision-makers is defined as follows:

k= 1, 2, 3, ..., k and $\tilde{R} = (a, b, c)$ (2)

Where $a = min_k\{a_k\}$, $b = \frac{1}{k}\sum_{k=1}^{k} b_k$ and $c = max_k\{c_k\}$. Fuzzy weight ($\widetilde{w}_j$) of each criterion could be defined as follows:

$$\widetilde{w}_j = \left(w_{j1}, w_{j2}, w_{j3}\right) \quad (3)$$

Where $w_{j2} = \frac{1}{k}\sum_{k=1}^{k} w_{jk2}$, $w_{j1} = min_k\{w_{jk1}\}$ and $w_{j3} = max_k\{w_{jk3}\}$.

In general, an MCDM problem could be presented as the following matrix:

$$\widetilde{W} = [\widetilde{w}_1, \widetilde{w}_2, \dots, \widetilde{w}_n] \quad \text{و} \quad D = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix}$$

To avoid mathematical complexity in the decision-making process, a linear transformation is used to convert the scale of different criteria into a comparative scale. The criteria could be divided into benefit and cost criteria. As a result, the normalized fuzzy matrix could be expressed as follows:

$$R = \left[\tilde{r}_{ij}\right]_{m\times n} \quad (4)$$

where B and C are the benefit and cost criteria, respectively. Thus, we have:

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \quad j \in B\ , c_j^* = max_i c_{ij}$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right) \quad j \in C\ , a_j^- = min_i a_{ij}$$

Considering the different importance of each criterion, the weighted normalized fuzzy matrix is created:

$$\tilde{v}_{ij} = \tilde{r}_{ij}\,(0)\widetilde{w}_j \quad \text{و} \quad \tilde{V} = \left[\tilde{v}_{ij}\right]_{m\times n} i, j = 1,2,\dots,m \quad (5)$$

Fuzzy positive (A^*) and negative (A^-) ideal solutions could be defined as follows:

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-) \quad (6)$$

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_n^*) \quad (7)$$

If $\widetilde{m} = (m_1, m_2, m_3)$ and $\tilde{n} = (n_1, n_2, n_3)$ are two triangular fuzzy numbers, and the distance between them could be calculated using the maximum height method (Chen and Hwang, 1992; Negi, 1989).

$$d_v(\widetilde{m}, \tilde{n}) = \sqrt{\frac{1}{3}[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2]} \quad (8)$$

As a result, the distance of each alternative from A* and A- could be calculated as follows:

$$d_i^* = \sum_{j=1}^{n} d_v\left(\tilde{v}_{ij}, \tilde{v}_j^*\right) \quad i = 1,2,\dots,m \quad (9)$$

$$d_i^- = \sum_{j=1}^{n} d_v\left(\tilde{v}_{ij}, \tilde{v}_j^-\right) \quad i = 1,2,\dots,m \quad (10)$$

The closeness coefficient is used to rank all the arrangements. This criterion considers the distance of arrangements from fuzzy positive and negative ideal solutions simultaneously. Then, the closest relative distance from the fuzzy positive ideal solution is selected.

$$0 \le cc_i \le 1 \quad \text{و} \quad cc_i = \frac{d_i^-}{d_i^* + d_i^-} \quad \text{i} = 1,2,\dots,\text{m} \quad (11)$$

To make a decision, ccis' are prioritized and an alternative with greater cci is selected. This applied and case study was conducted in Ahvaz industrial towns No. 2 and No. 3 to present a proper scenario for managing environmental problems and waste considering the conditions of industrial towns. The research steps could be summarized as follows:

1. Selecting the criteria that are more important than other criteria in an industrial town: This step was considered because the criteria for selecting scenarios and management options vary in industrial towns. This step was done through library and field studies.

2. Identifying the management methods that are more useful in the studied industrial town: This step was carried out by distributing the researcher-made questionnaire among the experts accessible in this field. The questionnaire was distributed among 50 individuals, including 6 university professors, 12 managers and 32 employees, and specialists in Ahvaz industrial towns No. 2 and No. 3, and, then, all the results were collected.

3. Choosing the most suitable alternative: The alternatives obtained in the second step were prioritized by the TOPSIS fuzzy method in Excel software using the more important criteria (output of step 1).

Study area

Ahvaz industrial towns (No. 2 and No. 3) are located near Ahvaz city in southern part of Iran. The total area of No. 2 is 282.4 hectare (ha), the area of the operational phase is 281.5 ha and the assigned area is 141.91 ha.

The total area of No. 3 is 160 ha, the area of the operational phase is 130 ha and the assigned area is 93.61 ha. Figures 2 and 3 indicate maps of the establishment of industrial units by the type of use in Ahvaz industrial towns No. 2 and No. 3, Also illustrate the number of active industries in Ahvaz towns No. 2 and No. 3 by type of use. Based on the data of town No. 2, 66 active units were operating in 8 types of industrial use, most of which were related to chemical, food, and metal uses, followed by cellulose, non-metallic mineral, service, and textile use with a smaller percentage. In town No. 3, 59 active units were operating in 6 types of industrial use, most of which were related to metal use with a significant difference, followed by chemical, non-metallic mineral, oil and gas service, electricity and electronic and food uses with a smaller percentage.

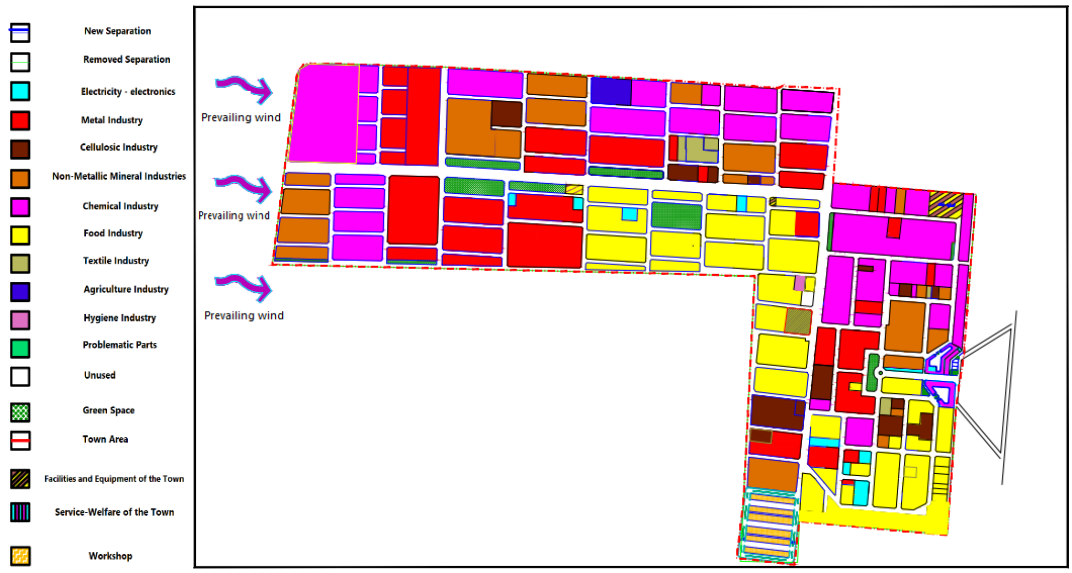

Figure 2. Zoning of Ahvaz town No. 2

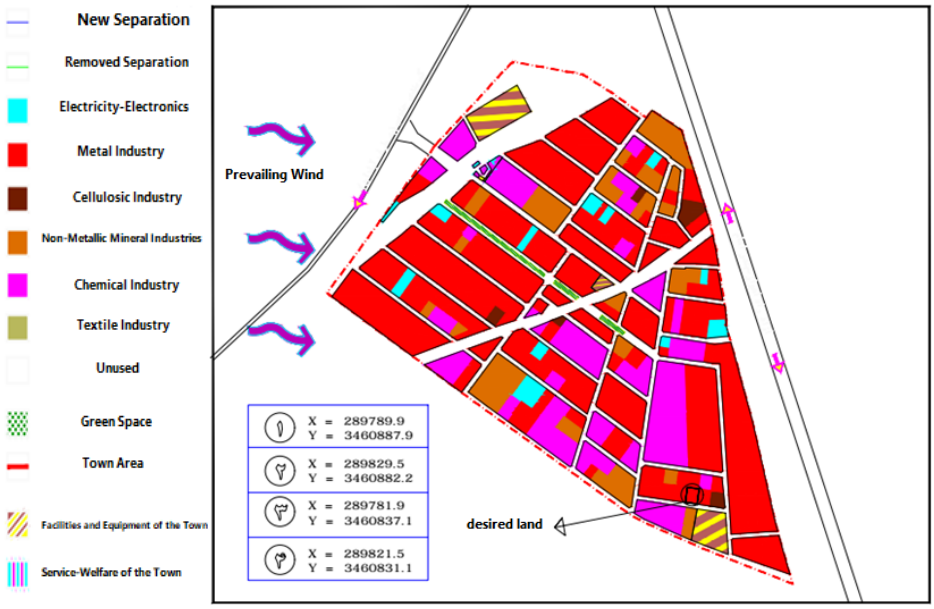

Figure 3. Zoning of Ahvaz town No. 3

The largest amount of manufacturing waste among all the uses of town No. 2 was related to industrial waste with a significant difference, followed by special waste, food, and green spaces. The largest amount of industrial manufacturing waste was related to non-metallic mineral, metal, food, chemical, and electricity and electronic uses, respectively. The lowest amount of industrial waste was related to service and textile uses. Regarding special waste, the largest amount of manufacturing special waste was related to service use, especially oil and gas services, followed by chemical use. The amount of special waste in electricity and electronics use was not noticeable. Also, non-metallic mineral, food, metal, and textile uses were insignificant.

The largest amount of manufacturing waste among all the uses of town No. 3 was related to industrial waste with a significant difference, followed by special waste, food, and green spaces. The largest amount of industrial manufacturing waste was related to non-metallic mineral, metal, chemical, electricity, and electronic uses, respectively. The lowest amount of industrial waste was related to service and food uses. Regarding special waste, the largest amount of manufacturing special waste was related to food and service uses, especially oil and gas services, followed by chemical and metal uses.

Results and Discussion

Identifying criteria

Based on the library and field studies as well as a detailed examination of conditions of Ahvaz industrial towns nos. 2 and 3, four main criteria (environmental, economic, social/legal, and specialized/technical) were considered, for each of which several sub-criteria were considered. There were 7, 8, 7, and 8 sub-criteria for environmental, economic, social/legal, and specialized/technical criteria, respectively. In total, 30 sub-criteria were considered. Table 2 presents the criteria, sub-criteria, and criterion number. The criteria were selected in a way to include environmental, social, technical, and economic factors.

Table 2. Criteria & Sub-criteria

Main criteria	Sub-criteria	Criterion number
Environmental	Prevention and management of environmental crises	1
	Development of recycling industries	2
	Reducing the emission of environmental pollutants	3
	Improving consumption of raw materials	4
	Improving energy consumption	5
	Water and wastewater recycling and its recycling	6
	Reuse of waste	7
Economic	Direct financial savings	8
	State of initial capital costs	9
	Management and implementation cost	10
	Maximum inclusion of beneficiaries	11
	Alignment with national development plans	12
	Employment	13
	Income generation	14
	Increasing cost efficiency	15
Social/legal	Short-term effect	16
	Long-term effect	17
	Monitoring good implementation	18
	Conflict of interests with the current state of laws and regulations	19
	Ability to attract national trust	20
	Ability to gain national and regional participation	21
	Complying with laws and international behavioral norms	22
Specialized and technical	Required technical knowledge	23
	Need for long-term planning	24
	Technical and specialized equipment and facilities	25
	Availability of expert staff	26
	Familiarity of industries with the necessary technical knowledge	27
	Being influenced by economic sanctions	28
	Sufficient practical, executive and managerial experience	29
	Increasing productivity of labor and all manufacturing agents	30

Identifying alternatives

To identify appropriate alternatives for managing environmental problems and waste in an industrial town and transform an industrial town into an eco-industrial park, the library and field

studies were reviewed and interviews were conducted with experts in this field. Finally, 6 alternatives, including modifying and updating laws and regulations, compiling executive guidelines and standards, developing research units, developing and training industries, tertiary education and infrastructural culture building, providing financial support for knowledge-based activities of industries, and developing industry monitoring and evaluation units were considered. Table 3 shows the alternatives clearly.

Table 3. Alternatives

Alternatives	Number
Modifying and updating laws and regulations	1
Compiling executive guidelines and standards	2
Developing research units, developing and training industries	3
Tertiary education and infrastructural culture building	4
Providing financial support for knowledge-based activities of industries	5
Developing industry monitoring and evaluation units	6

Scoring alternatives considering criteria

In total, six alternatives, including modifying and updating laws and regulations, compiling executive guidelines and standards, developing research units, developing and training industries, tertiary education and infrastructural culture building, providing financial support for knowledge-based activities of industries, and developing industry monitoring and evaluation units, were considered to determine the best scenario. Each alternative had strengths and weaknesses, and 30 criteria were used for prioritization. A questionnaire, including all the sub-criteria and alternatives, was distributed among the experts and employees of Ahvaz industrial towns nos. 2 and 3 and their opinions were collected as scores from 1 to 10. The questionnaire results were analyzed using TOPSIS fuzzy method. To prioritize the alternatives by TOPSIS fuzzy method, software was prepared in Excel software. In the following, the results of each step of the solution are presented. The decision makers' opinions about all the criteria and alternatives were converted into fuzzy numbers as the mean of opinions and examined. Table 5 presents the results. In the fuzzy environment, the distance between positive and negative ideals was calculated by Equations. (6) and (7). Then, the distance between alternatives and positive and negative ideals was calculated by Equations. (8), (9), and (10). To rank all the alternatives, the closeness coefficient was used based on Equation (11), and the final weight was obtained. The alternative with the highest weight was selected as the best scenario in Ahvaz industrial towns No. 2 and No 3. Table 4 presents fuzzy scores of each alternative considering the criteria. Table 5 presents the distance of criteria from fuzzy positive and negative ideals. Tables 6 and 7 show the distance of criteria from positive and negative ideals in real space. Table 8 presents the final score of each alternative. Thus, compiling executive guidelines and standards (0.591) was the most appropriate alternative, followed by tertiary education and infrastructural culture building (0.557), modifying and updating laws and regulations (0.535), developing industrial research, development and training units (0.462), providing financial support for knowledge-based activities of industries (0.419) and developing industry monitoring and evaluation units (0.371) as the first to sixth priorities.

Table 4. Fuzzy scores

Alternatives	Prevention and management of environmental crises			Development of recycling industries			Reducing the emission of environmental pollutants			Improving consumption of raw materials			Improving energy consumption			Water and wastewater recycling and its recycling			Reuse of waste			Direct financial savings			State of initial capital costs			Management and implementation cost		
	Criterion 1			Criterion 2			Criterion 3			Criterion 4			Criterion 5			Criterion 6			Criterion 7			Criterion 8			Criterion 9			Criterion 10		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Modifying and updating laws and regulations	0.1	0.3	0.5	0	0	0.1	0.3	0.5	0.7	0.3	0.5	0.7	0.3	0.5	0.7	0.1	0.3	0.5	0.1	0.3	0.5	0.1	0.3	0.5	0.9	0.9	1	0.5	0.7	0.9
Compiling executive guidelines and standards	0.5	0.7	0.9	0.1	0.3	0.5	0.1	0.3	0.5	0.3	0.5	0.7	0.3	0.5	0.7	0.3	0.5	0.7	0.5	0.7	0.9	0.1	0.3	0.5	0.5	0.7	0.9	0.5	0.7	0.9
Developing research units, developing and training industries	0.1	0.3	0.5	0.3	0.5	0.7	0.1	0.3	0.5	0.5	0.7	0.9	0.5	0.7	0.9	0.3	0.5	0.7	0.3	0.5	0.7	0.3	0.5	0.7	0.1	0.3	0.5	0.3	0.5	0.7
Tertiary education and infrastructural culture building	0.1	0.3	0.5	0.1	0.3	0.5	0.1	0.3	0.5	0.1	0.3	0.5	0.1	0.3	0.5	0	0	0.1	0.5	0.7	0.9	0.1	0.3	0.5	0.3	0.5	0.7	0.3	0.5	0.7
Providing financial support for knowledge-based activities of industries	0.1	0.3	0.5	0.5	0.7	0.9	0.9	0.9	1	0.5	0.7	0.9	0.5	0.7	0.9	0.5	0.7	0.9	0.3	0.5	0.7	0.3	0.5	0.7	0	0	0.1	0	0	0.1
Developing industry monitoring and evaluation units	0.3	0.5	0.7	0.3	0.5	0.7	0.5	0.7	0.9	0.3	0.5	0.7	0.3	0.5	0.7	0.3	0.5	0.7	0.3	0.5	0.7	0.1	0.3	0.5	0	0	0.1	0	0	0.1

Alternatives	Maximum inclusion of beneficiaries			Alignment with national development plans			Employment			Income generation			Increasing cost efficiency			Short-term effect			Long-term effect			Monitoring good implementation			Conflict of interests with the current state of laws and regulations			Ability to attract national trust		
	Criterion 11			Criterion 12			Criterion 13			Criterion 14			Criterion 15			Criterion 16			Criterion 17			Criterion 18			Criterion 19			Criterion 20		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Modifying and updating laws and regulations	0.3	0.5	0.7	0.9	0.9	1	0.1	0.3	0.5	0.3	0.5	0.7	0.5	0.7	0.9	0.1	0.3	0.5	0.9	0.9	1	0.5	0.7	0.9	0.1	0.3	0.5	0.3	0.5	0.7
Compiling executive guidelines and standards	0.3	0.5	0.7	0.5	0.7	0.9	0.3	0.5	0.7	0.3	0.5	0.7	0.5	0.7	0.9	0.1	0.3	0.5	0.5	0.7	0.9	0.3	0.5	0.7	0.3	0.5	0.7	0.5	0.7	0.9
Developing research units, developing and training industries	0.1	0.3	0.5	0.3	0.5	0.7	0.5	0.7	0.9	0.5	0.7	0.9	0.1	0.3	0.5	0.3	0.5	0.7	0.1	0.3	0.5	0.1	0.3	0.5	0.9	0.9	1	0.1	0.3	0.5
Tertiary education and infrastructural culture building	0.5	0.7	0.9	0.1	0.3	0.5	0.5	0.7	0.9	0.3	0.5	0.7	0.5	0.7	0.9	0.1	0.3	0.5	0.5	0.7	0.9	0.1	0.3	0.5	0.5	0.7	0.9	0.9	0.9	1
Providing financial support for knowledge-based activities of industries	0.1	0.3	0.5	0	0	0.1	0.9	0.9	1	0.9	0.9	1	0.1	0.3	0.5	0.5	0.7	0.9	0.1	0.3	0.5	0.1	0.3	0.5	0.1	0.3	0.5	0	0	0.1
Developing industry monitoring and evaluation units	0.1	0.3	0.5	0	0	0.1	0.1	0.3	0.5	0.1	0.3	0.5	0.1	0.3	0.5	0.3	0.5	0.7	0.1	0.3	0.5	0.3	0.5	0.7	0.3	0.5	0.7	0.3	0.5	0.7

Table 4 (continued). Fuzzy scores

Alternatives	Ability to gain national and regional participation			Complying with laws and international behavioral norms			Required technical knowledge			Need for long-term planning			Technical and specialized equipment and facilities			Availability of expert staff			Familiarity of industries with the necessary technical knowledge			Being influenced by economic sanctions			Sufficient practical, executive and managerial experience			Increasing productivity of labor and all manufacturing agents		
	Criterion 21			Criterion 22			Criterion 23			Criterion 24			Criterion 25			Criterion 26			Criterion 27			Criterion 28			Criterion 29			Criterion 30		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Modifying and updating laws and regulations	0.3	0.5	0.7	0.5	0.7	0.9	0.5	0.7	0.9	0.3	0.5	0.7	0.9	0.9	1	0.5	0.7	0.9	0.3	0.5	0.7	0.9	0.9	1	0.1	0.3	0.5	0.1	0.3	0.5
Compiling executive guidelines and standards	0.3	0.5	0.7	0.5	0.7	0.9	0.9	0.9	1	0.3	0.5	0.7	0.5	0.7	0.9	0.5	0.7	0.9	0.5	0.7	0.9	0.9	0.9	1	0.5	0.7	0.9	0.5	0.7	0.9
Developing research units, developing and training industries	0	0	0.1	0.1	0.3	0.5	0.9	0.9	1	0.5	0.7	0.9	0.1	0.3	0.5	0.1	0.3	0.5	0.1	0.3	0.5	0.1	0.3	0.5	0.3	0.5	0.7	0.5	0.7	0.9
Tertiary education and infrastructural culture building	0.9	0.9	1	0.3	0.5	0.7	0.3	0.5	0.7	0.1	0.3	0.5	0.1	0.3	0.5	0.9	0.9	1	0.5	0.7	0.9	0.5	0.7	0.9	0.5	0.7	0.9	0.9	0.9	1
Providing financial support for knowledge-based activities of industries	0	0	0.1	0	0	0.1	0.1	0.3	0.5	0.5	0.7	0.9	0.5	0.7	0.9	0.3	0.5	0.7	0	0	0.1	0.1	0.3	0.5	0.5	0.7	0.9	0.1	0.3	0.5
Developing industry monitoring and evaluation units	0.1	0.3	0.5	0	0	0.1	0.1	0.3	0.5	0.1	0.3	0.5	0.3	0.5	0.7	0.1	0.3	0.5	0.1	0.3	0.5	0.5	0.7	0.9	0.3	0.5	0.7	0.3	0.5	0.7

Table 5. Distance from positive and negative ideals (fuzzy)

Ideals	Prevention and management of environmental crises			Development of recycling industries			Reducing the emission of environmental pollutants			Improving consumption of raw materials			Improving energy consumption			Water and wastewater recycling and its recycling			Reuse of waste			Direct financial savings			State of initial capital costs			Management and implementation cost		
	Criterion 1			Criterion 2			Criterion 3			Criterion 4			Criterion 5			Criterion 6			Criterion 7			Criterion 8			Criterion 9			Criterion 10		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Positive ideals	0.9	0.9	0.9	0.9	0.9	0.9	1	1	1	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.7	0.7	0.7	1	1	1	0.9	0.9	1
Negative ideals	0.1	0.1	0.1	0	0	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0	0	0	0

Table 5 (continued). Distance from positive and negative ideals (fuzzy)

Ideals	Maximum inclusion of beneficiaries			Alignment with national development plans			Employment			Income generation			Increasing cost efficiency			Short-term effect			Long-term effect			Monitoring good implementation			Conflict of interests with the current state of laws and regulations			Ability to attract national trust		
	Criterion 11			Criterion 12			Criterion 13			Criterion 14			Criterion 15			Criterion 16			Criterion 17			Criterion 18			Criterion 19			Criterion 20		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Positive ideals	0.9	0.9	0.9	1	1	1	1	1	1	1	1	1	0.9	0.9	0.9	0.9	0.9	0.9	1	1	1	0.9	0.9	0.9	1	1	1	1	1	1
Negative ideals	0.1	0.1	0.1	0	0	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0

Ideals	Ability to gain national and regional participation			Complying with laws and international behavioral norms			Required technical knowledge			Need for long-term planning			Technical and specialized equipment and facilities			Availability of expert staff			Familiarity of industries with the necessary technical knowledge			Being influenced by economic sanctions			Sufficient practical, executive and managerial experience			Increasing productivity of labor and all manufacturing agents		
	Criterion 21			Criterion 22			Criterion 23			Criterion 24			Criterion 25			Criterion 26			Criterion 27			Criterion 28			Criterion 29			Criterion 30		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Positive ideals	1	1	1	0.9	0.9	0.9	1	1	1	0.9	0.9	0.9	1	1	1	1	1	1	0.9	0.9	0.9	1	1	1	0.9	0.9	0.9	1	1	1
Negative ideals	0	0	0	0	0	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Table 6. Distance from positive ideal

Distance from positive ideal	Prevention and management of environmental crises	Development of recycling industries	Reducing the emission of environmental pollutants	Improving consumption of raw materials	Improving energy consumption	Water and wastewater recycling and its recycling	Reuse of waste	Direct financial savings	State of initial capital costs	Management and implementation cost
	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	Criterion 7	Criterion 8	Criterion 9	Criterion 10
Modifying and updating laws and regulations	0.622	0.868	0.526	0.432	0.432	0.622	0.622	0.432	0.082	0.265
Compiling executive guidelines and standards	0.258	0.622	0.719	0.432	0.432	0.432	0.258	0.432	0.342	0.265
Developing research units, developing and training industries	0.622	0.432	0.719	0.258	0.258	0.432	0.432	0.258	0.719	0.451
Tertiary education and infrastructural culture building	0.622	0.622	0.719	0.622	0.622	0.868	0.258	0.432	0.526	0.451
Providing financial support for knowledge-based activities of industries	0.622	0.258	0.082	0.258	0.258	0.258	0.432	0.258	0.968	0.900
Developing industry monitoring and evaluation units	0.432	0.432	0.342	0.432	0.432	0.432	0.432	0.432	0.968	0.900

Table 6 (continued). Distance from positive ideal

Distance from positive ideal	Maximum inclusion of beneficiaries	Alignment with national development plans	Employment	Income generation	Increasing cost efficiency	Short-term effect	Long-term effect	Monitoring good implementation	Conflict of interests with the current state of laws and regulations	Ability to attract national trust
	Criterion 11	Criterion 12	Criterion 13	Criterion 14	Criterion 15	Criterion 16	Criterion 17	Criterion 18	Criterion 19	Criterion 20
Modifying and updating laws and regulations	0.432	0.082	0.719	0.526	0.258	0.622	0.082	0.258	0.719	0.526
Compiling executive guidelines and standards	0.432	0.342	0.526	0.526	0.258	0.622	0.342	0.432	0.526	0.342
Developing research units, developing and training industries	0.622	0.526	0.342	0.342	0.622	0.432	0.719	0.622	0.082	0.719
Tertiary education and infrastructural culture building	0.258	0.719	0.342	0.526	0.258	0.622	0.342	0.622	0.342	0.082
Providing financial support for knowledge-based activities of industries	0.622	0.968	0.082	0.082	0.622	0.258	0.719	0.622	0.719	0.968
Developing industry monitoring and evaluation units	0.622	0.968	0.719	0.719	0.622	0.432	0.719	0.432	0.526	0.526

Distance from positive ideal	Ability to gain national and regional participation	Complying with laws and international behavioral norms	Required technical knowledge	Need for long-term planning	Technical and specialized equipment and facilities	Availability of expert staff	Familiarity of industries with the necessary technical knowledge	Being influenced by economic sanctions	Sufficient practical, executive and managerial experience	Increasing productivity of labor and all manufacturing agents
	Criterion 21	Criterion 22	Criterion 23	Criterion 24	Criterion 25	Criterion 26	Criterion 27	Criterion 28	Criterion 29	Criterion 30
Modifying and updating laws and regulations	0.526	0.258	0.342	0.432	0.082	0.342	0.432	0.082	0.622	0.719
Compiling executive guidelines and standards	0.526	0.258	0.082	0.432	0.342	0.342	0.258	0.082	0.258	0.342
Developing research units, developing and training industries	0.968	0.622	0.082	0.258	0.719	0.719	0.622	0.719	0.432	0.342
Tertiary education and infrastructural culture building	0.082	0.432	0.526	0.622	0.719	0.082	0.258	0.342	0.258	0.082
Providing financial support for knowledge-based activities of industries	0.968	0.868	0.719	0.258	0.342	0.526	0.868	0.719	0.258	0.719
Developing industry monitoring and evaluation units	0.719	0.868	0.719	0.622	0.526	0.719	0.622	0.342	0.432	0.526

Table 7. Distance from negative ideal

Distance from negative ideal	Prevention and management of environmental crises	Development of recycling industries	Reducing the emission of environmental pollutants	Improving consumption of raw materials	Improving energy consumption	Water and wastewater recycling and its recycling	Reuse of waste	Direct financial savings	State of initial capital costs	Management and implementation cost
	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	Criterion 7	Criterion 8	Criterion 9	Criterion 10
Modifying and updating laws and regulations	0.258	0.058	0.432	0.432	0.432	0.342	0.258	0.258	0.935	0.719
Compiling executive guidelines and standards	0.622	0.342	0.258	0.432	0.432	0.526	0.622	0.258	0.719	0.719
Developing research units, developing and training industries	0.258	0.526	0.258	0.622	0.622	0.526	0.432	0.432	0.342	0.526
Tertiary education and infrastructural culture building	0.342	0.342	0.342	0.342	0.342	0.058	0.719	0.342	0.526	0.526
Providing financial support for knowledge-based activities of industries	0.258	0.719	0.835	0.622	0.622	0.719	0.432	0.432	0.058	0.058
Developing industry monitoring and evaluation units	0.432	0.526	0.622	0.432	0.432	0.526	0.432	0.258	0.058	0.058

Distance from negative ideal	Maximum inclusion of beneficiaries	Alignment with national development plans	Employment	Income generation	Increasing cost efficiency	Short-term effect	Long-term effect	Monitoring good implementation	Conflict of interests with the current state of laws and regulations	Ability to attract national trust
	Criterion 11	Criterion 12	Criterion 13	Criterion 14	Criterion 15	Criterion 16	Criterion 17	Criterion 18	Criterion 19	Criterion 20
Modifying and updating laws and regulations	0.432	0.935	0.258	0.432	0.622	0.258	0.835	0.622	0.258	0.526
Compiling executive guidelines and standards	0.432	0.719	0.432	0.432	0.622	0.258	0.622	0.432	0.432	0.719
Developing research units, developing and training industries	0.258	0.526	0.622	0.622	0.258	0.432	0.258	0.258	0.835	0.342
Tertiary education and infrastructural culture building	0.719	0.342	0.719	0.526	0.719	0.342	0.719	0.342	0.719	0.935
Providing financial support for knowledge-based activities of industries	0.258	0.058	0.835	0.835	0.258	0.622	0.258	0.258	0.258	0.058
Developing industry monitoring and evaluation units	0.258	0.058	0.258	0.258	0.258	0.432	0.258	0.432	0.432	0.526

Table 7 (continued). Distance from negative ideal

Distance from negative ideal	Ability to gain national and regional participation	Complying with laws and international behavioral norms	Required technical knowledge	Need for long-term planning	Technical and specialized equipment and facilities	Availability of expert staff	Familiarity of industries with the necessary technical knowledge	Being influenced by economic sanctions	Sufficient practical, executive and managerial experience	Increasing productivity of labor and all manufacturing agents
	Criterion 21	Criterion 22	Criterion 23	Criterion 24	Criterion 25	Criterion 26	Criterion 27	Criterion 28	Criterion 29	Criterion 30
Modifying and updating laws and regulations	0.526	0.719	0.622	0.432	0.835	0.622	0.526	0.835	0.258	0.258
Compiling executive guidelines and standards	0.526	0.719	0.835	0.432	0.622	0.622	0.719	0.835	0.622	0.622
Developing research units, developing and training industries	0.058	0.342	0.835	0.622	0.258	0.258	0.342	0.258	0.432	0.622
Tertiary education and infrastructural culture building	0.935	0.526	0.526	0.342	0.342	0.935	0.719	0.719	0.719	0.935
Providing financial support for knowledge-based activities of industries	0.058	0.058	0.258	0.622	0.622	0.432	0.058	0.258	0.622	0.258
Developing industry monitoring and evaluation units	0.342	0.058	0.258	0.258	0.432	0.258	0.342	0.622	0.432	0.432

Table 8. Final score

Alternatives	Final scores	Priority
Compiling executive guidelines and standards	0.591	1
Tertiary education and infrastructural culture building	0.557	2
Modifying and updating laws and regulations	0.535	3
Developing research units, developing and training industries	0.462	4
Providing financial support for knowledge-based activities of industries	0.419	5
Developing industry monitoring and evaluation units	0.371	6

Table 8 shows the final score of each alternative. Compiling executive guidelines and standards (0.591) was the most appropriate alternative, followed by tertiary education and infrastructural culture building (0.557), modifying and updating laws and regulations (0.535), developing industrial research, development, and training units (0.462), providing financial support for knowledge-based activities of industries (0.419) and developing industry monitoring and evaluation units (0.371) as the first to sixth priorities.

Based on the interviews and obtained results, developing executive guidelines and standards was selected as the best alternative that could be followed and implemented quickly due to the lack of a single and specific guideline and standard as well as the urgent need.

A clear and precise road map is required to start any activity in the first place. A single guideline and standard could be quickly developed and used as the guide and road map. Developing and evaluating industrial units have not received attention due to the long process and the need for continuous evaluation and abundant financial resources. Assessing industries requires guidelines, standards as well as training. Moreover, it requires the cooperation of several organizations and that is why this was selected as the last scenario. Providing financial support has not gained great attention due to similar unsuccessful experiences obtained before. Asking for financial support without detailed planning and specific guidelines will be only a waste of resources. After developing executive guidelines and standards, tertiary education and infrastructural culture building could be used to pave the way for transforming industrial towns into echo-industrial parks by training and employing technical experts because any activity requires infrastructural culture building and technical and academic training of people in that field to be fruitful. Furthermore, the infrastructure should be developed to implement the compiled guidelines. Thus, after the first alternative, special attention should be paid to the second alternative. In all stages of transforming industrial towns into echo-industrial parks, some old rules are sometimes problematic and slow down the transformation process. As a result, laws and regulations should be updated.

Transforming Ahvaz industrial town into an eco-industrial park requires the identification of criteria and indicators to assess the sustainability of the industrial zone and the development of alternative scenarios for its transformation.

In terms of identifying criteria and indicators, relevant stakeholders such as government agencies, industry representatives, and local communities can be engaged to participate in the process. The criteria and indicators should cover environmental, economic, and social aspects of sustainability, such as energy consumption, water use, air pollution, waste generation, job creation, and community engagement. The criteria and indicators should be measurable and relevant to Ahvaz industrial town to ensure their effectiveness in assessing the sustainability of the transformation process.

Once the criteria and indicators have been identified, the next step is to determine alternative scenarios for transforming Ahvaz's industrial town into an eco-industrial park. This involves analyzing the current state of the industrial zone, including its strengths, weaknesses, opportunities, and threats. Based on this analysis, potential scenarios can be developed to transform the industrial zone, considering the identified criteria and indicators. The scenarios can include measures such as resource efficiency, waste reduction, renewable energy adoption, and community engagement.

The implementation of the selected scenario(s) will require coordination among various stakeholders, including government agencies, industry, and local communities. It will also require adequate financial resources, technical expertise, and regulatory frameworks to support the transformation process.

In conclusion, transforming Ahvaz's industrial town into an eco-industrial park is a complex process that requires the identification of sustainability criteria and indicators and the development of alternative scenarios. The engagement of relevant stakeholders is crucial to ensuring the effectiveness of the process. The identified criteria and indicators should cover environmental, economic, and social aspects of sustainability, and alternative scenarios should be developed based on the analysis of the current state of the industrial zone. The implementation of the selected scenario(s) will require coordination among stakeholders, adequate financial resources, technical expertise, and regulatory frameworks. By transforming Ahvaz's industrial town into an eco-industrial park, it is possible to promote sustainable industrial development that balances economic growth with environmental protection and social responsibility.

Conclusion

With the development of industries in recent years, governments have realized that they are more capable of providing services, controlling and managing manufacturing pollutants, and reducing service costs by gathering industries in one place. Agglomeration of industries in a limited area has advantages and disadvantages, e.g., the cumulative effects of pollutants and manufacturing waste are among the most important disadvantages of these towns. High agglomeration of a specific industry in industrial towns is among the problems of industrial towns in Iran. Therefore, manufacturing waste in that industry is dominant and attracts the attention of the town waste management system. With the progress of studies on the design and development of echo-industrial parks, researchers in different fields have compiled the principles of designing and planning industrial sites to improve the ecological quality of these environments. Due to the variety of expertise in this field, although the compiled principles and rules have the same general framework, a diversity of attitudes and viewpoints will certainly create relatively different approaches. To identify the best alternative for managing environmental problems and waste in industrial towns, the criteria and indicators of transforming industrial towns into EIPs were collected and analyzed from different perspectives and, then, prioritized using fuzzy and TOPSIS fuzzy techniques. Accordingly, four main criteria (environmental, economic, social/legal, and specialized/technical) were considered, for each of which several sub-criteria were considered. According to the criteria and sub-criteria as well as library and field studies, six alternatives were considered.

Results of the questionnaire distributed among experts and employees in Ahvaz industrial towns nos. 2 and 3 were collected. Each criterion was scored 1-10. Calculations performed in fuzzy and real environments revealed compiling executive guidelines and standards (0.591) was the most appropriate alternative, followed by tertiary education and infrastructural culture building (0.557), modifying and updating laws and regulations (0.535), developing industrial research, development and training units (0.462), providing financial support for knowledge-based activities of industries (0.419) and developing industry monitoring and evaluation units (0.371) as the first to sixth priorities. The results indicated executive guidelines and standards should be compiled to manage environmental problems in industrial towns and transform towns into echo-industrial parks. It is hoped that decision-makers in this field will take an important step to transform industrial towns into echo-industrial parks, minimize environmental problems and manage waste by developing executive guidelines and updated and advanced standards.

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