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Sustainable Frozen Food Facility Location Selection under Pandemic Era

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ABSTRACT

Consumption of frozen food has increased significantly in many countries experiencing total closure due to epidemics. In order to meet this increase in demand, companies apply different strategies in both production and logistics processes. In particular, warehouse locations need to be closer to consumers so as not to disrupt the increasing demand and the cold chain. Considering the sustainable position in the frozen food industry, it is essential to focus on both commercial and economic impacts. However, especially the environmental and sustainable criteria have always been neglected in terms of planning the country and the city. Therefore, this study has three main research questions; (1) identify key criteria for sustainability-focused frozen food facility location, (2) understand the relationship between these criteria, and (3) develop a hierarchical sustainable location roadmap for practitioners. Initially, a literature review was conducted to find the answers to these questions and reveal suitable criteria. Secondly, PROMETHEE was used to determine the relative importance of the data-driven performance of the main and sub-criteria. Therefore, this study gives the reader a comprehensive insight into how sustainable data-driven performance criteria are applied in frozen food storage facility locations. Finally, the proposed model used real-life data to select a developing country's sustainable frozen food storage location.

Keywords: *Frozen food; Location Selection; Sustainability; PROMETHEE.*

1 Introduction

The global COVID-19 emergency has triggered an unexpected spike in demand for essential products that include food, especially frozen food. As a result, the global frozen food market value was valued at USD 291.3 billion in 2019 and is projected to be approximately 307.33 billion by 2020. The Frozen Food Market comprises four main groups: ready to eat, ready to cook, ready to drink, and others (Turan and Ozturkoglu, 2021). The most important feature of these groups is that they do not lose heat during transportation and stock keeping. However, the temperature change can cause some viruses to spread. For example, the sudden temperature changes from harvest to consumption increase the contamination risk of SARS-CoV-2 (Iyengar et al., 2021).

While a direct link between foodborne transmissions of the COVID-19 virus has not been established, some studies show that frozen foods are carriers for long-range transport of SARS-CoV-2 during the current epidemic (Won and Lee, 2020). Laborat y studies have shown that significantly SARS-CoV-2 increased contamination in frozen foods at 4 ° C in the refrigerator and between -10 and -80 ° C in freezing conditions after the cold chain was broken and temperature control was performed again (Han et al. 2020). Another study was traced with frozen shrimp imported from Ecuador, and SARS-CoV-2 was detected in the shipping container's interior (Togoh, 2020). Different studies show that SARS-CoV-2 has been detected in frozen foods, including packaging and storage environments. Meat, fi h, and animal skin, in particular, have proven to be highly stable at chilled (4 ° C) and freezing temperatures (- 20 and - 80 ° C).

In this case, it is vital to transport and store frozen foods in a controlled manner without spoiling the cold chains. Temperature re change or disruption of the cold chain is of great importance for human health rather than cost. When the literature is examined, an issue of such importance for human health has only been examined regarding temperature control and packaging.

However, the location of a warehouse consisting of such foods is an important decision regarding both human health and cost. In addition, such decisions requiring significant investment need to be very careful in planning the country and the city, and unfortunately, there is very little research on this. In the studies, the most suitable frozen food storage facility location was selected using the mathematical model, mainly ignoring the environmental and human criteria. However, no study considers the sustainable and logistics criteria that will affect this location selection.

To fill this gap in the literature, this study focuses on identifying potential criteria that affect frozen food storage facility location selection and proposing a road map that involves these main criteria. This road map is a kindly conceptual framework designed with a holistic view to guide producers, logistics service providers, managers, urban planners, and analysts. To the b st of our knowledge, this is the first study that highlights identifying the potential criteria that affect sustainability-oriented frozen food storage facility location selection decisions both theoretically and empirically, also designing a holistic framework. Therefore, the following research questions;

- What are the main sustainability criteria for the frozen food storage facility location decision?
- How should these identified criteria be prioritized?
- According to this scale, how should the frozen food storage facility location be selected for developing countries?

In order to find answers to these three research questions, a detailed literature review is conducted, and a criterion table for the frozen food storage facility location decision is determined. So, this study gives the reader a comprehensive insight into how sustainable data-driven performance criteria are applied in frozen food storage facility locations. One of t e multi-criteria decision-making methods, PROMETHEE, is used to determine the relative importance of the data-driven performance main and sub-criteria. After finding the weight of each criterion, the most suitable frozen food storage facility locations will be listed in the light of actual data, taking into account the whole of Turkey.

This study consists of six sections. The following section includes a proposed framework for the frozen food industry. This section identifies the factors related to frozen food storage through a comprehensive literature review. These are then categorized under the dimensions of the triple bottom line (TBL) approach (human, business, and environment). PROMETHEUS method is explained in section three. The implementation part is given in section four. Results and managerial implications are explained in section five. Finally, the paper concludes with a discussion of the main findings.

2 A Proposed Framework Model in Frozen Food Storage

This section presents frozen food storage location criteria with TBL-based approaches supported by the literature. The studies in the literature use both qualitative and quantitative data for the calculations of multi-criteria decision-making problems. In this study, we used just quantitative data because the results obtained with qualitative data may change according to the decision maker's knowledge, experience and opinion, so the results may not be reliable. Furthermore, especial y in strategic decisions like facility location selection, inappropriate decisions may be taken. Hence, in this study, only quantitative data are used.

One of the main criteria of this study is the environment, and the related sub-criteria are wind power plant capacity, solar power plant capacity, earthquake risk, and climate. Frozen f od warehouses need much more energy than the other warehouses because of cooling and ventilating processes. They need uninterrupted energy to save the products in required conditions. Hence, uninterrupted energy availability is vital for frozen food storage facilities. Since el electricity and natural gas supply is available in all cities and so in all regions of Turkey (Botaş, 2019), we exclude related data. In order to compare the regions, we considered the capacity of wind and solar power plants in this study. In addition to the study of Özceylan (2016), The Logistics master plan of Turkey (TLMP, 2019) declared that the earthquake risk is a location selection factor for logistics centers. Therefore, we include earthquake risk in our calculations as the third sub-criterion. The regions in Turkey have different climate conditions from each other. For example, in the regions in the west part of Turkey, outside temperatures during summer exceed well above 40 ℃. For such regions, even if the capacity for renewable energy is higher than in other regions, there are much more requirements for uninterrupted energy to preserve the cold chain according to other regions. Hence, these regions need many more frozen food warehouses, so the climate is an excellent determinative criterion for frozen food warehouse location. Therefore, we include climate as the fourth sub- criterion under the environment main criteria.

The second main criterion of this study is economical. All profit organizations' primary goal is making money. Their amount of revenue depends on demand and unit price. Therefore, the frozen food storage facilities as a profit organization should be established near the consumption points with high demand rates. In addition, the warehouse capacity depends on population, such as demand rate (Ashok et al., 2017; Sing et al., 2018). That is why, under economic criteria, we selected the sub-criteria that represent demand. They are population, hospitality capacity, expenditure distribution for food, distance to border crossing points, and the number of flights. Since the population is one of the most critical consumption indicators, we considered it in our computations. However, there is also a significant sector consuming frozen food, such as hospitality.

Many hotels use frozen food for their all-inclusive accommodation packages. All three meals (breakfast, lunch, and dinner) are offered in the open buffet style to the guests. Many of the menu items use ingredients from frozen food. Therefore, it could be essential to locate warehouses closer to the demand from the hospitality sector. Thus, we used hospitality capacity as a sub-criterion under the main economic criteria. Population n and hospitality capacity alone are not sufficient indicators. In the l st few decades, family lifestyles have changed. Women started to take part in business life. Due to changes in lifestyles, the trend in food consumption has changed. Especial y women in business life started to prefer frozen food because of its variety, quality, healthfulness and saving time (Balasubramaniam and Chinnan, 1997). Since fr zen foods are not cheap products, we may assume the expenditure distribution for food increased and decided to consider it as a sub-criterion in this study.

However, low-income people spend almost all of their income on food. They have no or minimal expenditure on education, tourism, or entertainment. Therefore, the expenditure distribution on food seems relatively high. On the o her hand, although people with high incomes can spend much more on food, they also spend on areas such as education, tourism, and entertainment, so the expenditure distribution on food seems low. Thus, the s criterion can lead to misleading results. Therefore, we used per capita gross domestic product (GDP) instead of the distribution of food expenditures as the third sub-criterion. Distance to border crossing points is an indicator of the international market and is used as a facility location selection criterion in the study of Kayıkçı (2010). It is important for frozen food export by highway transportation because it affects the duration of the transportation and indirectly the quality of the products, which meet the demand of foreign countries. Distance to border crossing point refers to the distance between the regions covered by this study and the border crossing points actively operating in Turkey. We considered the number of flights that correspond to airport service capacity (Zalluhoğlu et al., 2014) because airways mainly carry frozen food to shorten delivery time and save the quality of the products. The numb r of flights at airports refers to the total number of incoming and outgoing aircraft, which carry the load as domestic and international lines.

The third main criterion of the study is the existing business network. Sub-criteria is the number of frozen food producers, packaging firms, and frozen food facilities. Most studies use the target market as a criterion for location selection problems (Fagaraşan and Cristea, 2015). In this study target market refers to the firms that produce frozen food. As the s cond sub-criterion, we used the number of packaging firms. Packaging is crucial for food safety, especially for frozen foods. Packaging is vital to avoid food from heat, humidity, light, toxic materials, and microorganisms. In order to inhibit bacterial growth and extend product shelf life, special packaging techniques are required (Balasubramaniam and Chinna, 1997). Therefore, existing of a packaging firm is a big necessity for frozen food facilities. Hence, w considered the number of packaging firms for our calculations. The third sub-criterion is the number of frozen food facilities. When deciding on a facility location, the competition should be considered. Also, a location should be selected that has no service before. Therefore, we obtained the number of competitive firms and used it in our calculations.

Logistics capability is one of the most commonly used criteria for location selection studies, as shown in Table 2. Since fr zen food is perishable, logistics capability is much more critical for frozen food transportation because it affects the duration of the transportation and the quality of the products. Under the s main criterion, we used four sub-criteria to cover all transportation modes (road, rail, sea, and air). They are the density of highways, the density of railways, the number of ports, and the number of airports. At first, we obtained the length of highway and railway for each city in Turkey. Then, we have summed up the highway/railway lengths of all cities within a region. (For example, the length of highway/railway in Tekirdağ, Edirne, and Kırklareli is summed to find the length of highway/railway of Region TR21). Regions such as TR52 and TR72 seemed to be more advantageous in terms of railway length since their areas were more extensive than regions such as TR10 and TR31. Therefore, to prevent this unfairness, we decided to use the highway/railway density instead of the highway/railway instead of the length of the highway/railway. Density means the length of the highway/railway per square kilometer. In order to obtain the density, we divided the length of highway/railway of each region into the acreage of each region. In addition, we used the number of airports and, lastly, the number of ports to cover all transportation modes in the study.

Labor availability is one of the most commonly used criteria in facility location selection studies (Uysal and Yavuz, 2014; Jouzdani and Govindan, 2021). When selecting the facility's location, it is important to reach qualified labor that can meet the industry's requirements in this location. Therefore, the fifth main criterion of the study is labor availability. The sub-criteria, number of students, number of graduated students, number of employees who graduated from high school, and number of employees who graduated from university are included because they are potential workers for new frozen food facilities that will be constructed. This feature represents white and blue-collar employees employed in frozen food facilities (Lloyd and Cheyne, 2017; Ashok et al., 2017). In addition, newly established facilities may need consultancy to design the facility and operations to improve the firm's efficiency. Academic and may provide consultancy to this kind of firm and may support possible projects in the facilities. Therefore, we included the number of academicians as the sub-criterion in this study. The frozen food industry requires specialization in employment, so the frozen food facilities may need expertized personnel. Therefore, while determining the potential of labor requirements, only the students and academicians based on food-related departments such as food engineering, food processing, food technology, food hygiene, chemistry, and chemical engineering are included in the computations.

In deciding the facility location, attention should be given to regional development and the economic, environmental, and social benefits by the decision-makers. Although few studies cover the development index as the location selection criterion (Cristea and Cristea, 2016; Uysal and Yavuz, 2014; Zalullah et al., 2014), we include development as the sixth main criterion. The sub-criteria unemployment rate, life index, and government incentive scores are used. A facility employs the region in that it is constructed and decreases the unemployment rate. In facility location decision-making, the regions/cities with a high unemployment rate should be selected to reduce this ratio in the field. In addition, the regions should be selected to improve the life quality of the region. Life quality is an indicator that shows the development level of the cities. It has one sub-dimensions: housing, business life, income and wealth, health, education, environment, security, civic participation, access to infrastructure services, social life, and life satisfaction (TurkStat, 2015). Therefore, the life index is considered the sub-criterion. The last sub-criterion government incentive score is considered because the government shares the incentives to the cities according to their requirements. High scores are given to the cities that require more incentives; low scores are given to the cities that require fewer incentives (Invest in Turkey, 2018). A facility should be established in a city/region with high incentive scores.

The criteria are determined according to the related literature. The scope of the literature review is not limited only to frozen food facility location selection. As shown in Table 1, 6 main criteria and 24 sub-criteria are considered in this study.

By considering all these explanations, the proposed framework model for the frozen food storage industry is presented in Figure 1. The figure shows that the main criteria are categorized by triple bottom line (TBL) and business perspective in the proposed sustainable location in the frozen food industry. From the perspective of a holistic view and system approach, it can be said that criteria under different locations can be related to each other. Thus, to understand the structure and propose managerial implications for sustainable locations in the frozen food industry, it is essential to analyze possible locations based on determined criteria.

Up to now, potential criteria in the frozen food storage industry have been discussed. In the following section, the methodology is discussed with a proposed framework.

Table 1.

Main criteria and sub-criteria

Main criteria	**Sub-criteria**	**Related literature**
Cr1-Environmental	Cr1.1-Wind power plant capacity (MWm)	(Tomic et al., 2014), (Hamzaçebi et al., 2016)
	Cr1.2-Solar power plant capacity (MW)	(Tomic et al., 2014), (Hamzaçebi et al., 2016)
	Cr1.3-Earthquake risk	(Özceylan, 2016), (TLMP, 2019)
	Cr1.4-Climate	Thompson et al. (2002); Wang and Yip (2018)
Cr2-Economic	Cr2.1-Population	(Ashok et al., 2017; Sing et al., 2018)
	Cr2.2-Gross domestic product per capita (TL)	(Regmi and Hanaoka, 2013); Zanoni et al., 2019
	Cr2.3-Distance to border crossing point(km)	(Kayıkçı, 2010), (Ehsanifar et al., 2021)
	Cr2.4-Number of flights	(Zalluhoğlu et al., 2014)
	Cr2.5-Hospitality capacity	-
Cr3-Existing business network	Cr3.1- Number of frozen food producers	-
	Cr3.2-Number of frozen food warehouse	(Keller, 2011)
	Cr3.3-Number of packaging firms	-
Cr4-Logistics Capability	Cr4.1-Density of highway	(Erkayman et al., 2011), (Fernie and McKinnon, 2003), (Pelletier et al., 2011), (Seo et al. 2017), (Song et al., 2017)
	Cr4.2-Density of railway	(Tomić et al., 2014), (Önden et al., 2018), (Fernie and McKinnon, 2003), (Pelletier et al., 2011), (Seo et al. 2017), (Song et al., 2017)
	Cr4.3-Number of airports	(Özceylan et al., 2016), (Fernie and McKinnon, 2003), (Pelletier et al., 2011), (Seo et al. 2017), (Song et al., 2017)
	Cr4.4-Number of ports	(Regmi and Hanaoka, 2013), (Yıldırım and Önder, 2014), (Fernie and McKinnon, 2003), (Pelletier et al., 2011), (Seo et al. 2017), (Song et al., 2017)
Cr5-Labor availability	Cr5.1- Number of students in related departments	(Uysal and Yavuz, 2014), (Zalluhoğlu at al., 2014), (Keller, 2011)
	Cr5.2- Number of academicians in related departments	
	Cr5.3-Number of employees (high school)	
	Cr5.4-Number of employees (university)	
	Cr5.5- Number of graduated students in related departments	
Cr6-Development	Cr6.1-Rate of unemployment (%)	(Demirkıran and Öztürkoğlu, 2020)
	Cr6.2-Life index	(Saphiro, 2011)
	Cr6.3-Government incentive scores	(Uysal and Yavuz, 2014), (Zalluhoğlu et al., 2014), (Cristea and Cristea, 2016), (Pfoser et al., 2016)

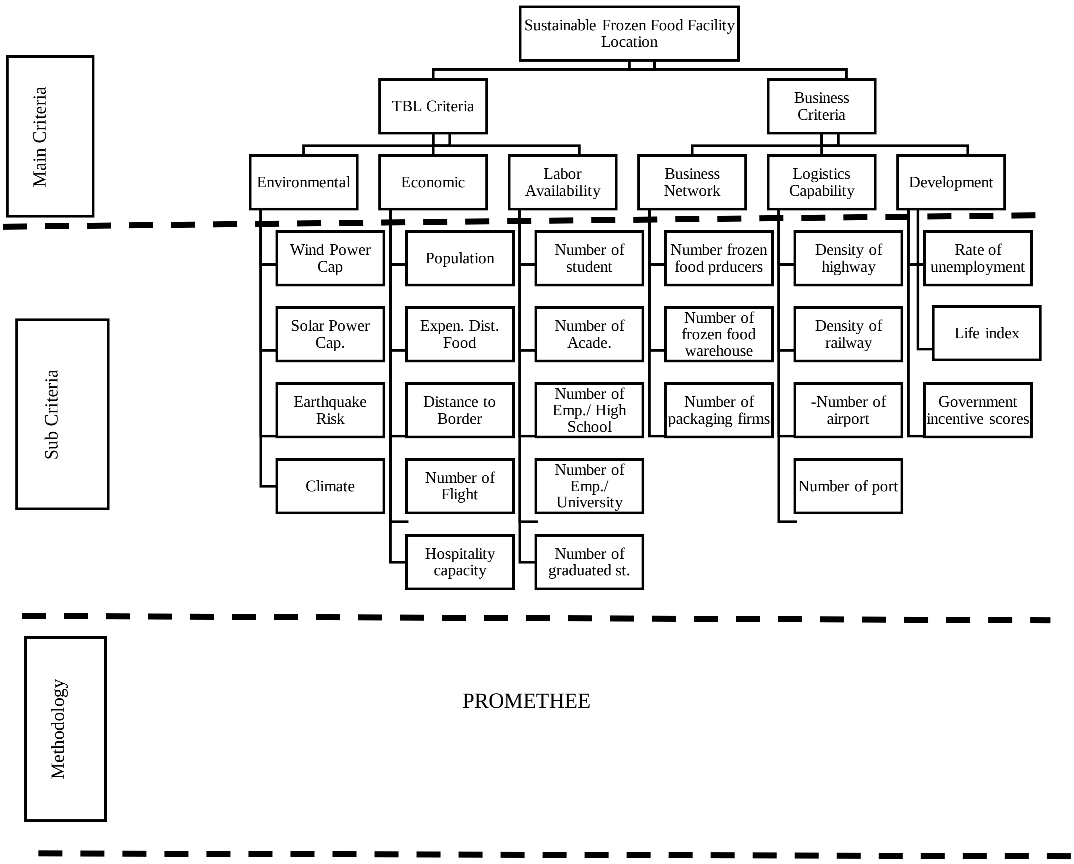


Figure 1. Proposed Conceptual model for Sustainable Frozen Food Facility Location

3 Methodology: PROMETHEE

In our study, PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) is used as a solution method. The method is used when many criteria affect the decision-makers and when it is necessary to choose from various alternatives. The method allows the decision-maker to use a different preference function for each criterion rather than a single preference function when comparing alternatives, unlike other multi-criteria decision-making (MCDM) techniques. In this way, decision-makers can follow a different way when evaluating the alternatives under each criterion if the criteria structures are different, as in real-life problems. Therefore, in this study PROMETHEE method is preferred. The method was generated by Brans in 1982 (Brans, 1982) and developed in 1985 (Brans and Vincke, 1985). It helps decision-makers by ordering the alternatives based on superiority. The meth d requires weights of criteria and values of each alternative related to each criterion. The main difference from other MCDM methods is the use of preference functions in evaluating alternatives. The Promethee method can give the decision-makers both the partial (PROMETHEE I) and the alternatives' full order (PROMETHEE II). In our study, full ranking is done only with PROMETHEE II.

Steps of the method:

Step 1: Determine the criteria, weights ($w_1, w_2, w_3, \ldots, w_k$), and values of the alternatives (a, b, c) related to each criterion.

Step 2: Define preference functions and threshold v alues for criteria. Preference e functions are used to determine how to decide the superiority of an alternative over another alternative (see Table 2).

Mareschal B. (2018) recommends the Type 1 preference function if the criterion has a discrete numerical scale equal to or smaller than five and if the values are perceived as quite different from each other. Our study used preference function Type 1 for the criteria Cr1.3, Cr4.3, Cr4.4, and Cr6.3. The preference Type 5 (Linear) is the best choice for quantitative criteria when an indifference threshold (s) is wished. For the criteria which have large quantitative values (Cr1.1, Cr1.2, Cr2.1, Cr2.2, Cr2.3, Cr2.4, Cr2.5, Cr3.3, Cr5.1, Cr5.2, Cr5.3, Cr5.4, Cr5.5) we used Type 5 function. The preference function Type 3 (V-shape) is a special case of Type 5, where the s indifference threshold is equal to 0. It is the s well suited to quantitative criteria when even small deviations should be considered (Mareschal, B., 2013). Therefore, we used Type 3 for the criteria Cr1.4, Cr3.1, Cr3.2, Cr4.1, Cr4.2, Cr6.1, and Cr6.2 which have quantitative smaller values. Besides that, Salabun et al. (2020) generated a simulation model with various types of preference functions and various criteria weights. They use many different parameters with all types of preference functions. They showed that the rankings are very close with the preference function Type 5. This means preference function Type 5 has robustness on the computations. Therefore, we used Type 5 for most of the criteria.

After the preference functions are determined, the threshold values are determined by decision-makers. The threshold value is the point where one alternative has superiority over another. For example, threshold values $s + r$ and s are required for the computations with preference function Type 5, and m is required for preference function Type 3. Salabun et al. (2020) calculated s and $s + r$ values by calculating the average differences of alternatives with equations 1 and 2. Different e means the difference value between two alternatives. $\overline{D}$ stands for positive values of the differences. k is coefficient and considered 0,5 as mentioned in Salabun et al. (2020). σ_D is s standard deviation.

$$s = \overline{D} - k.\sigma_D \tag{1}$$

$$s + r = \overline{D} + k.\sigma_D \tag{2}$$

The preference functions used in the Promethee II method and the threshold values considered in determining the superiority of the alternatives are shown in Table 6 in the implementation section.

Step 3: Determine common preference functions by using Equation 3. In this step, the decision-maker evaluates the difference between each alternative pair.

$$P(a,b) = \begin{cases} 0 \quad , & f(a) \leq f(b) \\ p[f(a) - f(b)], & f(a) > f(b) \end{cases} \tag{3}$$

Step 4: Calculate preference indexes for each alternative pair. Preference e indexes of alternatives a and b in terms of k criteria which have w_i weights, are calculated by Equation (4).

$$\pi(a,b) = \sum_{i=1}^{k} w_i \cdot P_i(a,b) \tag{4}$$

Step 5: Determine the positive (Φ^+) and negative (Φ^-) superiorities for alternatives by Equations 5 and 6, relatively.

$$\Phi^+ = \sum_{i}^{k} \pi\,(a,x) \tag{5}$$

$$\Phi^- = \sum_{i}^{k} \pi\,(x,a) \tag{6}$$

Step 6: Determine full superiorities Φ for alternatives by Equation 7.

$$\Phi(a) = \Phi^+(a) - \Phi^-(b) \tag{7}$$

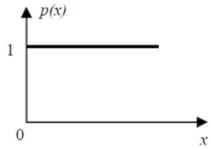
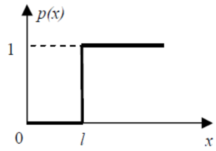
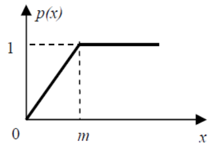
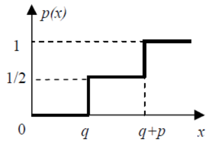
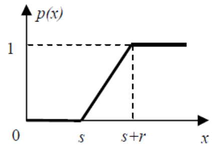
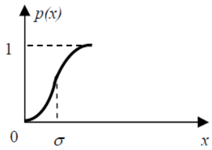
The following two decisions can be made by evaluating the total priority values calculated for the two alternatives such as a and b

If $\Phi\,(a) > \Phi\,(b)$, then alternative a is preferred to b.

If $\Phi\,(a) = \Phi\,(b)$, then the a and b alternative is no different.

Table 2.

Preference functions. Adapted from Brans and Vincke (1985).

Type	Threshold values	Function	Graphic, $p(x)$
Type 1 (Usual)	-	$p(x) = \begin{cases} 0, & x \leq 0 \\ 1, & x > 0 \end{cases}$	
Type 2 (U-Type)	l	$p(x) = \begin{cases} 0, & x \leq l \\ 1, & x > l \end{cases}$	
Type 3 (V-Type)	m	$p(x) = \begin{cases} x/m, & x \leq m \\ 1, & x > m \end{cases}$	
Type 4 (Level)	q, p	$p(x) = \begin{cases} 0, & x \leq q \\ 1/2, & q < x \leq q + p \\ 1, & x > q + p \end{cases}$	
Type 5 (Linear)	s, r	$p(x) = \begin{cases} 0, & x \leq s \\ \dfrac{x - s}{r}, & s < x \leq s + r \\ 1, & x > s + r \end{cases}$	
Type 6 (Gaussian)	Q	$p(x) = \begin{cases} 0, & x \leq 0 \\ 1 - e^{-x^2/2Q^2}, & x > 0 \end{cases}$	

4 Implementation of the Study

The implementation part consists of three stages. In the first step, the weights of the main and sub-criteria are determined. In the second step, data of each alternative region for each criterion are obtained. In the last step, the alternatives are ranked with the PROMETHEE method.

Salabun et al. (2020) used the three weights method in their PROMETHEE computations. They are equal weights, entropy, and standard deviation method. They generated simulation models with various variable sets, and they showed that weighting methods do not have a significant impact on results. Since it is one of the most popular methods for weights of criteria selection (Salabun et al., 2020), we used equal weights in our computations. Therefore, the weights of all main criteria are assumed equal (16.7%). In addition, it is assumed that the sub-criteria under each main criterion is not superior to each other in terms of importance. Hence, t e weights of the sub-criteria under the main criterion are equal. The calculated average weights are shown in Table 3.

Table 3.

Weights of main and sub-criteria

Main criteria	**Sub-criteria**	**Weights**
Cr1-Environment	Cr1.1-Wind power plant capacity (MWm)	4.2%
	Cr1.2-Solar power plant capacity (MW)	4.2%
	Cr1.3-Earthquake risk	4.2%
	Cr1.4- Climate	4.2%
Cr2-Economic	Cr2.1-Population	3.3%
	Cr2.2-Gross domestic product per capita (TL)	3.3%
	Cr2.3-Distance to the border crossing	3.3%
	Cr2.4-Number of flights (load)	3.3%
	Cr2.5- Hospitality capacity	3.3%
Cr3-Existing business network	Cr3.1-Number of frozen food producers	5.6%
	Cr3.2-Number of cold warehouses	5.6%
	Cr3.3-Number of packaging firms	5.6%
Cr4-Logistics Capability	Cr4.1-Density of highway	4.2%
	Cr4.2-Density of railway	4.2%
	Cr4.3-Number of airports	4.2%
	Cr4.4-Number of ports	4.2%
Cr5-Labor availability	Cr5.1-Number of students in related departments	3.3%
	Cr5.2-Number of academicians in related departments	3.3%
	Cr5.3-Number of employees (high school)	3.3%
	Cr5.4-Number of employees (university)	3.3%
	Cr5.5- Number of graduated students in related departments	3.3%
Cr6-Development	Cr6.1-Rate of unemployment (%)	5.6%
	Cr6.2-Life index	5.6%
	Cr6.3-Government incentive scores	5.6%

According to the determined criteria, the values of alternative regions are shown in Table 4 and Table 5. All data is obtained from TurkStat, Ministry official websites (Ministry of agriculture and forest, 2019), Higher Education Institution (YOK, 2019), General Directorate of Meteorology (2020), Tourism data bank (2020), or industrial reports to be as up to date as possible such as 2019 and 2020. The Visu l PROMETHEE software was used to solve our problem.

Table 4.

Data of regions for each criterion

	Cr1.1	Cr1.2	Cr1.3	Cr1.4	Cr2.1	Cr2.2	Cr2.3	Cr2.4	Cr2.5	Cr3.1	Cr3.2
TR10	256.9	2.9	1	16.2	15,519,267	15.6	1150	2,804,451	228,198	21	80
TR21	441.0	0.5	4	13.7	1,831,151	18.3	1249	1,854	6,634	0	0
TR22	1640.6	45.7	1	14.9	1,770,777	22.9	1235	5,003	33,393	1	33
TR31	1462.2	16.1	1	17.9	4,367,251	18.0	1283	126,631	58,085	9	11
TR32	434.5	72.3	1	16.3	3,131,322	20.8	1192	99,086	83,244	1	36
TR33	992.4	118.5	2	12.9	3,119,860	22.0	1260	1,346	10,172	1	9
TR41	168.4	27.1	2	12.8	4,163,022	18.3	1145	4,688	12,754	3	53
TR42	96.6	3.1	1	13.5	3,961,953	18.7	1103	546	10,423	0	42
TR51	0.0	158.9	4	11.9	5,639,076	17.8	940	132,505	35,671	2	33
TR52	164.9	447.0	5	11.9	2,485,653	21.1	956	10,691	7,663	2	37
TR61	61.2	106.1	2	14.8	3,227,410	19.6	1147	383,363	218,007	2	109
TR62	218.7	49.8	3	19.2	4,078,365	21.4	841	48,006	29,363	1	3
TR63	716.2	24.8	1	17.9	3,321,755	23.4	816	16,393	7,842	10	4
TR71	168.0	119.0	5	11.6	1,608,193	25.4	866	3,922	7,232	0	0
TR72	430.4	285.5	3	9.6	2,467,565	22.8	808	28,743	5,959	1	1
TR81	0.0	7.9	2	13.0	1,042,760	20.2	1081	537	4,796	0	5
TR82	0.0	1.9	4	11.8	793,437	21.0	1004	2,019	4,024	0	0
TR83	279.7	3.7	2	12.9	2,829,953	26.1	898	16,203	4,156	0	11
TR90	0.0	0.0	4	13.5	2,690,180	22.5	858	43,785	6,027	0	2
TRA1	0.0	18.7	3	7.9	1,081,652	23.4	757	13,532	4,464	2	3
TRA2	0.0	0.0	2	6.7	1,118,370	27.5	803	11,049	2,593	0	0
TRB1	11.7	44.1	2	12.9	1,755,735	22.9	734	18,206	2,142	0	17
TRB2	0.0	21.3	2	9.6	2,174,672	33.2	830	18,349	3,313	0	3
TRC1	93.1	102.8	4	16.6	2,838,319	24.2	730	26,418	5,148	1	9
TRC2	0.0	13.9	3	17.2	3,829,967	28.4	727	21,574	7,009	1	14
TRC3	0.0	6.5	3	15.8	2,307,332	29.3	774	16,331	3,183	0	3

Table 5.

Data of regions for each criterion (continue)

	Cr3.3	Cr4.1	Cr4.2	Cr4.3	Cr4.4	Cr5.1	Cr5.2	Cr5.3	Cr5.4	Cr5.5	Cr6.1	Cr6.2	Cr6.3
TR10	152	0.18	0.04	3	5	8736	670	1,531,000	2,010,000	1382	14.9	0.649	1.0
TR21	16	0.34	0.02	1	3	802	31	200,000	186,000	181	11	0.576	2.0
TR22	8	0.28	0.01	4	9	970	72	144,000	179,000	171	8.3	0.612	2.5
TR31	26	0.13	0.03	2	5	4488	255	422,000	557,000	646	16	0.600	1.0
TR32	20	0.08	0.01	4	7	843	51	270,000	317,000	211	9.2	0.559	1.7
TR33	12	0.38	0.02	2	0	804	44	249,000	252,000	202	9.8	0.627	3.5
TR41	67	0.15	0.03	3	2	1828	91	431,000	440,000	302	11.2	0.617	1.7
TR42	16	0.50	0.02	1	4	911	60	422,000	378,000	181	13.5	0.615	2.2
TR51	10	0.07	0.03	1	0	8142	591	561,000	858,000	1087	14.2	0.619	1.0
TR52	0	0.13	0.01	1	0	1374	82	152,000	186,000	362	8	0.603	2.5
TR61	17	0.20	0.00	3	6	807	45	312,000	369,000	187	13.3	0.589	2.0
TR62	48	0.09	0.01	1	5	1147	64	325,000	353,000	142	11.9	0.473	2.5
TR63	17	0.21	0.01	1	1	542	34	223,000	237,000	122	18.1	0.462	4.6
TR71	17	0.47	0.01	1	0	234	30	127,000	127,000	55	13.3	0.565	4.4
TR72	8	0.28	0.02	2	0	800	41	189,000	202,000	150	14.5	0.534	3.7
TR81	3	0.99	0.02	1	4	184	18	87,000	97,000	39	9.6	0.581	3.3
TR82	4	0.93	0.01	1	5	151	19	67,000	64,000	24	7.6	0.597	4.7
TR83	14	0.41	0.01	2	1	696	43	206,000	211,000	167	8.3	0.556	4.0
TR90	20	0.85	0.00	2	12	309	31	235,000	235,000	73	9.9	0.580	4.3
TRA1	0	0.22	0.01	2	0	535	45	76,000	99,000	136	11.2	0.484	4.7
TRA2	3	0.44	0.01	3	0	125	15	42,000	42,000	26	9.8	0.365	6.0
TRB1	50	0.45	0.02	3	1	381	38	140,000	163,000	87	9.9	0.472	4.8
TRB2	24	0.24	0.01	2	1	139	21	114,000	116,000	43	25.9	0.343	6.0
TRC1	47	0.45	0.02	2	0	676	26	145,000	182,000	146	15.2	0.416	4.3
TRC2	2	0.07	0.01	2	0	564	32	164,000	171,000	101	23.4	0.351	6.0

TRC3	3	0.36	0.01	1	0	107	7	120,000	124,000	32	30.9	0.340	6.0

We first determined which criterion must be minimized or maximized for our decision problem. Figure 2 demonstrates which criterion is being minimized or maximized. The objective of the following criteria are determined as maximization: Wind power plant capacity, solar power plant capacity, earthquake risk, population, hospitality capacity, expenditure distribution for food, number of flights, number of frozen food producers, number of packaging firms, the density of highway, density of railway, number of airports, number of port, number of students in related departments, number of academician in related departments, number of employees graduated from high school, number of employees graduated from university, rate of unemployment, government incentive scores. The high values of the alternatives for these criteria indicate that the relevant alternative has a good potential for the frozen food facility location.

In terms of earthquake risk criterion, the score for high-risk areas is indicated by a score of 1, and for low-risk areas is indicated by a score of 5. Therefore, we used maximization as the objective function to select low-risk regions among alternatives for frozen food facilities. A high level of the unemployment rate is a weakness for a region, so it is not a desired situation for location selection. However, choosing an alternative region for a facility location with a high unemployment rate will positively contribute to the country's development distribution. Therefore, regions with high unemployment rates are expected to prioritize frozen food warehouse location selection. High values of alternative regions for government incentive scores criterion is not a positive indicator. Regions were re-evaluated according to the need for support by the government and scored 1-6 according to the degree of need. Regions that need more support from the government take more incentives and get 6 points in terms of government incentive score; Regions that need less support get 1 point (Invest in Turkey, 2018). Hence, regions with high incentive scores are expected to prioritize frozen food warehouse location selection to contribute to the development of a region.

The objective functions of the following criteria are determined as minimization: climate, distance to border crossing points, number of frozen food facilities, and life index. Distance to border crossing point is determined by calculating the average distance between each city in a region and border crossing points which are actively operating (Akçakale, Aktaş (Çıldır), Aziziye (Dereköy), Cilvegözü, Çobanbey, Dilucu, Esendere, Gürbulak, Habur, Hamzabeyli, İpsala, Kapıköy, Kapıkule, Karaağaç (Pazarkule), Karkamış, Öncüpınar, Posof (Türkgözü), Sarp, Yayladağı, Nusaybin, Üzümlü). High values of the alternatives for distance to border crossing point criterion mean longer distances and slower deliveries. This is an undesirable situation for perishable food transportation. On the other hand, the proximity of the regions to the border points makes that region advantageous in terms of frozen food facility establishment. Therefore, minimization is selected as the objective function for this criterion. In addition, it is unfair to have a large number of frozen food warehouses in a region while there are regions without a frozen food storage facility. At last, although high values of alternative regions for the life index criterion are a positive indicator, it is considered that if the place where the frozen food storage facility will be established is in regions with weaknesses in terms of this criterion, it will make a positive contribution to the development distribution of the country. When evaluating regions in terms of life index criterion, regions with a small index are expected to have priority. Hence, t e objective functions of mentioned criteria are selected as minimization.

Scenario1	Cr1.1	Cr1.2	Cr1.3	Cr2.1	Cr2.2	Cr2.3	Cr2.4	Cr3.1	Cr3.2	Cr3.3	Cr4.1	Cr4.2	Cr4.3	Cr4.4	Cr5.1
Unit	MWm	MW	score	number	TL	km	number	number	number	number	1/km	1/km	number	number	number
Cluster/Group	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆
Preferences															
Min/Max	max	max	max	max	max	min	max	max	min	max	max	max	max	max	max
Weight	4,20	4,20	4,20	3,30	3,30	3,30	3,30	5,60	5,60	5,60	4,00	4,20	4,20	4,20	3,30
Preference Fn.	Linear	Linear	Usual	Linear	Linear	Linear	Linear	V-shape	V-shape	Linear	V-shape	V-shape	Usual	Usual	Linear
Thresholds	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute
- Q: Indifference	185,1	35,1	n/a	670099	32525	143	521396	n/a	n/a	10	n/a	n/a	n/a	n/a	463
- P: Preference	654,1	147,0	n/a	3875507	81162	297	631791	6	40	45	0,39	0,01	n/a	n/a	3093
- S: Gaussian	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Statistics															
Minimum	0,0	0,0	1,0	793437	36540	727	537	0	0	0	0,07	0,00	1	0	107
Maximum	1640,6	447,0	5,0	15519267	259446	1283	2804451	21	109	152	0,99	0,04	4	12	8736
Average	293,7	65,3	2,6	3198269	106605	969	148278	2	20	23	0,34	0,02	2	3	1396
Standard Dev.	436,4	100,0	1,2	2724557	46218	187	536794	4	27	31	0,25	0,01	1	3	2201
Evaluations															
TR10	256,9	2,9	1,0	15519267	76769	1150	2804451	21	80	152	0,18	0,04	3	5	8736
TR21	441,0	0,5	4,0	1831151	140831	1249	1854	0	0	16	0,34	0,02	1	3	802
TR22	1640,6	45,7	1,0	1770777	83300	1235	5003	1	33	8	0,28	0,01	4	9	970
TR31	1462,2	16,1	1,0	4367251	54305	1283	126631	9	11	26	0,13	0,03	2	5	4488
TR32	434,5	72,3	1,0	3131322	120076	1192	99086	1	36	20	0,08	0,01	4	7	843
TR33	992,4	118,5	2,0	3119860	147898	1260	1346	1	9	12	0,38	0,02	2	0	804
TR41	168,4	27,1	2,0	4163022	150382	1145	4688	3	53	67	0,15	0,03	3	2	1828
TR42	96,6	3,1	1,0	3961953	259446	1103	546	0	42	16	0,50	0,02	1	4	911
TR51	0,0	158,9	4,0	5639076	60249	940	132505	2	33	10	0,07	0,03	1	0	8142
TR52	164,9	447,0	5,0	2485653	76249	956	10691	2	37	0	0,13	0,01	1	0	1374
TR61	61,2	106,1	2,0	3227410	118289	1147	383363	2	109	17	0,20	0,00	3	6	807
TR62	218,7	49,8	3,0	4078365	69325	841	48006	1	3	48	0,09	0,01	1	5	1147

Figure 2. Partial screenshot of Visual PROMETHEE

After entering the values of alternative regions into the Visual PROMETHEE software, preference functions and their threshold values for each criterion are determined (see Table 6). In this study, data about considered criteria for 81 cities of Turkey are obtained, but they are grouped into 26 regions to make calculations easier. These cities are grouped into regions by TurkStat according to their economic, social, and geographical similarities.

Table 6.

Preference functions and threshold values are determined according to the sub-criteria

Main criteria	Sub-criteria		Preference function	Threshold values
Cr1-Environment	Cr1.1	Wind power plant capacity (MWm)	Type 5 (Linear)	s=185 s+r=654
	Cr1.2	Solar power plant capacity (MW)	Type 5 (Linear)	s=35 s+r=147
	Cr1.3	Earthquake risk	Type 1 (Usual)	-
	Cr1.4	Climate	Type 3 (V-shape)	m=4.83
Cr2-Economic	Cr2.1	Population	Type 5 (Linear)	s=670099 s+r=3875507
	Cr2.2	Gross domestic product per capita (TL)	Type 5 (Linear)	s=32525 s+r=81162
	Cr2.3	Distance to the border crossing	Type 5 (Linear)	s=143 s+r=297
	Cr2.4	Number of flights (load)	Type 5 (Linear)	s=521396 s+r=631791
	Cr2.5	Hospitality capacity	Type 5 (Linear)	s=9957 s+r=81150
Cr3-Existing business network	Cr3.1	Number of frozen food producers	Type 3 (V-shape)	m=6.218
	Cr3.2	Number of cold warehouses	Type 3 (V-shape)	m=40.27
	Cr3.3	Number of packaging firms	Type 5 (Linear)	s=9.837 s+r=44.81
Cr4-Logistics Capability	Cr4.1	Density of highway	Type 3 (V-shape)	m=0,389
	Cr4.2	Density of railway	Type 3 (V-shape)	m=0,014
	Cr4.3	Number of airports	Type 1 (Usual)	-
	Cr4.4	Number of port	Type 1 (Usual)	-
Cr5-Labor availability	Cr5.1	Number of students in related departments	Type 5 (Linear)	s=463 s+r=3093
	Cr5.2	Number of academicians in related departments	Type 5 (Linear)	s=20 s+r=220
	Cr5.3	Number of employees (high school)	Type 5 (Linear)	s=69537 s+r=401970
	Cr5.4	Number of employees (university)	Type 5 (Linear)	s=72452 s+r=529719
	Cr5.5	Number of graduated students in related departments	Type 5 (Linear)	s=88 s+r=454
Cr6-Development	Cr6.1	Rate of unemployment (%)	Type 3 (V-shape)	m=8.623
	Cr6.2	Life index	Type 3 (V-shape)	m=0.145
	Cr6.3	Government incentive scores	Type 1 (Usual)	-

The Classification of Statistical Regional Units is one of Turkey's criteria to fulfill in the EU membership process. The purp use of classification has been defined as collecting regional-based statistics, making socio-economic analyses and establishing the framework of regional policies towards society, and producing comparable data at the European level. While creating a 3-level regional system, 81 cities were defined as Level 3. Neighbor ng cities, which are economically, socially, and geographically similar, were determined as Level 2 (26 units) and Level 1 (12 units) regions, considering their regional development plans and population sizes. The data is gathered and given to the Visual PROMETHEE program in terms of 26 regions.

5 Results

In this study, 26 regions that cover the whole cities of Turkey are evaluated in terms of frozen food storage facility location selection. The evaluation is made with determined 24 sub-criteria that are assumed to have equal importance levels to reveal the potential of the regions. The findings are shown in Table 7.

As shown in Table 7, Istanbul Region (TR10) takes place at the top of the list. Since the s region has many advantages on issues about the environment, economy, existing business network, logistics capability, and labor availability, it will inevitably be at the top of the list. Demirkir n and Öztürkoğlu (2019) indicated that the İstanbul region is the top one region since it has superiority over other regions in terms of many criteria in their logistics village location selection study. These re ults show us logistics villages and frozen food facilities have similar requirements.

The second and third-biggest cities, Ankara and İzmir, which generate regions TR51 and TR31, exist in the Top-5 list. Since these regions have advantages on population, number of flights, hospitality capacity, number of frozen food producers, number of airports, number of students, employees, and academicians according to the other regions, the result is not surprising.

According to the Ministry of Agriculture and Forest (2019), in each region of Turkey, an average of 20 frozen food facilities already exist. When we look at the Top-5 regions in the ranking, we notice that these regions are TR10-İstanbul, TR31-İzmir, TRB2-Van, TRC1-Gaziantep, and TR51-Ankara. In the computation, we expect the regions that have a smaller number of frozen food facilities takes place at the top levels of the ranking but although TR10 has 80 and TR51 has 33 frozen food warehouse it takes place at the top of the list because, as we mentioned in the previous paragraph these regions have many advantages. However, the other regions except TR10 and TR51 have a smaller number of frozen food facilities according to the average number of frozen food facilities (see Table 4 and Table 5). This result shows that the model is working correctly because we expected the regions with no frozen food facilities to be prioritized in the ranking.

Table 7.

Ranking of the regions

Rank	Region code	Region name	Cities
1	TR10	İstanbul region	İstanbul
2	TR31	İzmir region	İzmir
3	TRB2	Van region	Van, Muş, Bitlis, Hakkâri
4	TRC1	Gaziantep region	Gaziantep, Adıyaman, Kilis
5	TR51	Ankara region	Ankara
6	TRB1	Malatya region	Malatya, Elazığ, Bingöl, Tunceli
7	TR72	Kayseri region	Kayseri, Sivas, Yozgat
8	TR90	Trabzon region	Trabzon, Ordu, Giresun, Rize, Artvin, Gümüşhane
9	TRA2	Ağrı region	Ağrı, Kars, Iğdır, Ardahan
10	TR63	Hatay region	Hatay, Kahramanmaraş, Osmaniye
11	TR71	Kırıkkale region	Kırıkkale, Aksaray, Niğde, Nevşehir, Kırşehir
12	TRC3	Mardin region	Mardin, Batman, Şırnak, Siirt
13	TRC2	Şanlıurfa region	Şanlıurfa, Diyarbakır
14	TR41	Bursa region	Bursa, Eskişehir, Bilecik
15	TRA1	Erzurum region	Erzurum, Erzincan, Bayburt
16	TR62	Adana region	Adana, Mersin
17	TR33	Manisa region	Manisa, Afyonkarahisar, Kütahya, Uşak
18	TR82	Kastamonu region	Kastamonu, Çankırı, Sinop
19	TR83	Samsun region	Samsun, Tokat, Çorum, Amasya
20	TR21	Tekirdağ region	Tekirdağ, Edirne, Kırklareli
21	TR61	Antalya region	Antalya, Isparta, Burdur
22	TR22	Balıkesir region	Balıkesir, Çanakkale
23	TR42	Kocaeli region	Kocaeli, Sakarya, Düzce, Bolu, Yalova
24	TR81	Zonguldak region	Zonguldak, Karabük, Bartın
25	TR32	Aydın region	Aydın, Denizli, Muğla
26	TR52	Konya region	Konya, Karaman

Figure 3 shows the top 10 regions with good potential to construct frozen food facilities. As seen in the figure, especially in the regions in the east part of Turkey, TRB2, TRC1, TRB1, TRA2, and TR63 have good potential for building frozen food facilities. Advantages ous the features that make them stand out are climate, distance to the border crossing, number of frozen food warehouses, and highway density. In addition, the sub-criteria such as unemployment rate, life index, and government incentives under the development criterion make these regions prior. Besides that, these regions have no or more minor frozen food producers, according to the other regions. Therefore, we see these regions in the top-10 of the ranking.

Figure 3. Top 10 regions listed in the rank of frozen food storage facility location

The regions in the north part of Turkey (Regions TR42, TR81, TR82, and TR83) except TR90 do not have a good potential for frozen food facilities. Those re ions have insufficient power plants in terms of population and labor availability; they have disadvantageous (see Table 5 and Table 6). The regions in the south part of Turkey (Regions TR52, TR61, and TR62) also do not have the potential for frozen food facilities. In addition, they have disadvantages in climate and government incentives. Besides all these shortcomings, they have advantages in the issues of hospitality capacity and the number of ports. However, they could not move these regions to the top of the ranking due to their disadvantageous issues.

Conclusion

Frozen food consumption has increased considerably in many countries where complete closure has been experienced due to epidemic diseases. In order to meet this increase in demand, companies apply different strategies in both production and logistics processes. Especial y, warehouse locations must be closer to consumers so as not to disrupt the increasing demand and cold chain. When the literature is examined, an issue of such importance for human health has only been examined regarding temperature control and packaging. However, the location of a warehouse consisting of such foods is an important decision regarding both human health and cost.

To fill this gap in the literature, this study focuses on identifying potential criteria that affect frozen food storage facility location selection and proposing a road map that involves these main criteria. This road map is a kindly conceptual framework designed with a holistic view to guide producers, logistics service providers, and managers. To the best of our knowledge, this is the first study that highlights identifying the potential criteria affecting frozen food storage facility location selection decisions theoretically and empirically and designing a holistic framework. To achieve e this aim, one of the multi-criteria decision-making methods, PROMETHEE, is used to determine the relative importance of the data-driven performance main and sub-criteria. Then, after de ermining the weight of each criterion, it was used to select a sustainable frozen food storage location for Turkey, a developing country.

The results show that the three biggest cities correspond to regions TR10, TR31, and TR51, and the regions, especially in the east part of Turkey (Region TRA2, TRB1, TRB2, TRC1, and TR63), have good potential for building frozen food facilities. Advantages the features that make them stand out are earthquake risk, climate, and distance to the border crossing, highway density, unemployment rate, life index, and government incentives. Furthermore, the main and sub-criteria identified in this study form a basis for other countries and companies. Therefore, this study gives the reader a comprehensive insight into how sustainable data-driven performance criteria are applied in frozen food storage facility locations.

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