Article

Sustainability Ranking of the Iranian Major Ports by Using MCDM Methods

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Abstract: The maritime industry is moving towards a sustainable supply chain (SSC), intending to increase the quality of logistics and make more profit. The sustainability of the maritime supply chain (MSC) in Iran is one of the topics that has not been widely studied. Ports play a crucial role in promoting Iran's position in the international transit of products, strengthening economic, social, and environmental connections with neighboring eastern and northeastern countries, improving GDP, and promoting the role of the free zone in the national development of the country. Port development is one of the essential elements in the government's strategic planning in developing and activating the East axis. It has a special priority in line with government policies based on deprivation elimination and improving people's living standards. This paper considers five significant ports of Iran that are part of special economic zones and studies the sustainability of those ports. In this research, different multi-criteria decision-making methods were applied to solve a sustainability-ranking problem of major Iranian ports. First of all, by using the SWARA method, sub-criteria of loading and unloading oil, pier length, and population obtained the highest scores in economic, environmental, and social aspects of sustainability, respectively, which shows that they had the greatest impact on the sustainability assessment of Iranian ports. Finally, the MARCOS and CoCoSo techniques were the most similar in all three dimensions of sustainability, and both seemed to be suitable methods for evaluating the sustainability of ports. Furthermore, the implementation of sensitivity analysis and definition of different scenarios for port evaluation and the high efficiency of the MARCOS method were determined in solving the port-ranking problem. According to the MARCOS method results, economic, environmental, and social criteria were all effective criteria in the sustainable development of major Iranian ports and have been largely applied in Astara, Bushehr, and Imam Khomeini ports. Based on the analysis of the results, several managerial insights to make better industry decisions are also revealed.

Keywords: sustainability; supply chain; port performance criteria; multiple-criteria decision-making (MCDM); SWARA; MARCOS; CoCoSo

1. Introduction

1.1. Marine Supply Chain

The ratio of maritime transport in the movement of goods in international trade is about 90%. That is about six billion tons of goods, about a third of which are petroleum goods, a third of which are dry and bulk goods, and the rest non-bulk goods. Given such a percentage of the movement of goods in world trade, the importance of trade and maritime transport can be examined as two inseparable parts. The maritime industry comprises different industries, including transportation, logistics, and the marine supply chain (MSC). The maritime industry focuses only on the carriage of goods through interconnected ports

by sea. In contrast, maritime logistics integrates activities to control the flow of goods from suppliers to end customers.

The difference between marine logistics and MSC industries is that marine logistics can be considered a part of the MSC. Logistics focuses only on the flow of materials and information, as well as chain management. At the same time, the SC has a greater view of the chain and considers management and collaboration throughout the chain. Therefore, SC management includes managing key aspects of transportation, material control, production, and distribution from producer to customer.

As a key link in the maritime transport chain, ports play a key and decisive role in the development of the country's transportation economy and world trade. Increasing demand in maritime transport requires the development of ports in various dimensions of sustainability. This development includes increasing the number of ships and size of ships, the capacity on the mooring structure, and operational and port activities. On the other hand, an increase in the number of ships leads to a rise in climate pollution, the discharge of significant volumes of marine litter, the release of thousands of tons of oil and oil waste at sea, and other threats to the environment. Therefore, the study of indicators that develop ports in different dimensions of sustainability is significant.

Two critical industries in the MSC are the shipping industry and ports, which play the role of a customer for the port system, and ports have a significant impact on the MSC, as they serve as a link between sea and land for international trade. So, any significant improvement in the quality and infrastructure of ports will also significantly impact the maritime supply chain. The new maritime supply and SC trend requires new management developments, methods, and liberalization and creates more competition, due to which maritime logistics provide higher service quality for the customer.

Making any interruptions in port development projects requires the payment of high and unpredictable costs. Preservation of current capital and resources for future generations is directly affected by applying sustainable development indicators on port development projects, so reviewing and implementing a sustainable development indicator is necessary and effective in helping managers decide.

1.2. Marine Supply Chain in Iran

The country's commercial ports are divided into three categories: special economic zones, freeport zones, and normal zones in terms of location, main facilities, and the type of services they provide, as well as according to the prevailing laws and regulations and enjoying legal benefits and facilities.

Iran's position in the transit of goods and strengthening economic ties with neighboring countries has become a strategic focus of government in the southeast of the country, which is expected to see the start of change in this region with non-governmental investment and port activation. Iran is on its way to international transportation. Due to the strategic geographical location of Iran in the region and having about 3000 kilometers of water borders in the north and south of the country, Iran has a privileged position in international transportation. The reform of the port structure with the participation and investment of the private sector in infrastructure and current affairs has an essential role in the growth and development of the country's economy; therefore, conducting studies in the field of ports will play an important role in the development of the country.

According to the Islamic Republic of Iran's administration of special economic zones law, special economic zones are protected areas. Currently, they include the special economic zones of Shahid Rajaei, Bushehr, Astara, Nowshahr, Imam Khomeini, and Amirabad. Special economic zones play an important role in increasing international trade and job creation around the world. From the global economic perspective, special economic zones are considered one of government policies' tools to promote industrialization, job creation, and regional development. Some of the goals of this region are non-oil exports, mobilization in the regional economy, establishing international trade relations, and the production

and processing of goods. Table 1 shows the classification of essential ports of the country in the mentioned regions.

Table 1. Iranian commercial ports.

Normal Port Zones	Freeport Zones	Special Economic Zone
Chabahar	Anzali	Shahid Rajaei
Shahid Bahonar	Khorramshahr	Imam Khomeini
Shahid Haghani	Abadan	Bushehr
Lengeh		Amirabad
Qeshm		Nowshahr
Jask		Astara
Genaveh		
Fereydunkenar		
Neka		

1.3. The Importance of Sustainability

Sustainability does not mean that nothing changes. A sustainable society seeks to preserve and improve the economic, environmental, and social characteristics of an area so that its members can survive in a healthy, productive way. It considers the sustainability of the SC with social, economic, and environmental dimensions.

SSC can be considered managing information, resources, activities, and financial flows to maximize economic productivity and social welfare and reduce destructive effects on the environment. Researchers have considered this topic frequently in recent years. Optimizing operations with economic improvement in terms of cost-effectiveness and, at the same time, the efficiency of working conditions in the SC is an essential goal of sustainable development (SD) in economic and social dimensions. On the other hand, the environmental dimension of SD focuses on reducing the negative effects of the environment.

The maritime industry is moving towards an SSC, intending to increase the quality of logistics and make more profit. Ports are essential components of this chain, are part of the country's basic infrastructure, and form the country's main import and export channel. The need for further port development should be considered in maritime planning. Consequently, it is necessary to consider the environmental, social, and economic effects of all planning that has a specific impact on shipping activity and leads to optimizing decisions and selecting SD strategies in the maritime industry. Each of the dimensions of sustainability pursues goals that are explained below.

- **Economic goals**

Minimizing operating costs such as transportation and inventory costs are economic goals in SD. Ports have an essential effect on SC design to reduce costs by increasing the quality of port services and simultaneously reducing waiting time in attracting customers.

- **Environmental goals**

The environmental goals of SD are to reduce the destructive effects of ports and the shipping industry. Various environmental sub-criteria have been defined to assess pollution, environmental regulations, recycling, and future development strategies.

- **Social goals**

The development of ports and their conversion into special economic zones directly impact social justice, unemployment, population growth rate, literacy rate, and social participation in the region.

Today, the effects of port development exist not only in the environmental field but also in the economic and social aspects. The purpose of port development, in addition to providing the basis for extensive and continuous environmental operations, is to create a balance in the implementation of other aspects of sustainable development. Other methods have been developed locally and internationally to achieve the goal of sustainable

development with the support of environmental management. Legal requirements and environmental management in ports include the following:

- **International Maritime Organization (IMO) rules**

  The IMO introduced strategic plans for the protection of the marine environment by presenting the Convention on the Prevention of Emissions of Waste and Other Materials, including dredging from rivers and the sea, as well as the Convention on the Prevention of Oil Pollution and the Relocation of Ship Waste.

- **Agenda of the 21st Rio Conference**

  This agenda is related to environmental protection, sustainable coastal and marine development and natural resources, environmental impact assessment of large projects, establishing facilities for ports, oil reactions, and marine environmental monitoring systems.

- **International Association of Ports and Harbors (IAPH)**

  This association established links between ports to share environmental concerns about air pollution, the handling of hazardous materials, dredging, and waste. It has also developed environmental impact analysis; the prevention of major accidents and climate pollution, dredging, and waste management, and enforces applicable laws and regulations.

- **United Nations Conference on Trade and Development (UNCTAD)**

  UNCTAD has surveyed port sectors in different countries and established regulations to identify important factors contributing to port services' efficiency and sustainable development.

1.4. Definition of Problem

Port activities are divided into two groups: operational and development activities. For example, ship navigation, unloading goods, industrial activities, ship maintenance, dredging, etc., are among the most crucial port operations. Port development activities also include expanding ports, creating new container areas, land reclamation, dredging, etc. Both operational and development activities, in turn, can affect the three indicators of SD. Activities such as increasing the capacity of ports, the amount of transport and unloading and loading of ships, the number of vessels entering or leaving each port, and the attractiveness of a seaport to attract tourists are among the activities that directly impact the economic aspects of SD. Simultaneously, marine litter discharged from ships, sewage discharged from ships, and fuel consumption of the shipping sector in each port and the rate of land and sea degradation are among the factors that affect the environmental aspects of SD. The development of ports and the conversion of ports into special economic zones will directly impact social justice, unemployment, population growth rates, literacy rates, and the level of social participation in the region, subsets of a sustainable social aspect.

Initially, the port service quality Foster considered in his research [1] demonstrated its importance via HA [2]. Alena and Vagaská [3] also provided valuable studies in the field of mathematical modeling and their applications.

This study aims to rank Iran's high-traffic ports using sustainability criteria. In each dimension of the sustainability criteria, some sub-criteria are defined and collected according to the information available in the Ports Organization of Iran and the Statistics Center of Iran. In the sub-criteria where the required data are not available, provincial information is cited. This approach can be used similarly in other seaports. This paper aims to answer the following questions:

- What sub-criteria should be considered for assessing marine sustainability?
- What is the degree of importance of each sub-criterion?
- Which of the alternative assessment methods are suitable for solving the sustainability ranking of the problem of major Iranian ports?
- Which solution has better results than others?

The relevant literature on sustainability communications and environmental sustainability in SCs is investigated in Section 2. In Section 3, criteria and alternative assessment

methods are described, and in Section 4, the solutions' results and sensitivity are analyzed. Based on the final results, the subject is summarized, and finally, the conclusions and outlook of the research are given in Section 5.

2. Related Literature

The economic, social, and environmental dimensions are embedded in sustainable supply chain management (SSCM). It should be noted that all the studies presented until 2015 considered deterministic parameters, whereas, for the first time, uncertainty in demand was introduced into this set of problems. In general, sustainability criteria play an essential role in the development of a sustainable supply chain. These criteria are the relationship between suppliers and customers.

By using AHP methodology, Lam and Dai [4] presented the architecture and the port selection procedure of the web-based DSS and then illustrated three different cases. The results showed how technology advancement could bring positive effects of strategic planning to shipping firms. Faulin et al. [5] also used AHP to select the most sustainable distribution routes to mitigate the pollution impact of transportation activities. They also incorporated them into software development to select the most environmentally suitable routes in the delivery processes for customers. Sayareh and Alizmini [6] weighed the most dominant decision-making criteria by Technique for Order Preference to Similarity by Ideal Solution (TOPSIS) and selected an optimized container seaport in the Persian Gulf via the analytical hierarchy process (AHP) according to decisive port selection factors.

Wang et al. [7] identified the main factors motivating cruise lines to select specific ports of call and to provide information to port operators that would enable them both to improve their management strategies and to attract more cruise ships, thereby contributing to the revenues of the port and regional economy. Asgari et al. [8] investigated the sustainability performance of five major UK ports and used the AHP method to rank the ports based on both economic and environmental aspects. The identification of environmental initiatives and measures that affect maritime ports was the aim of Beškovnik and Bajec [9]. They showed that it is possible to build a commonly used platform for a port's environmentally and socially sustainable development, even if a certain port had not been following sustainable and environmentally friendly development thus far. Hakam [10] proposed a paper to fill that gap by proposing a conceptual intelligent sustainability performance management framework for Nordic container ports. Shiau and Chuang [11] developed port sustainability indicators (PSIs) using social construction of technology, and the study suggested 34 expert-based PSIs.

Wang [12] reported findings regarding assessing the energy efficiency of port operations in China based on the data from public domains by using the combination of data envelopment analysis (DEA) and panel data estimation (PDE). Zavadskas et al. [13] proposed an integrated multi-criteria decision-making model to solve the problem. The backbone of the proposed model consisted of a combination of analytic hierarchy (AHP) and fuzzy ratio assessment (ARAS-F) methods. The model was presented as a form of decision aiding that could be implemented regarding any specific port or similar site selection. Boulos [14] identified how sustainable connections between cities and ports can develop through principles of sustainable planning and city–port connectivity.

Laxe et al. [15] used the analysis of the relationship between the findings obtained for the economic and environmental dimensions, which enable the existence of links between ports and economic and environmental indicators, for a sample of 16 Port Authorities of Spain to be verified. Lu et al. [16] examined the effects of sustainable supply chain management on sustainability performance in the port context. They showed that external sustainable collaboration is positively associated with internal sustainable management, which positively influences sustainability performance. Roh et al. [17] conducted a comprehensive review of related literature and confirmatory in-depth interviews with port authorities. The challenges, opportunities, and managerial implications for Vietnamese ports are also discussed in this study accordingly. For this purpose, Akbari et al. [18]

reconciled the diverse criteria involved in offshore wind port selection by using AHP. The wind farm location's distance is considered the key selection criteria for installation and O&M ports. Laxe et al. [19] analyzed and ranked a sample of 16 Port Authorities of Spain that grouped 23 ports of general interest using a global synthetic index of sustainability (developed using the four dimensions of sustainable development: economic, institutional, environmental, and social). Lai X et al. [20] aimed to examine the incentives of forecast information sharing from the port and the effect of carrier's risk behavior on such sustainability investment decisions in a maritime supply chain. They found that the relationship between sustainability investment level and the port's service fee/the carrier's freight rate can be positive or negative.

Hsu and Wang [21] focused on allocating two scarce resources, i.e., berth and quay cranes. The experimental results showed that combining the MPSO with the event-based heuristic leads to a better result. Papachristou et al. [22] examined the criteria structuring cruise lines' decisions of the port to use for home-porting using a database constructed with input from cruise lines, ports, and cruise terminal operators and stakeholders. In another study, Sahin and Soylu [23] aimed to develop a multi-layer, multi-segment iterative optimization algorithm for the operations of a single agent, which can be either a container in a distribution system, an automated guided vessel in a transport network, or a vessel in a maritime environment with obstacles.

Sawik [24] presented a review of selected multiple-criteria problems used in supply chain optimization. Prevention, response, protection, and recovery strategies were explained. The practical part focused on risk-averse models to minimize the expected worst-case scenario by single sourcing. In an investigation, Gupta et al. [25] solved a bi-level decision-making process that minimizes the total costs of transportation in the first level and then minimizes the total delivery time of the SCN and balances the allocation order between various sources and destinations in the second level. Fuzzy goal programming (FGP) was used to solve the multi-objective of the supply chain network in a real-life case study. [26] developed a port-choice model in regions with multiple ports as a linear city in which the model incorporates the behaviors of both shippers and shipping lines simultaneously. Sahin et al. [27] aimed to solve the maritime supply chain problem operating under uncertain demand conditions. Finally, the proposed model can enable decision-makers to decide on both situations in terms of possible pessimistic, probable, and optimistic values of demand and the priorities of the decision; decision-makers can also decide on the minimum level of losses or damages.

Some other developments of decision-making models based on the SWARA method up to now are listed below. Kersuliene et al. [28] conducted a study on the selection of the rational dispute resolution method and Kersuliene and Turskis [29] conducted another on architect selection. Alimardani et al. [30] used hybrid SWARA in supplier selection in an agile environment. Zolfani [31] used the SWARA method in the design of products. He also optimized the problem of mechanical longitudinal ventilation of tunnel pollutants in [32]. Karasan and Bolturk [33] also used CoCoSo with interval-valued neutrosophic numbers to select the site of the disposal of solid waste in Istanbul. Peng et al. [34] created a new MCDM model in the 5G industry by using CoCoSo and CRITIC. Yazdani et al. [35] assessed supplier performances for a construction business located in Madrid using the CoCoSo method. The generation of diverse ranking results or optimal alternatives is a significant criticism of MCDM approaches. CoCoSo (combined compromise solution) was thus primitively developed. Zolfani et al. [36] used this method in manufacturing technology and sustainable supplier assessments. Deveci et al. [37] studied a novel on the compromise solution (CoCoSo) methodology, including the logarithmic method. Limited use of SWARA and CoCoSo methods in port selection problems can be seen in the literature. Vagaská and Gombár [38] also provided valuable studies in the field of mathematical modeling and their applications.

This study aims to fill this gap and uses SWARA and CoCoSo methods in port selection for significant ports in Iran. In this paper, quantitative sub-criteria can be objectively

compared and evaluated, and qualitative factors have subjective effects, such as port marketing, flexibility, level of collaboration, and tradition. In many cases, quantitative and qualitative factors have been used to evaluate or analyze factors related to the quality of port services. Table 2 shows the major recent procedures in the maritime supply chain.

The concept of sustainable development has been implemented in some foreign ports, and several programs related to significant and specific issues for spatial development have started. On the other hand, other ports have considered only thinking and cognition in this field. However, the decision-making and planning of environmentally friendly processes in port development are very complex. Significant issues need to be addressed first, but ports have difficulty segregating the degree of importance of sustainable development sub-criteria. Many types of research have been done on sustainable development, but there is no specialized research on port development in Iran. The Domestic and foreign research on sustainable port development shows that most researchers in this field have the following three central issues:

- Most research on sustainable port development has focused on the environment, emphasizing the key role of development in line with environmental protection. Environmental aspects have been studied during the executive process of port development, and by stating the role of pollutants and environmental effects resulting from measures in this area, they have stated strategies to reduce these effects of the sustainable development framework. If port development is not implemented in line with sustainable development of the environment and energy resources, it will not meet the needs of the next generation.
- Sustainable development has been stated as the only issue to cover the increase in trade and transportation ports. In this regard, sustainable port development has been noted to meet trade demand, which should be in line with economic and environmental development and executive strategies.
- Considering the necessity of implementing sustainable development, they have dealt with how to implement it, for example, through port intelligence, in which the way to achieve sustainable development in the port development process through the smart development of ports will be done by creating technological innovations based on comprehensive cooperation between different systems, especially social, cultural, and economic ones.

Table 2. The major recent procedures in the maritime supply chain.

No.	Reference of Study	Year	Case Study	Research Method		Sustainable Attitude	MCDM Methodology						Other Methodologies		
				Quantitative	Qualitative		DEA	AHP	SWARA	MARCOS	COCOSO	TOPSIS	Non-Mathematical	Fuzzy Sets	Other Methods
1	[3]	2012		+				+							
2	[5]	2013	Spain	+		+		+							
3	[7]	2014	East Asia	+										+	
4	[6]	2014	Iran	+				+				+			
5	[13]	2015	Eastern Baltic Sea	+										+	
6	[10]	2015	Nordic		+	+							+		
7	[14]	2015	Port Said, Egypt		+	+	+								
8	[12]	2015	China	+		+							+		
9	[9]	2015	-	+		+							+		
10	[8]	2015	UK ports	+		+		+							
11	[11]	2015	Keelung Port	+	+	+							+		
12	[15]	2016	Spanish ports	+		+							+		
13	[16]	2016	Taiwan	+		+							+		
14	[19]	2016	Spanish ports	+		+							+		
15	[17]	2016	Vietnamese ports		+	+							+		
16	[18]	2017	UK ports	+		+		+							
17	[20]	2019		+		+									+
18	[21]	2020		+											+
19	[23]	2020		+	+									+	
21	This study	2021	Iran	+		+			+	+	+	+			

3. Methods

In multiple-criteria decision-making (MCDM), several criteria that can even conflict with each other are evaluated. Considering multiple criteria explicitly leads to more informed and better decisions. In this study, the stepwise weight-assessment ratio analysis (SWARA), measurement of alternatives and ranking according to compromise solution (MARCOS), combined compromise solution (CoCoSo), and technique for order preference by similarity to ideal solution (TOPSIS) were used to solve the problem, which is discussed below.

3.1. SWARA Method

The stepwise weight-assessment ratio analysis (SWARA) method was introduced by Kersuliene et al. [28]. The decision-maker must consider the relative importance of all criteria in this method. After that, values must be sorted in descending order. Then, the final ranking is calculated. Kersuliene et al. employed this method in the selection of a packaging design, and Alimardani et al. used hybrid SWARA in supplier selection in an agile environment. The SWARA procedure is presented for j = 1, 2, . . . , n attributes:

- **Step 1.** Prioritize the attributes in terms of relative importance (Sj), which are assumed.
- **Step 2.** Compute the coefficient (K_j) of an attribute by Equation (1).
- **Step 3.** Calculate the initial weight of an attribute (q_j) by Equation (2).
- **Step 4.** Calculate the relative weight of an attribute (w_j) by Equation (3).

$$K_j = \begin{cases} 1, & j = 1 \\ S_j + 1, & j > 1 \end{cases} ; \forall j \in 1, 2, \ldots, n \tag{1}$$

$$q_j = \begin{cases} 1, & j = 1 \\ \frac{q_j}{K_j}, & j > 1 \end{cases} ; \forall j \in 1, 2, \ldots, n \tag{2}$$

$$w_j = \frac{q_j}{\sum_{j=1}^{n} q_j}; \forall j \in 1, 2, \ldots, n. \tag{3}$$

3.2. MARCOS Method

MARCOS is a novel methodology with a variety of applications. This method is used in solving the whole problem in an ideal and anti-ideal way, and then the value of the alternatives is determined. Then different utility functions are calculated based on the value of the alternative utilities to find the alternative weightings and their ranking. The methodology was applied to this study based on the following steps:

Step 1. Calculate the normalized data (n_{ij}) by using a decision matrix (x_{ij}) with Equation (4), where elements xij and x_{ai} represent the elements of the matrix x_{ij}.

Step 2. Calculate the weighted matrix (v_{ij}) by using the weight of each criterion (w_j) with Equation (5).

Step 3. Calculate the utility degree (k_i) based on the ideal and anti-ideal solution values with Equation (6).

Step 4. Calculate the utility functions $f(k_i)$ based on the utility values by using Equation (7).

Step 5. The ranking step is based on the utility function derived from step 5 using Equation (8).

$$n_{ij} = \begin{cases} \frac{x_{ij}}{x_{ai}}, & \text{if jth criterion is beneficial} \\ \frac{x_{ai}}{x_{ij}}, & \text{if jth criterion is cost} \end{cases} \forall j \in 1, 2, \ldots, n, \ \forall i \in 1, 2, \ldots, m \tag{4}$$

$$v_{ij} = n_{ij} * w_j; \forall j \in 1, 2, \ldots, n, \ \forall i \in 1, 2, \ldots, m \tag{5}$$

$$s_i = \sum_{j=1}^{n} v_{ij} \rightarrow k_i^- = \frac{s_i}{s_{aai}}, \ k_i^+ = \frac{s_i}{s_{ai}}; \forall j \in 1, 2, \ldots, n, \ \forall i \in 1, 2, \ldots, m \tag{6}$$

$$f\left(k_i^-\right) = \frac{k_i^+}{k_i^+ + k_i^-} \ and \ f\left(k_i^+\right) = \frac{k_i^-}{k_i^+ + k_i^-}; \forall i \in 1, 2, \dots, m \tag{7}$$

$$f(k_i) = \frac{k_i^+ + k_i^-}{1 + \frac{1 - f\left(k_i^+\right)}{f\left(k_i^+\right)} + \frac{1 - f\left(k_i^-\right)}{f\left(k_i^-\right)}}; \forall i \in 1, 2, \dots, m. \tag{8}$$

3.3. CoCoSo Method

This method is based on an integrated, simple additive weighting and an exponentially weighted product model. To solve a CoCoSo decision problem, after preparing the data matrix, the following steps must be done:

Step 1. Calculate the normalized data (r_{ij}) by using a decision matrix (x_{ij}) with Equation (9).
Step 2. Calculate the weighted comparability sequence (s_i) with Equation (10).
Step 3. Calculate the power weight of comparability (p_i) with Equation (11).
Step 4. Calculate the relative weights (k_{ia}, k_{ib}, k_{ic}) with Equations (12)–(14).
Step 5. Calculate the final ranking (k_i) with Equation (15).

$$r_{ij} = \begin{cases} \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}}, & \text{if jth criterion is beneficial} \\ \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}}, & \text{if jth criterion is cost} \end{cases} ; \forall j \in 1, 2, \dots, n, \ \forall i \in 1, 2, \dots, m \tag{9}$$

$$s_i = \sum_{j=1}^{n} w_j . r_{ij} ; \ \forall i \in 1, 2, \dots, m \tag{10}$$

$$p_i = \sum_{j=1}^{n} (r_{ij})^{w_j} ; \ \forall i \in 1, 2, \dots, m \tag{11}$$

$$k_{ia} = \frac{p_i + s_i}{\sum (p_i + s_i)}; \ \forall j \in 1, 2, \dots, n, \ \forall i \in 1, 2, \dots, m \tag{12}$$

$$k_{ib} = \frac{s_i}{\min s_i} + \frac{p_i}{\min p_i}; \ \forall j \in 1, 2, \dots, n, \ \forall i \in 1, 2, \dots, m \tag{13}$$

$$k_{ic} == \frac{\lambda(s_i) + (1 - \lambda)(p_i)}{(\lambda \max s_i + (1 - \lambda) \max p_i)}; \ \forall i, j, \ 0 \le \lambda \le 1 \tag{14}$$

$$k_i = (k_{ia} . k_{ib} . k_{ic})^{1/3} + 1/3(k_{ia} + k_{ib} + k_{ic}); \ \forall i \in 1, 2, \dots, m. \tag{15}$$

3.4. Case Description

According to studies and additional information, the ports of Shahid Rajaei, Imam Khomeini, Bushehr, Amirabad, and Astara are the country's five main and busiest ports, and are special economic zones. The provinces of Hormozgan, Khuzestan, Bushehr, and Mazandaran are located in Gilan Province. It should be noted that the problem data set was collected using field studies by the researchers, which was then used for information processing. Figure 1 shows the location of each port on the map of Iran. In the following, each of the mentioned ports will be examined. Table 3 shows the alternatives and economic, environmental, and social sub-criteria of sustainability considered in this paper, along with their acronyms.
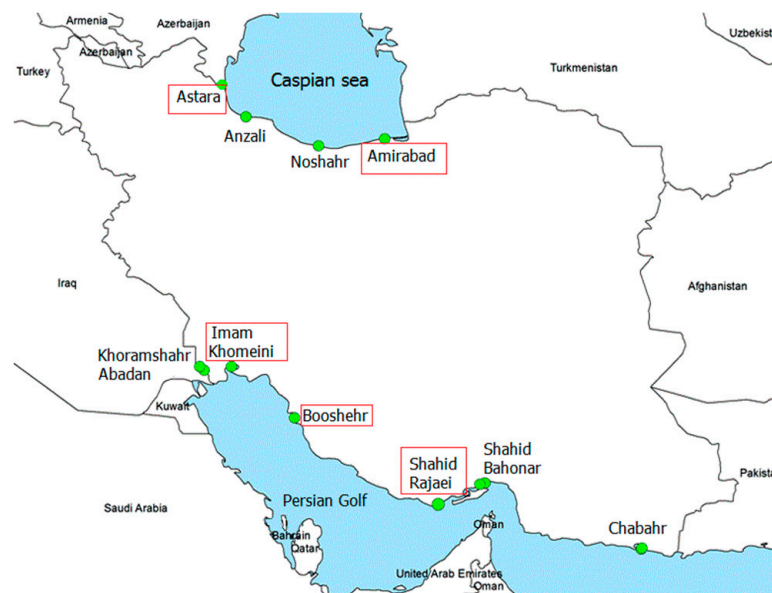
Figure 1. Location of each port on the map of Iran.

Table 3. List of alternatives and criteria.

Alternatives	Economic Criteria	Environmental Criteria	Social Criteria
A_1. Port of Shahid Rajaei	C_{11}. loading and unloading (oil) (ideal)	C_{21}. Pier length (anti-ideal)	C_{31}. Population (ideal)
A_2. Port of Imam Khomeini	C_{12}. loading and unloading (non-oil) (ideal)	C_{22}. Depth of port waterline (anti-ideal)	C_{32}. Unemployment rate (anti-ideal)
A_3. Port of Booshehr	C_{13}. Number of floating (ideal)	C_{23}. Forest cover (ideal)	C_{33}. Urbanization rate (ideal)
A_4. Port of Amir Abad	C_{14}. Number of tourists (ideal)	C_{24}. Desert phenomenon (anti-ideal)	C_{34}. Economic participation rate (ideal)
A_5. Port of Astara	C_{15}. Warehouse area (ideal)	C_{25}. Fuel consumption (anti-ideal)	C_{35}. Literacy rate (ideal)
	C_{16}. Number of piers (ideal)	C_{26}. Aquatic fishing (anti-ideal)	C_{36}. Internet usage (ideal)
	C_{17}. Port capacity (ideal)		C_{37}. Number of hotels (ideal)

4. Experimental Results

In this study, citing maritime transport indicators published by the Ports and Maritime Organization, statistics published by the Statistics Center of Iran, and the Ministry of Energy, a review of SD indicators of world ports is embedded below the criteria for each port. In this section, we will analyze the results obtained from the different methods. Tables 4–6 presents the decision matrix for economic, environmental, and social criteria.

Table 4. Decision matrix for economic criteria.

Ports/Criteria	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}
A1	3,789,086	171,090	2221	10,062	31	5	8.2
A2	36,890,637	99,836	3114	11,114	262	7	55
A3	165,049	0	145	8182	5	1	0.6
A4	2,452,419	514	1374	713	21	5	2.7
A5	54,701,698	1,439,107	6849	839	549	6	93.3

Table 5. Decision matrix for environmental criteria.

Ports/Criteria	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}
A1	2238	9.5	204	332	153,050	217,057
A2	6750	14	938	521	265,402	47,379
A3	130	5.5	545	1	6406	57,734
A4	1455	5.5	1006	1	18,077	23,382
A5	9810	15	1053	1515	268,818	15,252

Table 6. Decision matrix for social criteria.

Ports/Criteria	C_{31}	C_{32}	C_{33}	C_{34}	C_{35}	C_{36}	C_{37}
A1	1,032,949	9.7	68.2	36.3	83.6	19.8	31
A2	4,531,720	11	71	37.5	83.5	14.8	65
A3	2,480,874	11	60.3	41.1	84.29	14.9	78
A4	3,073,943	12.1	54.7	41	85.7	16.6	201
A5	1,578,183	11.9	50	37.2	83.67	13.9	24

4.1. Criteria Assessment

In this paper, the SWARA method was used to calculate the weight of each sub-criteria, and the results are shown in Figure 2. Based on the obtained results, loading and unloading (oil), pier length, and population were the most significant criteria in the economic, environmental, and social aspects of sustainability, as well as port capacity, aquatic fishing, and number of hotels. After determining the values of the weights for all criteria, the MARCOS, CoCoSo, and TOPSIS methods were used to rank and select the desired ports.
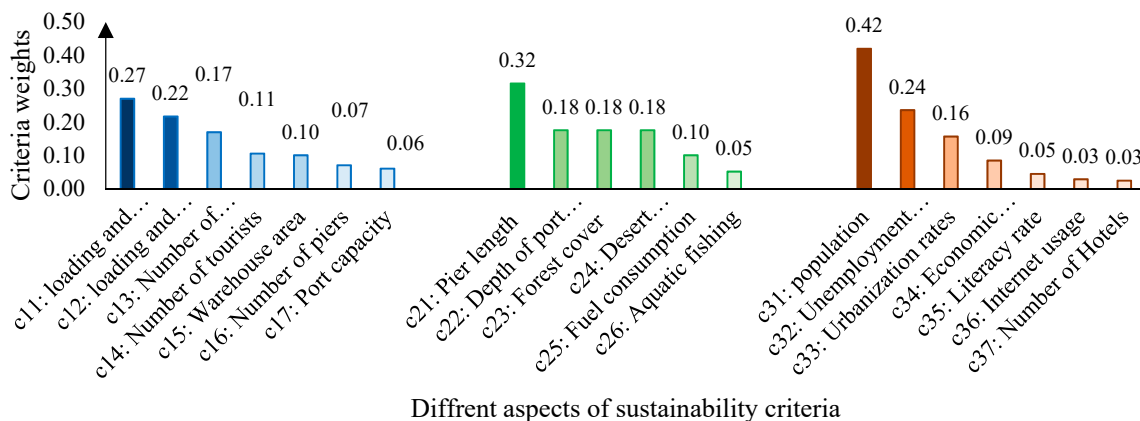

Figure 2. Weight of each sub-criteria for all aspects of sustainability.

To ensure the best alternative in each of the dimensions of sustainability and ensure high accuracy ranking and an appropriate comparison of the solution methods, the three methods of MARCOS, CoCoSo, and TOPSIS were applied.

4.2. Alternative Assessment

The results obtained in different methods show that they were very close to each other despite some differences and had relatively similar results in solving this problem. Figures 3–5 show the results obtained using the MARCOS, CoCoSo, and TOPSIS solution methods, respectively. According to the MARCOS method, using economic criteria, the alternatives of A5, A2, A3, A4, and A1 were ranked first to fifth, respectively. Considering the environmental criteria, the MARCOS method placed the alternatives of A3, A4, A1, A2, and A5 in the first to fifth place, respectively. According to the social criteria, the

alternatives of A2, A4, A3, A1, and A5 were in the first to fifth ranks in the MARCOS method, respectively.
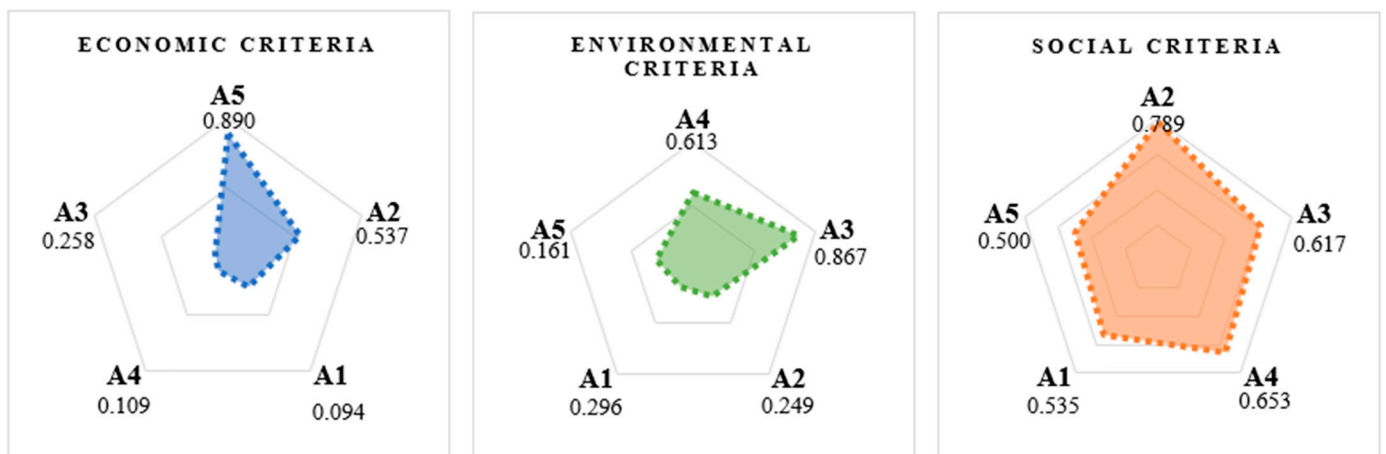

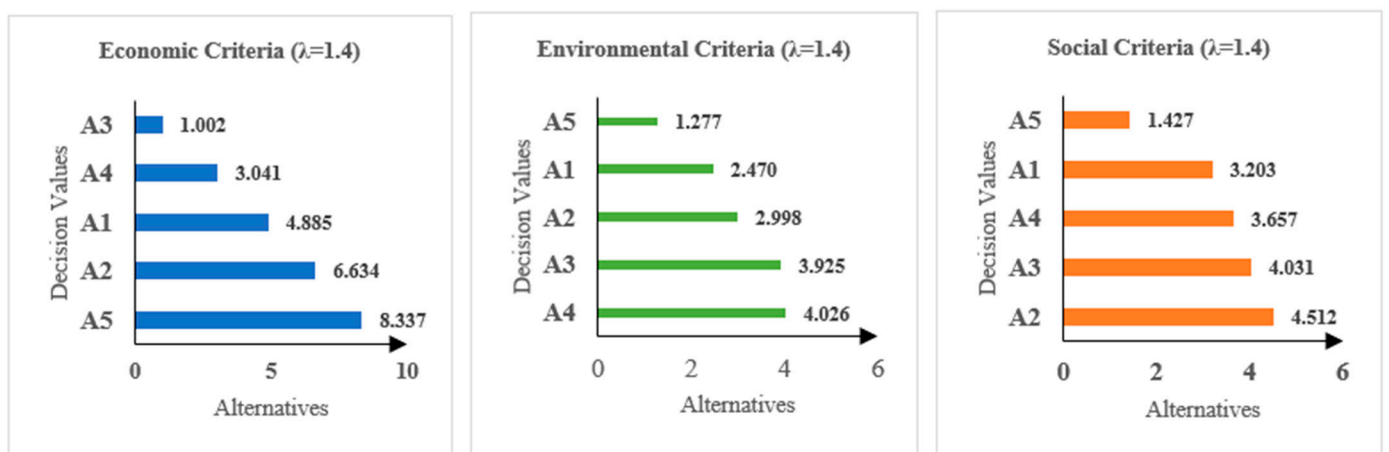**Figure 3.** Results of the MARCOS method for different aspects of sustainability.

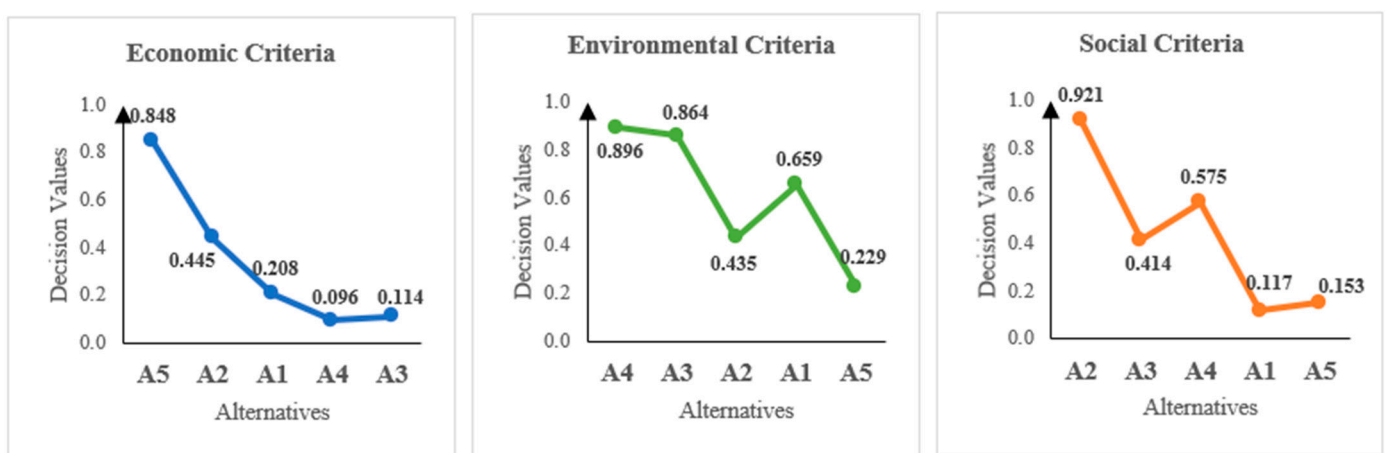**Figure 4.** Results of the CoCoSo method for different aspects of sustainability.

Figure 5. Results of the TOPSIS method for different aspects of sustainability.

Another approach to classifying alternatives into different categories was proposed by Chen et al. (2006), which is a more realistic approach. Table 7 shows the suggested intervals, and the range from 0 to 1 is divided into five categories.

Table 7. Class types for CC_j.

Class	Closeness Coefficient	Evaluation status
II	CC_j in [0.00, 0.45]	Do not recommend
III	CC_j in [0.45, 0.50]	Usually recommended
IV	CC_j in [0.50, 0.55]	Approved
V	CC_j in [0.55, 0.60]	Highly approved
VI	CC_j in [0.60, 1.00]	Highly approved and preferred

Alternative class types are also shown in Table 8. According to Table 4, using economic criteria with the TOPSIS method, port A5 was highly approved and preferred, and other alternatives were not recommended. Using the TOPSIS method based on environmental criteria, the A4, A3, and A1 alternatives were highly approved and preferred, and other alternatives were not recommended. In addition, considering social criteria, port A2 was highly approved and preferred, port A4 was highly approved, and other alternatives were not recommended.

Table 8. Alternative class types.

Ports/Evaluation Status		Do not Recommend	Usually Recommended	Approved	Highly Approved	Highly Approved and Preferred
Economic Criteria	A5					✓
	A2	✓				
	A1	✓				
	A4	✓				
	A3	✓				
Environmental Criteria	A5	✓				
	A2	✓				
	A1					✓
	A4					✓
	A3					✓
Social Criteria	A5	✓				
	A2					✓
	A1	✓				
	A4				✓	
	A3	✓				

4.3. Sensitivity Analysis

Sensitivity analysis is one of the most critical steps after solving mathematical problems. In this paper, the obtained results were analyzed, and after that, several managerial insights were obtained from these results. In the first phase of sensitivity analysis, the methods used to rank ports were compared and analyzed. The CoCoSo method was analyzed in the second phase, and the relationship between changing solutions and changing λ parameter values was investigated. Changing the weight of criteria is one of the most critical parts of MCDM problems. By changing the weights in a specific way, the variability of the alternatives, their sensitivity to the calculated weights, and their stability can be examined, which was addressed in the third phase of sensitivity analysis. In the fourth phase of sensitivity analysis, the initial data matrix was changed, and its effects on the ranking of other alternatives were examined.

4.4. Comparison of Applied Methods

After obtaining the results using different MCDM methods, the solution methods were compared with each other. As shown in Figure 6, in comparison to methods in different dimensions of sustainability, the MARCOS and CoCoSo methods had relatively similar behavior in the results, and the correlation between these two methods was very high. Still, the TOPSIS method had differences compared to these two methods in the ranking of alternatives. Thus, MARCOS and CoCoSo are recommended for solving performance assessment and port ranking or port selection problems.
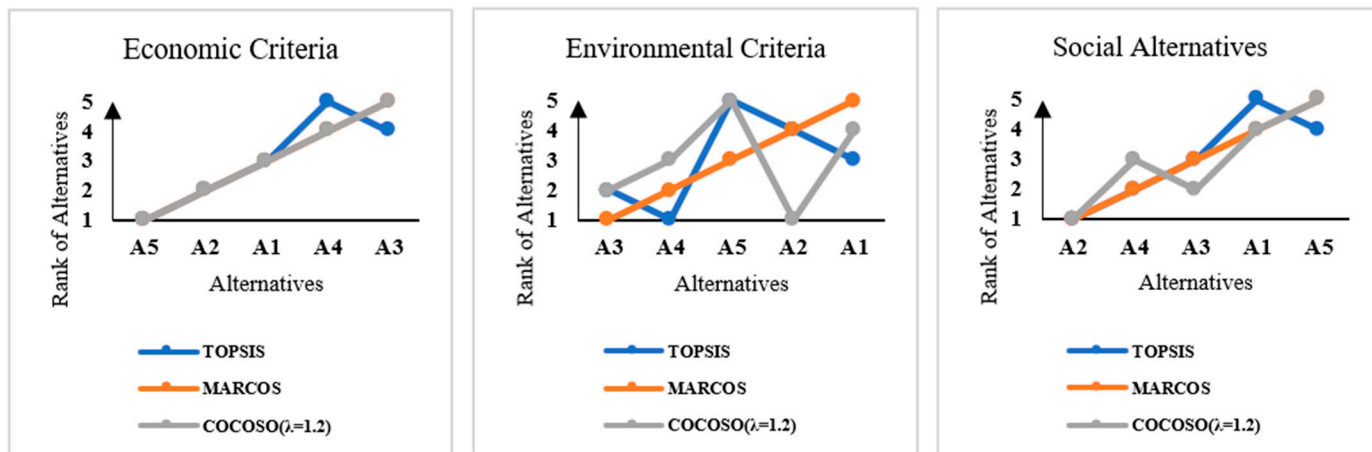
Figure 6. Comparison of the applied methods with each other.

4.5. Analyzing the λ Parameter in CoCoSo

Figure 7 shows the results and the effect of parameter λ in the CoCoSo method. In this paper, the CoCoSo method was applied to solve the problem using different values of λ. As shown in Figure 7, the λ parameter in the CoCoSo method effectively ranked alternatives in all three dimensions of sustainability and changed the obtained results. Therefore, due to the complexity of estimating the value of this parameter in solving the problem and the proximity of the solutions of the MARCOS method to the CoCoSo method, it is suggested to use the MARCOS method for solving this type of problem.
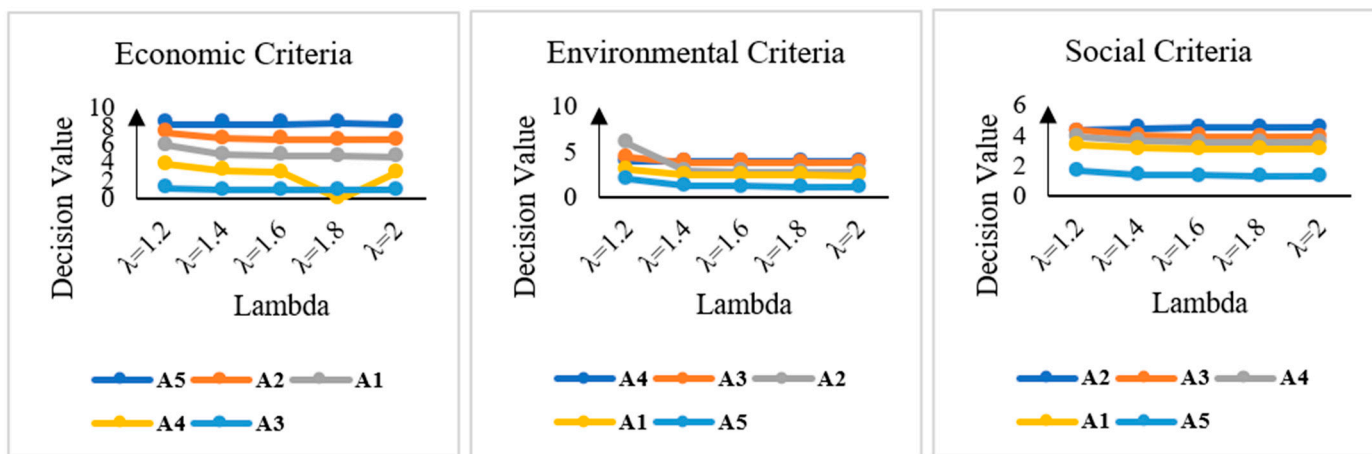

Figure 7. Effect of parameter λ in the CoCoSo method.

4.6. Effect of Criteria Weight Values in the Proposed Method

As mentioned in the previous section, examining the impact of the weight of criteria is an important step in analyzing the sensitivity in MCDM problems. For this purpose, in

each dimension of sustainability, the most important criterion is selected, and the weights of other criteria change according to that criterion. In this section, 11 scenarios are specified to analyze the sensitivity of the criteria weight. It should be noted that there are two basic assumptions in the design of scenarios:

(a) $\alpha_s = 1$, where α_s is the elasticity for the most significant criterion.
(b) The ratio of weights for all variables remains constant during the calculations.

Table 9 shows the problem parameters and Tables 10–12 also show the new criteria weights for different aspects of sustainability. Therefore, the new proportionality weights were calculated as follows:

Step 1. Find the most significant criterion ($\alpha_s = 1$).
Step 2. Calculate the limits of Δx by using Equation (16).
Step 3. Define n scenarios and divide the Δx into n scenarios.
Step 4. Calculate the new value of w_s by using Equation (17).
Step 5. Calculate the new value of w_c by using Equation (18).

$$- w_s \leq \Delta x \leq min\left\{ \frac{w_c^0}{\alpha_c} \right\} \tag{16}$$

$$w_s = w_s^0 + \alpha_s \Delta x ; \tag{17}$$

$$w_c = (-w_s) \cdot \left(\frac{w_c}{w_c^0} \right). \tag{18}$$

Table 9. Alternative class types.

Parameters	Description
α_c	Weight coefficient of elasticity
w_c^0	Basic weights of criteria
W_c^0	Sum of the weights of criteria (after changing)
w_c	Change in the weights of criteria
w_s	Weight of the most significant criterion
Δx	Weight coefficients changes

Table 10. New criteria weights for economic criteria.

	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11
A1	0.329	0.302	0.277	0.251	0.225	0.199	0.173	0.147	0.121	0.096	0.069
A2	0.487	0.505	0.524	0.543	0.562	0.581	0.599	0.618	0.637	0.656	0.674
A3	0.128	0.115	0.103	0.090	0.079	0.066	0.053	0.041	0.028	0.016	0.003
A4	0.134	0.125	0.116	0.107	0.099	0.089	0.080	0.071	0.063	0.054	0.045
A5	0.850	0.866	0.880	0.895	0.910	0.925	0.941	0.955	0.970	0.985	1.000

Table 11. New criteria weights for environmental criteria.

Environmental Criteria	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11
A1	0.208	0.193	0.179	0.164	0.149	0.134	0.119	0.104	0.089	0.074	0.058
A2	0.353	0.321	0.288	0.255	0.222	0.188	0.155	0.122	0.088	0.054	0.019
A3	0.803	0.823	0.844	0.864	0.884	0.904	0.923	0.943	0.962	0.981	1.000
A4	0.849	0.776	0.701	0.626	0.551	0.474	0.398	0.322	0.245	0.167	0.089
A5	0.424	0.385	0.344	0.304	0.263	0.222	0.181	0.139	0.097	0.056	0.013

Table 12. New criteria weights for social criteria.

Social Criteria	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11
A1	0.679	0.645	0.608	0.569	0.527	0.483	0.436	0.386	0.333	0.277	0.219
A2	0.659	0.687	0.715	0.745	0.775	0.806	0.837	0.868	0.899	0.930	0.959
A3	0.644	0.638	0.630	0.622	0.612	0.602	0.589	0.576	0.561	0.544	0.525
A4	0.656	0.659	0.661	0.663	0.664	0.665	0.665	0.663	0.661	0.656	0.651
A5	0.563	0.547	0.530	0.511	0.491	0.470	0.446	0.421	0.394	0.365	0.334

The effect of changing the criteria weights on the solutions is shown in Figure 8. As predicted, the model was sensitive to changes in weight coefficients and social and environmental dimensions of sustainability. Only in the economic dimension of sustainability was no change observed in any scenario, which shows that the solutions in this dimension were completely stable. According to the results, A3 and A4 were ranked first and second throughout the scenarios, except for the first scenario. In the first scenario, the value of the weight coefficient considered for the most crucial criterion was zero, and the variability of these two alternatives in this scenario was predictable. Other alternatives did not change their rank in more than 70% of the scenarios, as shown in Figure 8, and their ranking could be assured, which shows the high accuracy of the MARCOS method in ranking the alternatives in this case.
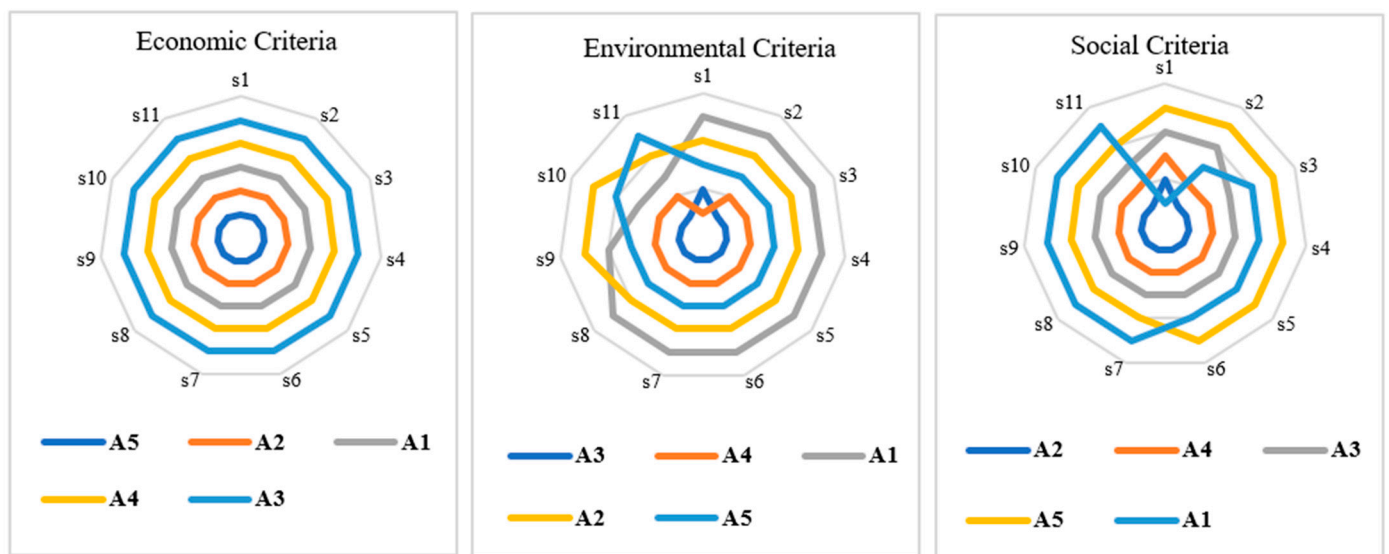

Figure 8. Sensitivity analysis of the ranks of alternatives in 11 scenarios.

4.7. Effect of Dynamic Data Matrices on the Rank of Alternatives

This section of sensitivity analysis aimed to change the elements of the data matrix and re-evaluate the remaining alternatives. In each dimension of sustainability separately, the worst alternative was removed from the next review in each scenario. Therefore, firstly, we could understand the robustness of the solution obtained in uncertain conditions. Secondly, we could analyze the performances of the MARCOS model in the conditions of a dynamic initial matrix of decision-making in each aspect of sustainability. Generally, using the MARCOS method, the A5, A2, A1, A4, and A3 alternatives were ranked from first to fifth, respectively, using economic criteria, which generated the initial solution. According to the former results, A3 was the worst alternative. Therefore, it was removed in the first scenario. Thus, a new data matrix was created with four alternatives. The new solution was obtained based on the new data matrix: A5 > A2 > A1 > A4. According to new results,

A5 remained the best, and at the same time, A4 was the worst alternative. Figure 9 shows the results for all aspects of sustainability.
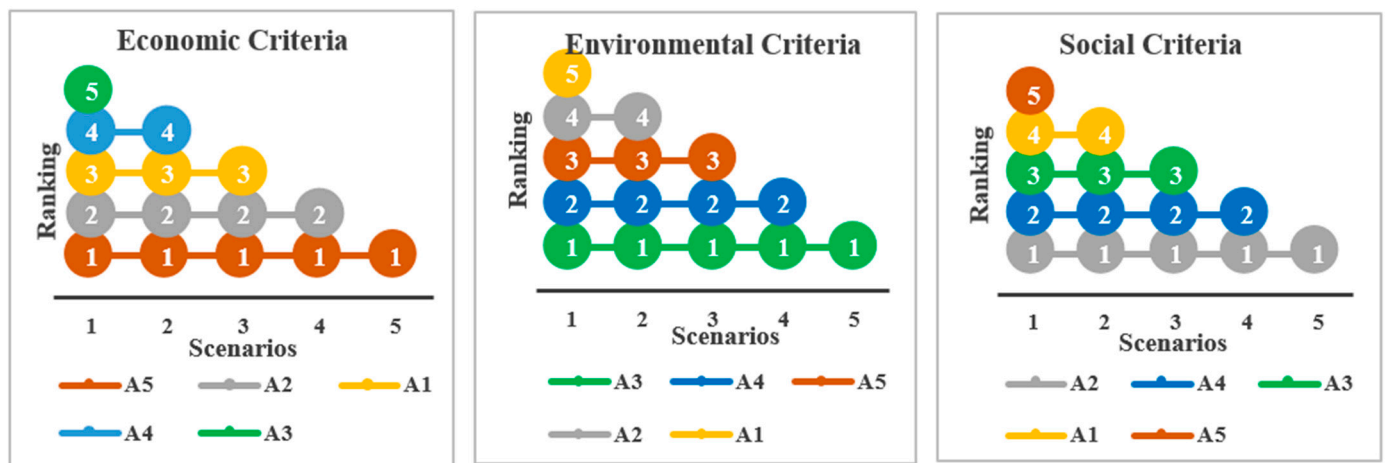

Figure 9. The new alternative ranks in the dynamic decision matrix.

5. Conclusions and Managerial Insights

The main application of sustainable development indicators is to support and reform policies and decision-making at different levels of the organization. An essential part of the decision-making cycle is recognized and implemented by these indicators because it can be used to plan. Previous cases that will prevent the implementation of projects in the future will be revealed.

In this study, first, the sub-criteria collected to evaluate ports were evaluated using the SWARA method. Secondly, using different MCDM methods, the five crucial parts of the country that are part of special economic zones were ranked. Among the main challenges in this study, were the definition of sub-criteria and their desirability or desirability in each of the indicators of SD and obtaining accurate information on the sub-criteria to achieve reliable results in the field. According to the MARCOS method results, economic criteria is an effective criterion for the sustainable development of major Iranian ports. It has been applied to a large extent in Astara Port. Environmental criteria are one of the effective criteria for the sustainable development of significant Iranian ports, and they have been applied to a large extent in Bushehr Port. Social criteria are one of the effective criteria for sustainable development of major Iranian ports, and have been applied to a large extent in Imam Khomeini.

In this paper, a comprehensive analysis of the results was performed, and several managerial insights were also provided as follows: Firstly, according to the criteria assessment section results, the loading and unloading sub-criteria (oil, non-oil, and container) became the most crucial sub-criteria in the economic aspect of sustainability. Sub-criteria such as the development and improvement of unloading and loading equipment, increasing the productivity of ports in choosing the optimal time of unloading and loading, employing a dedicated workforce, and reducing the transfer time significantly impacted the increase in the productivity of ports in unloading and loading. Secondly, employment creation and employment prosperity can be studied in various aspects, including the need for guidance services, unloading and loading goods, warehousing and maintenance of goods, logistics towns, and providing value-added services, container repair workshops, and repair workshops for ship floats. One way to create employment is through marine equipment manufacturing workshops. For example, the leading equipment and tools required for shipbuilding and the procurement of the country's navy are currently supplied from abroad, but can be built with international standards in the country by developing a targeted program and attracting investors. Considering that the organization of a single port does not independently follow the process of the sustainable development of ports, it

is suggested that the stages of extending sustainable development in port development projects be implemented as follows, and a sustainable development committee be formed:

- Preparing documents and educational materials and forming a working group (committee) for sustainable development in the organization.
- Familiarity with the concepts of sustainable development, such as holding training courses, preparing executive instructions for sustainable development, familiarity with sustainability concepts, and familiarity with the agenda of the 21st Rio Conference.
- Explaining the approach of sustainable development in the field of activities of the organization, including the development of sustainability in all actions of the organization, creating interaction between the activities of the organization and the principles of the agenda of the 21st Rio Conference, and assigning actions that are in line with sustainable development.
- Using sustainable development indicators to identify the factors affecting the sustainability of port development and provide expert solutions via the indicators and principles of sustainable development.

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