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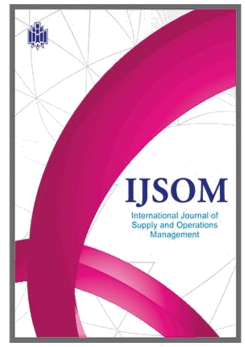

Green Ports Assessment Model regarding Uncertainty by Best-Worst and Hesitant Fuzzy VIKOR Methods: Iranian Ports

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Abstract

These days, environmental protection has crucial importance in different scopes of scientific research due to the environmental climate change, and popular concern about the future of the world. Ports and maritime transportation also play a noteworthy role in sustainability owing to the fact they are known as crucial and significant economic hubs all around the world. Hence, here environmental factors associated with the ports have been illustrated and according to the experts 'attitudes by using the Best-Worst method (BWM) to find less incompatibility, the criteria's weight would have been calculated. Emissions of pollutants into the waters, environmental pollution, and General waste handling are the best, and Technology and Education, Hazardous waste handling, and Port staff training are the worst criteria respectively. Afterward, owing to the ambiguity in experts 'attitudes, the combination of the VIKOR decision-making method and the hesitant fuzzy has been utilized in order to compare alternatives through uncertainty in data and to decrease related errors. Finally, the proposed assessment model has been examined with sensitivity analysis in a real case of Iranian Ports.

Keywords: Green Ports Assessment; BWM; Hesitant Fuzzy Set; VIKOR Method; Uncertainty; Iran Ports.

1. Introduction and literature review

Today, maritime transportation of goods in international trade generally accounts for about 80% of the total trade, which is even higher in developed countries. In terms of tonnage, this is about six billion tons of commodities, of which about one-third is petroleum and one-third is bulk and dry products while the rests are non-bulk. Given the importance of such a percentage of freight traffic in world trade, the importance of maritime trade, shipping, and ports as indispensable parts can be investigated. Hence, providing efficient maritime transport services seems to be one of the required and effective objectives for prosperous international trade (Wei, 2015).

According to the European Commission (2012), road freight transport represents 73% of inland freight transport within the European Union (EU). However, due to the harmful effects commonly associated with road transport, the European Commission suggests that 30% of road freight of more than 300 km should transfer to other modes of transportation such as rail or water transport by 2030, and more than 50% up to 2050.

Generally, environmental disasters that ports and sea transportation could bring consist of water pollution caused by fuel leaks in the sea, air pollution, and noise pollution due to the ships and logistics systems (Lee et al.,2016; Kandakoglu, Frini, & Ben Amor, 2019, Alfian H.A.S. et al.,2022. According to these limitations and hazards and

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simultaneously, current worldwide green activities' attention, transportation shareholders have been encouraged to switch to green and sustainable inland and international waterway transportation. (Monios et al.2017, Meramo-Hurtado and González-Delgado, 2021). Furthermore, they have also taken on a voluntary basis in terms of economic conditions and have made major investments in energy efficiency technologies. Energy management thus places ports and terminals at the center of a complex network of energy flows (Maragkogianni & Papaefthimiou, 2015, Shan et al., 2022). If public and private sector managers oversee their investment in port developments as supply and consumption methods, a coordinated approach can preserve considerable energy and create a new perspective on the utilization of new and sustainable energy which is environmentally friendly in the form of green ports.

Investment in port development can be related to the creation of new ports, port development, and improvement of existing conditions and facilities. In the process of port development, environmental, social, and economic aspects must be recognized. Activities in port development and future productivity may reveal aspects of the direct and indirect effects (Yigit and Acarkan,2018). Today, the impacts of port development exist not only on the environment but also on the economic and social aspects. The goal of port development is not only to provide broad and continuous environmental operations but also to balance other aspects of sustainable development. Other approaches have been developed locally and internationally to achieve the goal of sustainable development by supporting environmental management according to the legal requirements compromised the International Maritime Organization (IMO) Laws, Rio Conference Agenda 21, International Association of Ports and Harbors (IAPH), United Nations Conference on Trade and Development (UNCTAD) (Lam and Yap; 2019).

According to the fact that there are a lot of standards, agendas, criteria, and factors, finding the right way to evaluate these benchmarks and port ratings could be individually another challenge and it could be more elaborate when we encounter by uncertainty in the decisions. (Lam & Notteboom,2014).

Moon et al. worked on green ports and economic opportunities in which some policy instruments have been used based on the system dynamics (SD) approach (Moon, et al.,2018). Wan et al. considered a case study which was located in the major ports of China in order to expand a new model for green port expansion (Wan, C. et al., 2018). Chang et al. have investigated Taiwan's Kaohsiung harbor which estimates the green port policy in order to reduce the pollutants (Chang & Wang, 2012). Chin-Shan Lu et al. developed an investigation on sustainability at ports, which tries to expand a sustainable supply chain from a manager's point of view and perspective (Lu, et al., 2016). They try to demonstrate that only the innovations have a way to succeed that to adapt dynamically to the demands of the harbor operators and to the institutional harbor environment.

Assunta Di Vaio et al. have worked on environmental sustainability in seaports which includes balanced scorecard, managerial accounting instruments, and port authority (Di Vaio, A. et al., 2018). Rong-Her Chiu et al. studied the factors and performance of the green port by using the fuzzy AHP analysis in the estimations (Solangi et al., 2019). According to this study, the results have shown priority attributes which are the top five on the list: hazardous and dangerous waste handling, air and water pollution, port greenery, and maintenance of the habitat quality. Tai-Gang Li et al. studied the green logistics operation system of port which uses a fuzzy AHP method to reach the solution (Tai-Gang Li, & Bin Yang., 2010). Ji-Yeong Park et al. surveyed an investigation on green ports of Korean ports by using fuzzy set theory and factor analysis (FA) (Park, J., & Yeo, G., 2012). Munim et al. Consider the appropriate port governance model for the implementation of green port management. (GPM) practices. . They compare the Analytic Network Process (ANP) method with the more recently developed Best-Worst Method (BWM) of MCDM problem analysis to find the correct port governance model for military occupation. (Munim,Z.H.,Friese,H.S.,Dushenko,M.,2020).Chengpeng et al. created an assessment template for the quantitative measurement of green port development. The weights of each index are calculated using a hierarchical analytical methodology. The evaluation results of the ports studied for each index are aggregated using an approach based on factual reasoning.(Chengpeng ,W.,Di,Z.,Xinping,Y.,Zaili,Y.,2018). The concept of hesitant fuzzy set preference relation has been proposed by Liao et al. in which the multiplicative consistency of a hesitant fuzzy preference relation and the group consensus among different decision makers have been surveyed (Liao, H.et al., 2014; Noori et al., 2018).In reality, this development would have been really significant owing to the comparing two alternatives, which is called the preference relation (Çalık, Çizmecioğlu, and Akpınar,2019, Xu et al., 2022).

To cope with the aforementioned issues, here in this study after a survey on port assessment criteria and gathering experts' opinions, the BWM method has been utilized for convenient application, less computation, and incompatibility to calculate the weight of selected criteria (Vahabzadeh Najafi, Arshadi Khamseh, and Mirzazadeh, 2020). Afterward, owing to the inconsistency and ambiguity of experts' opinions, the VIKOR method accompanied by hesitant fuzzy sets, was utilized for port comparisons. In the hesitant fuzzy approach, instead of considering a membership degree, a few membership degrees could be considered for every element which covers more uncertainty and helps reduce the uncertainty error. Our proposed model has been surveyed for the assessment of green ports through three nominated large international ports in Iran. Generally, our procedure has been depicted in Figure.1

The rest of the document has the following structure:

In section two, briefly, BMW, HF, and VIKOR methods and their procedure for decreasing uncertainty would be illustrated. In section three, the implementation of our proposed model based on our real case study has been implemented. In part four, a sensitivity analysis of the problem will be explained and finally, in part five, the conclusion and future development will be discussed.

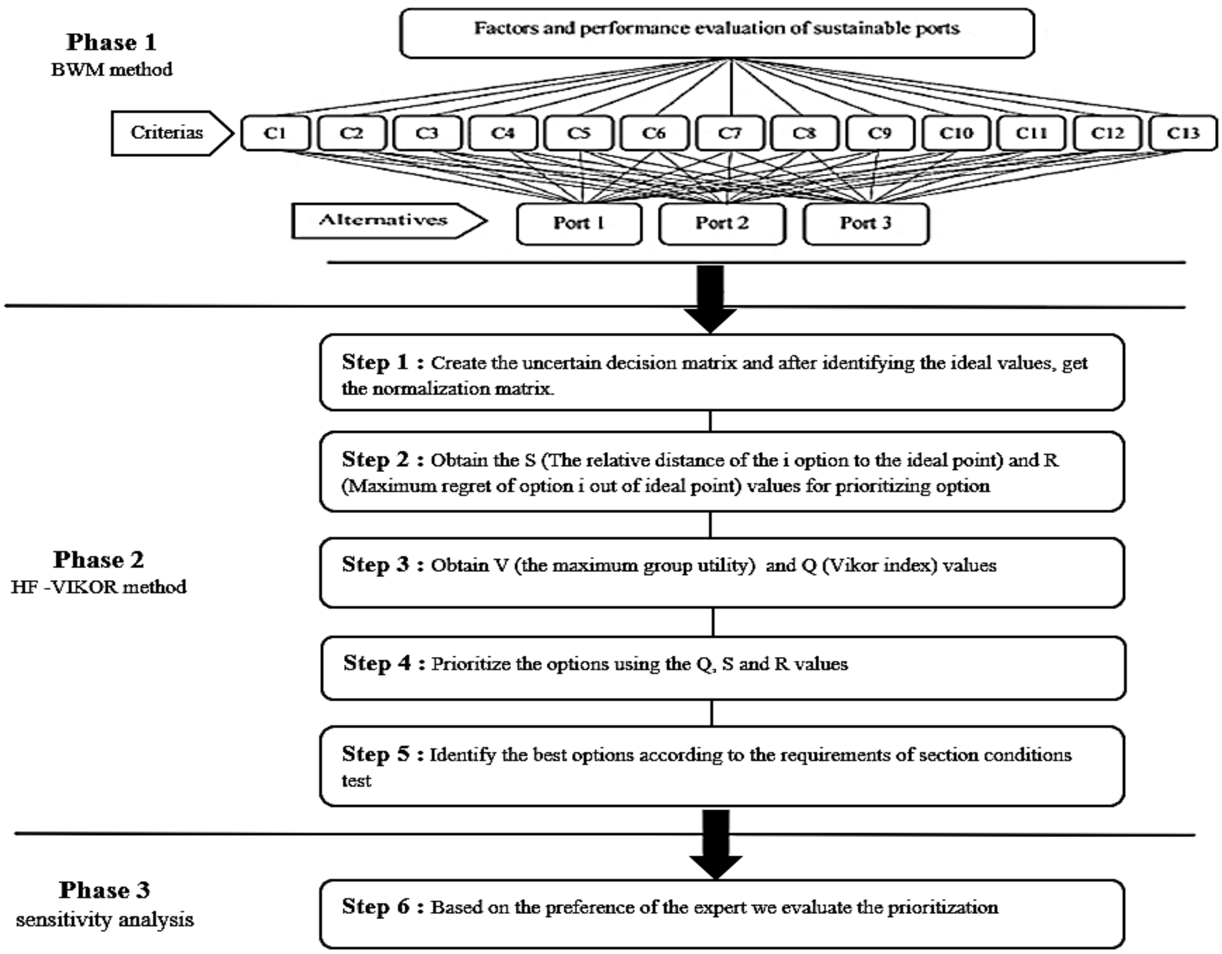

Figure 1. Our proposed assessment Steps

2. Research methodology

Here the BMW method, Hesitant Fuzzy set, and HF –VIKOR will be illustrated to be applied in the next session for our real case in Iranian Ports.

2.1. BWM method

Based on the Best-Worst method presented by Rezai in 2015. The best and worst indicators are determined by policymakers and matched comparisons among the two arrows (the best and the worst), and The other ones are the relative importance of the best of the other criteria and the relative importance of the other worst of all criteria. Next, a maximum-minimum problem is formulated and resolved to determine the weight of the different indexes. In this method, a formula to calculate incompatibility rates has also been considered to validate the comparisons. This method would be more convenient for intricate decision making when it is challenging to decide on the criteria and would be more comfortable than others, owing to the fewer computations, pairwise comparisons and covering more incompatibility in contrast to the other multi-criteria decision-making methods.

2.1.1. Steps of the BWM Method

Step 1: Determine the set of decision indicators. In this step, set the indicators to $C = \{C_1 . C_2 . \dots C_J\}$.
Step 2. Identification of the best (most important, most desirable) and worst (least important and least desirable) indicators. At this stage, the decision-maker sets the best and the worst, indicators generally.
Step 3.: Identify the best index over other indices with numbers from 1 to 9. The preferred index over the other indices is displayed as $A_B = (a_{B1} . a_{B2} . \dots . a_{Bn})$, a_{Bj} indicates that the best criterion is superior to the jth criterion.
Step 4. Determine the preference for all indexes relative to the worst. index with numbers from 1 to 9. The index of preference of other indices to the worst index is displayed as $A_w = (a_{1w} . a_{2w} . \dots . a_{nw})$. A_{jw} indicates that the jth criterion is superior to the worst criterion.
Step 5: Figure out the optimal weight values for each criterion W = [w_1, w_2, …, w_n] with the following optimization model.

$$\textbf{Min Max} \left\{ \left|\frac{W_B}{W_j} - a_{Bj}\right| . \left|\frac{W_j}{W_W} - a_{jw}\right| \right\}$$

$$\textbf{s.t.} \qquad \sum_j W_j = 1$$

$$W_j \geq 0 \qquad \forall j \in J \tag{1}$$

The aforementioned relation is a non-linear model which Jafar Rezaei converted into a linear model in 2016 as follows:

$$\textbf{Min } \zeta$$

$$\textbf{s.t.} \quad \left| \frac{W_B}{W_j} - a_{Bj} \right| \leq \zeta \qquad \forall j \in J$$

$$\left|\frac{Wj}{W_W} - a_{jw}\right| \leq \zeta \qquad \forall j \in J$$

$$\sum_j W_j = 1$$

$$W_j \geq 0 \qquad \forall j \in J \tag{2}$$

Step 6: Using the obtained ζ^*, the compatibility rate is calculated. It is clear that larger ζ^* indicates higher compatibility rate, which is calculated according to the following formula:

$$\text{Consistency Rate} = \frac{\zeta}{\text{consistency index}} \tag{3}$$

Consistancy rate which is closer to zero represents more compatibility.

2.2. Hesitant Fuzzy Set

Decision-makers confront hesitancy and ambiguity through decision-making and get a final agreement. In that situation, Tora and Narukawa introduced the new concept as a fuzzy set of doubts. In the real world and in practical applications, hesitant fuzzy sets can prevent some of the decision-making problems with multiple criteria such as anonymity, privacy, and decision makers’ mentality. Considering hesitant fuzzy is helpful to address multiple-criteria decision-making problems in ambiguous situations when deciding brings uncertainty. Fuzzy sets also

provide an efficient way of dealing with decision problems under uncertainty when multiple degrees of membership for an object or a criterion are possible.
According to the material mentioned above, Torah and Narukawa (2009) and Torah (2010) presented fuzzy relationships as illustrated in Appendix A.

2.3. HF -VIKOR method

The VIKOR is one of the most commonly used multi-criteria decision-making systems that systematically rank the available options according to the criteria. As a result of the large capacity of this method, it has been used by various researchers to resolve multi-criteria decision-making issues.
A combination of the hesitant fuzzy and Vikor, known as the Vikor hesitant fuzzy logic, can incorporate all aspects of decision making into modelling and improve the results of decision analysis. However, the Vikor method cannot model Uncertainty due to lack of information or, in some instances, lack of accurate information. At the same time, the fuzzy method was one of the most useful and efficient methods for modelling. Complex environments have proven to be successful in this area. Therefore, the Vikor method is combined with the hesitant fuzzy method and is known as the hesitant fuzzy Vikor. To evaluate options based on this method, we follow the steps below:
Consider MCDM problem with hesitant fuzzy information, which has a discrete set of I alternatives, $A = \{A_1 . A_2 \dots . A_I\}$. Let $C = \{C_1 . C_2 . \dots . C_J\}$ be the set of all criteria. The HFS C_J of the ith alternative on C is given by $C_j = \left\{ < A_i . h_{C_j}(A_i) > \middle| A_i \in A \right\}$. where $h_{C_j}(A_i) = \{\gamma \mid \gamma \in h_{C_j}(A_i). 0 \le \gamma \le 1. i = 1.2. \dots . I ; j = 1.2. \dots . J\}$. $h_{C_j}(A_i)$ indicates the possible membership degrees of the i^{th} alternative A_i under the jth criterion C_j ,which is represented by a set of possible values and is illustrated as a HFE h_{ij} for short. The hesitant fuzzy decision matrix H is:

$$H=\begin{bmatrix} h_{11} & \cdots & h_{1j} \\ \vdots & \ddots & \vdots \\ h_{i1} & \cdots & h_{ij} \end{bmatrix} \tag{4}$$

The weights $\omega_j . (j = 1.2. \dots . J)$ of the criteria represent the relative importance degrees of the criteria, where $0 \le \omega_j \le 1. (j = 1.2. \dots . J)$, and $\sum_{j=1}^{J} \omega_j = 1$.
Given that in many cases the opinions of several decision makers are used in the decision-making process, it is therefore necessary to integrate the opinions of different individuals and form the final matrix of fuzzy decision making. The final integrated matrix of people's opinions is the basis for the calculations in the next steps.
The outputs of this step are $h_j^* = \max_i h_{ij}$ and $h_j^- = \min_i h_{ij}$, which are the best and worst values of A_i over the benefit-type criterion C_j , respectively. The best and the worst values of A_i over the cost-type criterion can be derived similarly.

Step1. The Manhattan Lp metric of HFSs over the benefit-type criterion is in terms of the following form:

$$L_{p.i} = \left(\sum_{j=1}^{J} (W_j \frac{d(h*j.hij)}{d(h*j.h-j)}) p \right)^{\frac{1}{p}} \tag{5}$$

where $\omega_j . (j = 1.2. \dots . J)$ are the corresponding weights of criteria, and satisfy $0 \le \omega_j \le 1$, $j = 1.2. \dots . J$, and $\_J_j = 1\ \omega_j = 1$. $d(h_j^* . h_j^-)$ is the Manhattan distance between $d(h_j^* . h_{ij})$, which is in the following mathematical form:

$$d(h_j^* . h_j^-) = \frac{1}{lj} \sum_{j=1}^{J} \left| h_j^* - h_j^- \right| \tag{6}$$

Where h_j^* and h_{ij} are the tth largest values in h_j^* and h_{ij} respectively, and l = max{ l_{h*j}, $l_{hi\ j}$}. $d(h_j^* . h_j^-)$ can also be defined similarly.

Up to now We've developed the Manhattan LP metric of HFSs over the benefit-type criterion. It is similar to driving the Manhattan LP metric from HFSs on the criterion of type of cost. Under the conventional VIKOR method, standardization would be carried out to equalize the value of the criteria. In vague and hesitant circumstances, even though all criteria values are in [0.1]; nonetheless, in order to eliminate the influence of various criteria, it would be necessary to standardize the distance.

Step2. The measurement of the utility of the hesitant fuzzy group on the benefit type criterion is based on the wording:

$$S_i = \sum_{j=1}^{J} W_j \frac{d(h_j^* . hi\, j\,)}{d\,(h_j^* . h_j^-)} \tag{7}$$

where ω_j ($j = 1.2 \ldots .J$) are the corresponding weights of criteria satisfying $0 \leq \omega_j \leq 1.(j = 1.2. \ldots .J)$, $\sum_{j=1}^{J} \omega_j = 1$, $d\,(h_j^* . h_{ij})$and $d\,(h_j^* . h_j^-)$ can be determined through Eq. (6).

Step 3. The measurement of individual hesitant fuzzy regrets against the type of advantage test is based on the relationship:

$$R_i = L_i^{\infty} = \max_j (W_j \frac{d(h_j^* . hi\, j\,)}{d\,(h_j^* . h_j^-)}) \tag{8}$$

where ω_j ($j = 1.2 \ldots . J$) are the corresponding weights of criteria satisfying $0 \leq \omega_j \leq 1.(j = 1.2. \ldots .J)$, $\sum_{j=1}^{J} \omega_j = 1$, $d\left(h_j^* . h_{ij}\right)$ and $d(h_j^* . h_j^-)$ can be determined through the Eq. (6).

Step 4. The hesitant fuzzy compromise measure is based on the following equations:

$$Q_i = V \frac{S_i - S^*}{S^- - S^*} + (1 - V) \frac{R_i - R^*}{R^- - R^*} \tag{9}$$

Where $S^* = \min_i S_i$, $S^- = \max_i S_i$, $R^* = \min_i R_i$, $R^- = \max_i R_i$, and V is the weight of the strategy of the majority of criteria or the maximum aggregate usefulness. Without loss of generality, the value V would be regarded as 0.5 in the Eq. (9). Clearly, there are two parts to the hesitant measurement of the fuzzy compromise: the first is distance in terms of group usefulness; the second is distance in terms of personal regret. The lower the value of unclear and hesitant trade-offs, the greater the benefit of the alternative. So we need to pick out the smallest one among Q_i $(i = 1.2. \ldots . I)$

3. Case Study

Regarding the priority of environmental concerns and green strategies in maritime and assessment international ports, here we utilize our proposed assessment model and indices definitions in the prioritization of three Iranian Ports as bellows:

A) The Shahid Beheshti port lies in Chabahar and along the Oman Sea and the Indian Ocean, adjacent to major shipping lines to Africa, Asia, and Europe, and can well serve as an international gateway to Central Asian and neighboring countries

B) Shahid Bahonar Port is one of the old multi-purpose ports of the province and one of the active ports of Iran. The Shahid Bahonar Port is the third export port in the country, which has a special place in the export of non-oil goods, freight, and domestic and international passenger transportation.

C) The Special Economic Zone of Shahid Rajaei Port, located in 23 kilometers west of Bandar Abbas in the north of Qeshm Island and 80 the Hormuz strait, holds about half of Iran's trade through maritime relations and trade with internationally known ports. The Special Economic Zone of Shahid Rajaei Port is located in the center of the South-North Transit Corridor, one of the most important international transit corridors in the world.

The geographical location of each port is shown in Figure 2 and the characteristics that make a green port, have been investigated through literature review and by the international experts' opinion and some local experts' notions in Table 1.by 13 criteria.

Figure 2. The Geographical Location of Each Port

Table 1. Factors for Environmental/Green port operation

S.NO	Criteria	Brief description
C_1	Water consumption	Reduce wastage of drinking water, water consumption in the area and water treatment for reuse
C_2	Hazardous waste handling	Isolation and disposal of dangerous goods and pesticides during construction and loading in the epidemic area
C_3	Emissions of pollutants into the waters of the region	Rapid investigation of oil spills and other pollutants in the sea, a survey of sewage systems, water quality check
C_4	clean energy	Use of environmentally friendly energy in the port area and control energy consumption
C_5	Desertification and disposal of harmful substances	Increase green spaces in the zoning and use of non-chemical fertilizers and pesticides
C_6	Green construction	Build green standards buildings in port areas and use environmentally friendly materials
C_7	Technology and Education	Promote and teach the concepts of sustainable ports to the community through virtual spaces and educational tours in ports
C_8	Clear the land	Collection of sediments in port areas and reuse of these dredged resources
C_9	Port staff training	Port staff training by providing seminars and implementing environmental systems to prepare for the creation of a Sustainable Port.
C_{10}	Sound emission rate	Examine the noise level in the area and reduce it and use fewer noise devices in all parts of the port.
C_{11}	environmental pollution	Use of air filters, renewable energy sources, reduction of smoke and dust in the area and environmentally friendly transport
C_{12}	Climate change in the region	Environmental monitoring in the area and increasing tidal area to reduce damage to the natural environment
C_{13}	General waste handling	Establishment of recycling centers in port areas, recycling of regional waste and ships and reduction of plastic consumption in these areas

3.1. BWM results

In this section, all the notions and attitudes of the local experts have been gathered and incorporated into the survey on the literature review. After consolidating the comments, C_3 and C_7 would have been selected as the best and the worst criteria respectively. Then we finalized our criteria as C_1 to C_{13} and the final weights of associated criteria have been calculated through the BMW method using Eqs. (1) and (2). See Fig.3.

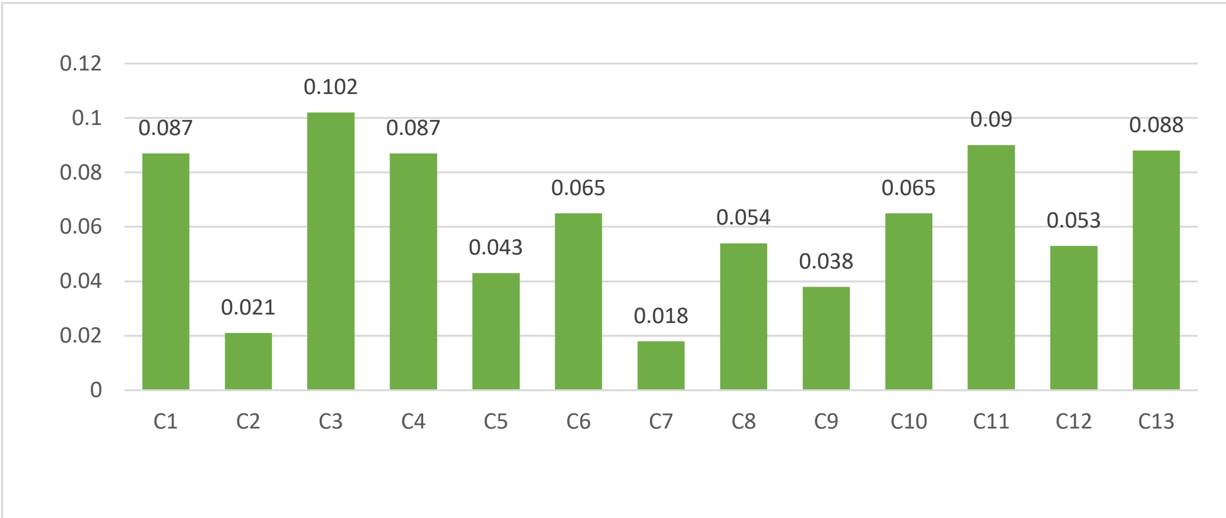

Figure 3. The result of BWM

The numerical compatibility rate that must be between zero and one has been calculated by 0.0187, which illustrated strong compatibility in our study.

3.2. Hesitant fuzzy VIKOR result

After obtaining the weight of the criteria from the BWM method, we examine the three existing ports and their compliance with the mentioned criteria. First, the hesitant fuzzy direct relationship matrix is formed based on the expert opinion obtained from the questionnaire and is presented in Table 2. Definitions 4 and 5 in appendix A are used to compare the hesitant fuzzy numbers and determine the superiority of each of the hesitant sets in this matrix. The results of definition 4 are presented in Table 3. Since some of these sets have the same value and cannot be compared, definition 5 which is known as the variance of sets is used and is presented in Table 4. In the following, according to the obtained results and the comparisons of the upper and lower bound of the hesitant fuzzy sets, the specified Definition 2 is determined and the distance between these sets is obtained for subsequent computation of Eq.(6). In the following, it would be obvious that the desired values of S_i, R_i and Q_i are obtained for each of the ports in accordance with Eqs.(7-9) presented in Table 5 and priorities are finalized by the VIKOR method.
By ordering the alternatives according to the values of S_i, R_i and Q_i ($i = 1, 2, \ldots, I$).we will have :
$Q_B<Q_C<Q_A$, $S_B<S_C<S_A$ and $R_B<R_A=R_C$

This implies that ports no. A and C could be the most appropriate option for green and environmental development. In this case study Port S. Beheshti will be the first priority for environmental and green strategies, activities, and development plans

Table 2. The Hesitant Fuzzy Decision Matrix

Criteria	Ports		
	A	B	C
C_1	(0.3,0.5,0.7)	(0.2,0.4,0.6)	(0.6,0.8,0.9)
C_2	(0.1,0.3,0.6)	(0.2,0.5,0.6)	(0.3,0.4,0.5)
C_3	(0.2,0.5,0.6)	(0.5,0.6,0.8)	(0.5,0.7,0.9)
C_4	(0.4,0.5,0.9)	(0.5,0.6,0.7)	(0.3,0.5,0.7)
C_5	(0.2,0.4,0.6)	(0.3,0.4,0.7)	(0.2,0.5,0.8)
C_6	(0.3,0.6,0.9)	(0.7,0.8,0.9)	(0.6,0.7,0.9)
C_7	(0.4,0.5,0.8)	(0.1,0.3,0.4)	(0.2,0.4,0.6)
C_8	(0.5,0.6,0.8)	(0.6,0.7,0.8)	(0.3,0.5,0.6)
C_9	(0.2,0.3,0.7)	(0.4,0.6,0.7)	(0.3,0.5,0.6)
C_{10}	(0.5,0.6,0.8)	(0.2,0.4,0.5)	(0.6,0.7,0.9)
C_{11}	(0.4,0.6,0.7)	(0.5,0.6,0.8)	(0.2,0.4,0.7)
C_{12}	(0.3,0.4,0.8)	(0.2,0.5,0.9)	(0.4,0.5,0.8)
C_{13}	(0.1,0.4,0.6)	(0.2,0.4,0.6)	(0.3,0.7,0.9)

Table 3. Alternative 'Score Value from Cross Function

Ports	Criteria												
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
A	0.5	0.33	0.43	0.6	0.4	0.6	0.56	0.63	0.4	0.63	0.56	0.5	0.36
B	0.4	0.43	0.63	0.6	0.46	0.8	0.26	0.7	0.56	0.36	0.63	0.53	0.4
C	0.76	0.4	0.7	0.5	0.5	0.73	0.4	0.46	0.46	0.73	0.43	0.56	0.63

Table 4. Variance Values

Ports	Criteria												
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
A	-	-	-	0.17	-	-	-	-	-	-	-	-	-
B	-	-	-	0.12	-	-	-	-	-	-	-	-	-
C	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 5. The Overall Computational Results

Criteria	**Ports**					
	A	**B**	**C**	**h^***	**h^-**	d_{hnh} $(h^*_j$ $h^-_j)$
C_1	(0.3,0.5,0.7)	(0.2,0.4,0.6)	(0.6,0.8,0.9)	(0.6,0.8,0.9)	(0.2,0.4,0.6)	0.36
C_2	(0.1,0.3,0.6)	(0.2,0.5,0.6)	(0.3,0.4,0.5)	(0.2,0.5,0.6)	(0.1,0.3,0.6)	0.1
C_3	(0.2,0.5,0.6)	(0.5,0.6,0.8)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.2,0.5,0.6)	0.26
C_4	(0.4,0.5,0.9)	(0.5,0.6,0.7)	(0.3,0.5,0.7)	(0.5,0.6,0.7)	(0.3,0.5,0.7)	0.1
C_5	(0.2,0.4,0.6)	(0.3,0.4,0.7)	(0.2,0.5,0.8)	(0.2,0.5,0.8)	(0.2,0.4,0.6)	0.1
C_6	(0.3,0.6,0.9)	(0.7,0.8,0.9)	(0.6,0.7,0.9)	(0.7,0.8,0.9)	(0.3,0.6,0.9)	0.2
C_7	(0.4,0.5,0.8)	(0.1,0.3,0.4)	(0.2,0.4,0.6)	(0.4,0.5,0.8)	(0.1,0.3,0.4)	0.3
C_8	(0.5,0.6,0.8)	(0.6,0.7,0.8)	(0.3,0.5,0.6)	(0.6,0.7,0.8)	(0.3,0.5,0.6)	0.23
C_9	(0.2,0.3,0.7)	(0.4,0.6,0.7)	(0.3,0.5,0.6)	(0.4,0.6,0.7)	(0.2,0.3,0.7)	0.16
C_{10}	(0.5,0.6,0.8)	(0.2,0.4,0.5)	(0.6,0.7,0.9)	(0.6,0.7,0.9)	(0.2,0.4,0.5)	0.36
C_{11}	(0.4,0.6,0.7)	(0.5,0.6,0.8)	(0.2,0.4,0.7)	(0.5,0.6,0.8)	(0.2,0.4,0.7)	0.2
C_{12}	(0.3,0.4,0.8)	(0.2,0.5,0.9)	(0.4,0.5,0.8)	(0.4,0.5,0.8)	(0.3,0.4,0.8)	0.06
C_{13}	(0.1,0.4,0.6)	(0.2,0.4,0.6)	(0.3,0.7,0.9)	(0.3,0.7,0.9)	(0.1,0.4,0.6)	0.26
S_i	0.8341	0.403	0.4923	-	-	-
R_i	0.21	0.089	0.21	-	-	-
Q_i	1	0	.104	-	-	-

4. Sensitivity analysis

Regarding our proposed model and illustrative example , sensitivity analysis was performed to evaluate the results obtained from the changes made by experts. The expert response would be fluctuated due to the various factors that influence their decision-making. Therefore, here we investigated the sensitivity analysis of the results by changing the expert feedback to explore associated effects on final ranking. Sensitivity analysis is performed on parameter *v* according to the preference of experts. As this value depends on the DM's opinion and unanimous decision , we consider the three sections as

- Unanimous agreement, $v > 0.5$
- Moderate Agreement, $v = 0.5$
- Weak Agreement $v < 0.5$

In this research, sensitivity analysis tries to obtain different values of Q by varying the values of v from 0 to 1 and examining the desired options according to the obtained results as shown in Figure 4. As we can see in the figure, by changing the values of *v* from 0 to 0.5 the obtained solutions have not been changed significantly and the trend of the ideal options is constant. But if the value of parameter *v* changes from 0.5 to 1, there is an increasing trend in Q, but nevertheless, the increment does not change the prioritization of the available options. These results indicate changes in decision-making by professionals that can influence and change the outcome of decision-making. However, in this study, these changes did not affect the prioritization of the options and the initial results could be considered resilient.

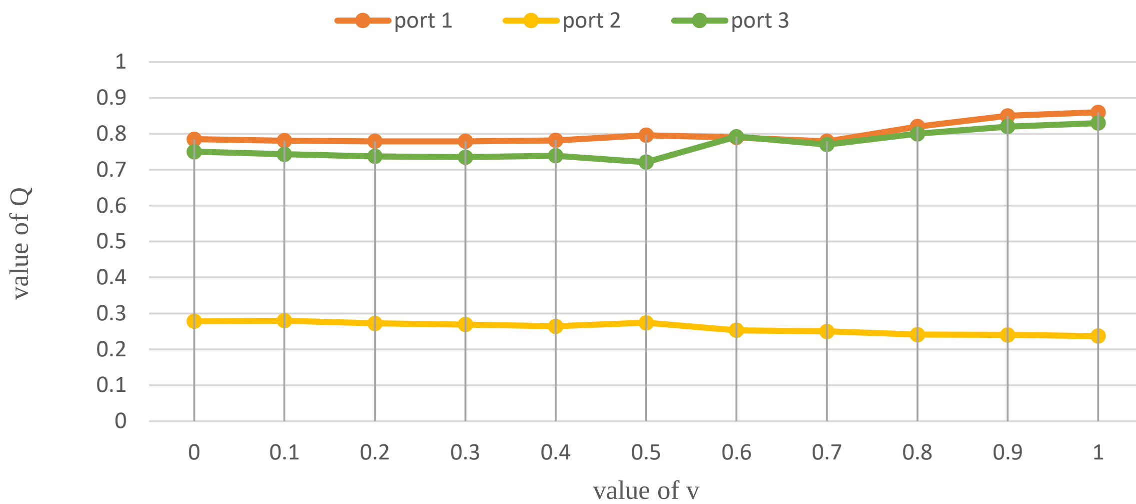

Figure 4. SensitivityAnalysis

5. Managerial implications

The importance of the development of green ports has become more and more critical in the global debate. Decision-makers relied on multiple criteria for determining the result of a green pot. For port managers, it would be essential to configure a less complex green framework. Given the Iranian port industry, managers must understand the importance of different criteria for green port documentation and probable cases Port managers must understand these factors and take into account their priority in terms of the level of requests. Criteria such as emissions of pollutants that are rated higher need to be taken into consideration by port managers. The second consideration with respect to expert opinions would be.

Employees are sensitized to the environment and the extension of these beyond the harbor premises will ultimately lead to stronger societal relationships. Other initiatives classified above need to be considered to achieve sustainability. This can assist managers, practitioners, and decision-makers to attain better sustainable outcomes. Industry professionals are able to implement sustainable initiatives in Indian ports on a priority basis depending on the results obtained in this study.

6. Conclusion

Building green ports as a new strategy to reduce environmental challenges and greenhouse gas emissions, as well as achieving clean fuel and smarting, is on the agenda of the World Ports Organization and a way to find sustainable ports step by step. In green ports, environmental regulations fully comply, in such a way there is no serious debate on environmental pollution. Although many experts described it as ambitious from the beginning of the project, during the time, it has been demonstrated that the activity of most ports is towards achieving clean fuel and environmentally friendly ports. Increasing concerns about the environmental instability of past economic growth patterns and raising awareness of the potential climate crisis in the future have proven that the environment and the economy can no longer be considered isolated parameters. Sustainable growth is a way for economic development and prevents environmental degradation and biodiversity loss due to the consumption of natural resources.

Due to these concerns, assessment and development of ports regarding gigantic quantities of transportation through the international and national, and inland water transportation nowadays is a crucial issue. In this research, we investigated the remarkable factors for green and environmental port development by expert notions through questionnaires for our case study of Iranian Ports. By means of the BWM method and its advantage in less incompatibility and facilitated computing, the final weights of criteria would have been calculated. Afterward, VIKOR method was integrated with a hesitant fuzzy matrix to decrease the ambiguity of the expert's opinions and uncertainty. This study concludes that among the current performance of the three mentioned green ports, Emissions of pollutants in the waters, environmental pollution, and General waste handling are the significant criteria, and Technology and Education, Hazardous waste handling, and Port staff training are the insignificant criteria respectively. Finally, ports A (Beheshti) and C (Rajaee) are nominated as the first priorities. In our case study through a sensitivity analysis which has been on the value of v, the robustness of the best solution has been considered.

Under resource constraints, ports will face difficulties in implementing all the green needs in order to build facilities and operational activities and under these circumstances, more practical action is to select superior factors as the priority execution items and owing to that, the BWM and HF-VIKOR techniques are appropriate solutions to support decision makers take appropriate action. For future developments, the authors suggest using subjective and objective data separately and including them in decision-making methods in an appropriate way.

Our suggestions for further work contain: Firstly, the ANP method can be extended to the VIKOR method, which can better resolve the uncertainty in the comparison matrix provided by experts. Second, the Dempster-Shafer method replaces the fuzzy method of supplier selection in an uncertain environment.

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Appendix A

Definition 1. Suppose X is a set of fixed integer. The fuzzy hesitant of X is used when X is a subset of [0,1].
If $M = \{u_1 . u_2 . \dots . u_n\}$is a set of n membership functions, then a HFS associated to M is as in the following:
$\vartheta_M : X \to \varphi([0.1])\ .\ \vartheta_M(x) = \cup_{\mu \epsilon M} \{\mu(x)\}$
In order to better understanding, fuzzy set skepticism has defined as relation:
$\mathrm{E} = \{\langle x . h_E = (x)\rangle \,|\mathrm{x} \in \mathrm{X}\}\ . H = \cup\, h_E(x)$
Such that $h_E(x)$ is a set of some values in the interval [0,1] based on the membership degree of the values and it is hypothesized that H = $h_E(x)$ is a fuzzy set of doubts.
HFS in the constant set X has the function situation of h and is used when X is a subset of [0,1].
Hence, if h has no value, it means that a set is meaningless. By analogy, if the set contains the whole interval 0 and 1, including all possible values of 0 and 1, in which case the membership of the elements becomes completely indefinite. Also, if it contains only a unique number, it means that the views are the same and the environment is the same. When $\gamma = 0$, this means that the membership of the elements is zero. So we can say this set is empty. However, if $\gamma = 1$, this means that fog is a complete set. It should be noted that the null set should not be considered as a set that contains no values, nor should the whole set be considered as a set of all integers.
In this study, we use triangular fuzzy hesitant fuzzy sets (TFHFS).

Definition 2. A number of basic relationships used in mathematical operations are defined as follows:
Lower bound: $h^-(x) = min\, h(x)$;
Upper bound: $h^+(x) = max\, h(x)$;
$h^c = \cup_{\gamma \in h} \{1 - \gamma\}$;
$h_1 \cup h_2 = \{h \in h_1 \cup h_2 | h \geq max(h_1^- . h_2^-)\}$;
$h_1 \cap h_2 = \{h \in h_1 \cup h_2 | h \leq min(h_1^+ . h_2^+)\}$;
$h_1 \cup h_2 = \cup_{\gamma 1 \in h1 . \gamma 2 \in h2}\ max\{\gamma_1 . \gamma_2\}$;
$h_1 \cap h_2 = \cup_{\gamma 1 \in h1 . \gamma 2 \in h2}\ min\{\gamma_1 . \gamma_2\}$;
Definition 3. Some operations regarding the relationship between the fuzzy doubt sets and the hesitant fuzzy elements are defined as follows:
$h_1 \oplus h_2 = \cup_{\gamma_1 = h_1 . \gamma_2 = h_2} \{\gamma_1 + \gamma_2\}$
$h_1 \otimes h_2 = \cup_{\gamma_1 = h_1 . \gamma_2 = h_2} \{\gamma_1 \cdot \gamma_2\}$
$h^\lambda = \cup_{\gamma = h} \{\gamma^\lambda\}$
$\lambda h = \cup_{\gamma = h} \{1 - (1 - \gamma)^\lambda$
$$h_1 - h_2 = \cup_{\gamma_1 = h_1 . \gamma_2 = h_2} \begin{cases} \dfrac{\gamma_1 - \gamma_2}{1 - \gamma_2} & if\ \gamma_1 \geq \gamma_2\ and\ \gamma_2 \neq 1 \\ 0 & otherwise \end{cases}$$

$$\frac{h_1}{h_2} = \cup_{\gamma_1 = h_1 . \gamma_2 = h_2} \begin{cases} \frac{\gamma_1}{\gamma_2} & if\ \gamma_1 \leq \gamma_2\ and\ \gamma_2 \neq 1 \\ 1 & otherwise \end{cases}$$

Definition 4. To compare the types of HFS, Xia, M. and Xu, Z. (2011) introduced the following comparative method according to which the hesitant fuzzy set score h is as follows:

$$s(h) = \frac{1}{l_h} \sum\nolimits_{\gamma \in h} \gamma$$

In the above relation l_h is the number of components h. For the two HFSs h_1 and $h_2$the results that can be obtained by definition 4 are as follows:
If $s(h_1) < s(h_2)$. then $h_1 < h_2$,$MAX\{h_1 h_2\} = h_2$, and $MIN\ \{h_1 . h_2\} = h_1$;
If $s(h_1) = s(h_2)$, then
It is clear that by definition 4, the equality of points $s(h_1)$ and $s(h_2)$ is not only a criterion of equivalence h_1 and h_2 but may vary in deviation degree. The degree of deviation of all components according to the mean values in an HFS indicates how the components are compatible with each other and to what extent each of them is stable. To better understand this, Chen et al. (2013) defined the concept of deviation degree as follows:
Definition 5. For a h of HFs, the degree of deviation $v(h)$ from h is defined as follows:

$$v(h) = \frac{1}{l_h} \sqrt{\sum\nolimits_{\gamma i . \gamma\ j \in h} (\gamma_i - \gamma_j)2}$$

As noted, $s(h)$ denotes statistical mean and $v(h)$ denotes variance indicating degree of deviation between all values in a fuzzy set of doubt and average value. According to this approach, based on the rating $s(h)$ and degree of deviation $v(h)$, Chen et al. (2013a) have a method for comparing and ranking two HFSs as follows:
If $v(h_1) < v(h_2)$, then $h_1 > h_2$,$MAX\{h1 . h2\} = h_1$, and $MIN\ \{h_1 . h_2\} = h_2$;
If $v(h_1) = v(h_2)$, then $h_1 = h_2$, and $MAX\{h1 . h2\} = MIN\ \{h1\ h2\} = h1 = h2$;
Definition 6. Consider h_M and h_N are two hesitant fuzzy sets, the general distance relation is defined as follows:

$$d_{gh}(h_M . h_N) = \left(\frac{1}{l_{x_i}} \sum_{j=1}^{l_{x_i}} \left| h_M^{\sigma(j)}(x_i) - h_N^{\sigma(j)}(x_i) \right|^{\lambda} \right)^{\frac{1}{\lambda}}$$

Appendix B: Conditions test

Condition 1: Acceptable advantage condition
If A_1 and A_2 are the first, second, and alternatives based on the value of Q, respectively, and n denotes the number of choices, this relation is defined as follows: :

$$[Q(A_2) - Q(A_1)] \geq \frac{1}{n-1}$$

Condition 2: Condition of Acceptable Stability in Decision Making
Option A_1 should be recognized as the top rank in at least one of the R or S groups.
The following situations:
1: When the first condition is not met, a set of options are selected as the top options:

$$\text{Top Options} = Q(A_m) - Q(A_1) < \frac{1}{n-1}$$

2: When only the second condition is not met, two options A_1 and A_2 are selected as the top options.
3: If both conditions were met, the ranking would be Q-based. Decreasingly: The lower Q is the better option.