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Location selection of a manufacturing unit using BWM and ELECTRE III

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Abstract – One of the most essential factors in a company's overall supply chain management success is the location of its manufacturing facilities. Due to the emerging energy crisis, the demand for insulation materials is rising, which increases the competition for insulation material companies. To stay competitive, the companies might consider expanding to different locations. This decision entails the consideration of various factors and alternatives, which could be formulated as a multi-criteria decision-making (MCDM) problem. This paper contributes to the problem of location selection in the chemical industry, by implementing two MCDM methods, Best-Worst Method (BWM) and ELECTRE III, in a real-world case company. Based on a thorough literature study and data from interviews with the decision-makers, seven criteria and nine countries as alternatives were chosen. The BWM was used to elicit the weights of all the criteria from a group of decision-makers. Then, ELECTREE III was used to generate a ranking of the alternative countries. Based on the results, the main recommendation to the case company was to choose France as the most appropriate location for the new manufacturing unit. The findings of this research have insights for other companies in the chemical industry deciding on new locations for their manufacturing.

Keywords: Location selection; Insulation material; Manufacturing; MCDM; BWM; ELECTRE

1. Introduction

The present global energy crisis, as well as increasing gas, coal, and electricity costs, provide a significant challenge for homes and companies suffering severe budget constraints, affecting their quality of life and viability (Office for National Statistics 2022). Concerning this issue, the EU has established energy-saving targets and intends to improve building energy efficiency. Apart from that, the building construction industry is one of Europe's greatest users of energy resources, accounting for almost 35% of total greenhouse gas emissions. As a result, most European countries are heavily investing and adopting legislative guidelines to design or renovate energy-efficient buildings (Frost and Sullivan 2022). Consequently, the competition in the thermal insulation industry is expected to increase due to the increased demand for efficient and affordable insulation materials. Between 2016 and 2027, worldwide demand for thermal insulation materials in construction applications was expected to grow at a Compound Annual Growth Rate (CAGR) of 4.5%, with the most common building insulation materials being wool minerals (glass and stone wool) and plastic foams (Expanded Polystyrene, Extruded Polystyrene, Polyurethane) (Pavel and Blagoeva 2018). Stone wool is widely used in the construction sector for heat loss mitigation, especially in low-temperature zones, due to its high thermal properties, safety, cost-effectiveness, and compatibility with many structural products regarding thermal insulation (Frost and Sullivan 2022). Moreover, the construction sector had a higher share of 34% regarding the end-user categories of insulation materials in 2021 due to the increasing trend of insulating buildings regarding the current energy crisis and sustainability goals (Precedence Research 2022).

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Considering the energy crisis problem, intense competition in the European industry of thermal insulation materials is expected to emerge. Western Europe has a larger building insulation market, with considerable mineral wool consumption for residential and non-residential construction and renovations. Specifically, Germany, France, Poland, Italy, and Spain account for most of the demand. At the same time, in Eastern European countries, such as the Czech Republic, and Austria, the market for insulation materials is expected to grow significantly in the upcoming years (Frost and Sullivan 2022). For instance, Germany's insulation market is highly competitive, with a CAGR of 5% predicted through 2026. There are several significant rivals who continually pursue strategic efforts, such as mergers, acquisitions, and regional expansions, to improve their market share (Research and Markets 2020). Even though the EU construction industry's development has slowed owing to the COVID-19 pandemic and the present increase in material prices due to inflation, the predicted loss of demand for insulating materials will be offset by an increase in renovation projects for greater energy efficiency (Frost and Sullivan 2022).

Consequently, insulation companies are trying to stay competitive by introducing innovative, effective insulation materials, being able to cover their customer's increasing demands, and acquiring new markets (Global Trends in the Thermal Insulation Market 2021). Many businesses no longer limit their manufacturing to their home nations but are increasingly looking for new places to perform cross-border activities to positively influence their revenue and performance (Arunyanart et al. 2021). To accomplish this, different strategic decisions have to be made. The problem of location selection for a new manufacturing unit is one of those strategic decisions, which is influenced by the company's inbound-outbound logistics as well as its strategic posture (Kalantari 2013, MacCarthy and Atthirawong 2003). For the most effective and favourable strategic option, numerous factors are considered during the site selection process, and particularly when it includes foreign lands (Arunyanart et al. 2021). In other words, decision-makers have to consider a variety of criteria, both tangible and intangible, such as the accessibility to resources, and the proximity to facilities (Mousavi et al. 2013).

Multi-criteria decision-making (MCDM) methodologies can provide support for complex decision-making issues by aiding in problem structuring and giving all relevant parties a similar vocabulary for discussing and understanding the problem. The objective is to establish a preferred ranking among different choices, whose performance is evaluated against several criteria (Vassoney et al. 2021). Different MCDM methods have been applied to solve problems regarding location selection. In our work, we present the combination of the Best-Worst Method (BWM) and ELECTRE III that have not been researched nor applied to a case regarding location selection in supply chains. First, a Linear BWM is used to derive the weights of the selected criteria. The Linear BWM method was selected for several reasons. First, the BWM data collection procedure is simple and do not require in-depth knowledge about multi-criteria decision-making from the chosen decision-makers, which makes it easier for communication. Furthermore, BWM is expected to lower the probability of the effect of anchoring bias and equalizing bias (Rezaei et al. 2022a, 2022b). Then, ELECTRE III (Roy 1990) utilized the output of weights from the BWM to rank the alternatives. Through our literature review, it was found that ELECTRE III method has already been applied in similar cases for the ranking of alternatives (Norese 2006). Moreover, the non-compensatory characteristic of the method is an important advantage. Also, the method is suggested for similar cases, where there are uncertainties, and incomparable alternatives (Tscheikner-Gratl et al. 2017). We think that the weights found by the BWM can be interpreted as intrinsic weights or the voting power of each criterion (Figueira et al. 2013), which makes them appropriate to be used in ELECTRE methods.

The paper is structured as follows. Section 2 is the literature review, where we present the problem of location selection in supply chain management, followed by Section 3, where we present our proposed research methodology. In Section 4, the real-case study of the location selection problem for an insulation material company is discussed, while in Sections 5 and 6 we present the findings and discuss them, ending with specific recommendations for the case. Finally, Section 7 presents a summary of the work and possible future research directions.

2. Literature Review

The following section presents the general problem of location selection, the criteria considered for it, as well as why it can be considered a multi-criteria decision-making (MCDM) problem. Finally, we present a review of the relevant studies.

2.1 Location selection as an MCDM problem

The process of location selection is a crucial part of the strategy of any organization that needs to carry out some form of operational management (MacCarthy and Atthirawong 2003). The main reason for this is that facility location has a tremendous impact on the overall operation cost, as well as the logistics network, i.e. the efficiency of the whole supply chain (Chang and Lin 2015, Raut et al. 2017). On top of that, each individual case of location selection involves a different set of stakeholders and decision-makers. For this reason, there is no universal solution applicable to all organizations. Furthermore, there are different types of problems that can occur in this sphere. Namely, location selection can be done in different sectors of the supply chain, such as manufacturing, storage, and warehouse (Dey et al. 2017, Hale and Moberg 2005, Raut et al. 2017). With globalization taking place across all industries, the issue of location selection is becoming even more prominent, and increasingly more complex, as external factors (social, economic, and political) need to be considered as well when looking for a suitable solution (Kalantari 2013). Another challenge for the field is the fact that not all the relevant influencing factors are quantitative, but qualitative as well (Chang and Lin 2015).

Traditional plant location issues have been discussed over time, starting with Weber and Friedrich's work (1929). After the introduction of automatic computation capabilities in 1996, by Laporte and Ravelle, various methods have been applied (Revelle and Laporte 1996). Specifically, location selection problems were solved with a metric K-Median method proposed by Arya et al.(2004), as well as with an Operations Research (OR) technique used by Koopmans and Beckmann (1957). Also, for location selection, Kirkwood (1982) used a multi-attribute utility theory model, Chuang (2002) a Quality Function Deployment (QFD) methodology, while Chan and Chung (2004) applied a multi-criterion optimization for problems in the distribution network.

The problem of location selection within supply chains illustrates a good example of an MCDM problem and is one of the key issues for almost all companies, as the solution impacts the efficiency of the whole supply chain (Raut et al. 2017). This implies that this decision-making problem is influenced by several different factors, making it increasingly complex. In addition, the solution for each problem of this kind is based on a different set of criteria (attributes), which vary based on the decision-makers involved, the type of problem, and the type of company. For instance, the problem structuring, and with it, the solution for an offshore-wind company deciding on a location for a new wind farm will be very different from that of a clothing company looking for a new manufacturing location (Wu et al. 2019). Even smaller differences, such as choosing a location for a warehouse but for two different companies often require different approaches and solutions, because of the differences in the preferences of the company's decision-makers. This means that the problem addressed in this paper cannot be resolved solely by relying on desk research, but field research in terms of interviews, accompanied by a thorough analysis, needs to be conducted in order to gain insight into the specific criteria that need to be considered in this field.

The fact that there is extensive research in this area suggests that location selection for supply chains is a contemporary issue that requires attention by researchers. The biggest research gap, according to the body of literature in this area, is in determining the collection of factors, i.e. criteria that should be considered when choosing a site (Chang and Lin 2015, Dey et al. 2017, Hale and Moberg 2005, Kalantari 2013, Schmenner et al. 1987).

2.2 Criteria selection

Although not enough on its own, the existing literature proves helpful in making a choice on the criteria that will be considered in identifying a suitable solution. So, the criteria presented in Table 1 are derived from a variety of papers in the MCDM literature.

A significant milestone in the research of the Industrial Location Decision was made by Weber's theory, in which he suggested the transportation cost, labor cost, and agglomeration forces, as the three major factors for location selection (Kalantari 2013). Researchers have grouped and discussed numerous criteria with different approaches. For example, Saha et al. (2015) presented two categories of critical demand factors, such as the location of competitors, and proximity to markets, and the cost factors, such as labor, transportation, and raw materials (Saha et al. 2015). In Table 1, we present some of the most significant factors for global facility location found in the literature of MCDM problems, which are categorized into the three dimensions of the Triple Bottom Line (TBL) of sustainability: the social, environmental, and economic (Terouhid et al. 2012, Kheybari et al. 2019).

Regarding the literature review, we identified and confirmed our remark in the above section, that the criteria determined and analyzed by each company, are selected by the firm's decision-makers, whose goal is the optimization of the location selection regarding their strategy.

Table 1. An overview of criteria for location selection.

Category	Criteria	References
Social	Labor availability	(Liang and Wang 2007),(Alam et al. 2015),(Sriniketha et al. 2014), (Terouhid et al. 2012),(Boutkhoum et al. 2015),(Kheybari et al. 2019),(Ertuğrul 2010),(Saha et al. 2015),(Farahani et al. 2010),(Mousavi et al. 2013),(Rahman and Kabir 2019),(Sriniketha et al. 2014)
	Governmental Policy and Incentives	(Saha et al. 2015),(Kheybari et al. 2019),(Terouhid et al. 2012) (Kahraman et al. 2003),(Alam et al. 2015),(Liang et al. 2021),(Saha et al. 2015)
	Quality of life	(Ertuğrul 2010),(Saha et al. 2015)
Economic	Market volume	(Alam et al. 2015),(Mousavi et al. 2013),(Liang et al. 2021),(Alimoradi et al. 2011),(Ulutaş and Karakuş 2021),(Saha et al. 2015)
	Investment costs	(Alimoradi et al. 2011),(Alam et al. 2015),(Mousavi et al. 2013),(Sriniketha et al. 2014),(Boutkhoum et al. 2015),(Terouhid et al. 2012),(Saha et al. 2015)
	Production and operation costs	(Alam et al. 2015),(Sriniketha et al. 2014),(Boutkhoum et al. 2015),(Terouhid et al. 2012),(Saha et al. 2015)
	Logistic activity costs	(Alimoradi et al. 2011),(Sriniketha et al. 2014),(Alam et al. 2015),(Mousavi et al. 2013),(Ulutaş and Karakuş 2021),(Terouhid et al. 2012),(Saha et al. 2015)
	Global competition	(Saha et al. 2015),(Boutkhoum et al. 2015),(Alimoradi et al. 2011),(Liang et al. 2021)
	Safety and security cost	(Kheybari et al. 2019)
Environmental	Resources	(Terouhid et al. 2012),(Saha et al. 2015),(Kheybari et al. 2019)
	Waste Disposal	(Saha et al. 2015),(Terouhid et al. 2012)
	Climate	(Saha et al. 2015),(Terouhid et al. 2012),(Kheybari et al. 2019)

From Table 1 it can be seen that most criteria are set in the economic category. Furthermore, *safety and security cost* is mentioned in only one of the reviewed papers, while *labor availability* is addressed the most.

2.3 MCDM studies for the location selection problem

Within the field of multi-criteria decision-making (MCDM), many methods are available to aid the decision-making process. The decision is ultimately a result of a ranking of the alternative solutions available. More precisely, based on the selected criteria and their weights, which depend on the available data and the preferences of the decision-makers involved in the process, the alternatives are ranked. The alternative with the highest ranking represents the solution that will be recommended by the analysts to the decision-makers (Velasquez and Hester 2013, Wątróbski et al. 2019).

In their literature review, Wątróbski et al. have identified 49 different MCDM methods that can be used (Wątróbski et al. 2019). Other reviews, such as the ones written by Ceballos et al. (2016) and Vasquez and Hester (2013) were also taken into account. Specifically, Analytic Hierarchy Process (AHP), which was introduced by Saaty (1977), has been used for manufacturing plant location selection problems (Chang and Lin 2015), but also to structure the problem and get the weights of the selected criteria. AHP has also been combined with the PROMETHEE method to assess and rank the alternatives (Mousavi et al. 2013). Fuzzy AHP has been used in some studies (Sehra et al. 2012), while in others the Fuzzy AHP and fuzzy TOPSIS techniques have been applied together (Alimoradi et al. 2011, Chu 2002, Ertuğrul 2010, Ertuğrul and Karakaşoğlu 2008, Yang and Hung 2007, Yong 2006). These methods employ the same scale and preference functions, based on conflicting tangible and/or intangible criteria. However, different preference functions for the criteria can be viewed as important variables that affect how accurately the decision-making process's outcome is reached (Mousavi et al. 2013). To tackle facility location selection problems, other works have applied the PROMETHEE II (Athawale and Chakraborty 2010), and the Best-Worst-Method for renewable energy facility (Kheybari et al. 2019). Best-Worst-Method

(BWM) is a recently introduced MCDM method by Razaei, in which firstly the "best" and "worst" criteria are identified by the decision-makers, and secondly, pairwise comparisons are conducted to obtain the weights of the different criteria (Rezaei 2015). This method provides more reliable results by ameliorating the consistency ratio, since it requires fewer pairwise comparisons than other similar MCDM methods (Rezaei 2015), and has already been applied in various supply chain problems (Duchemin and Matheus 2021, Govindan et al. 2019, Kheybari et al. 2019,Rahmawati and Salimi 2022, Rezaei et al. 2016). Another method used in deciding the appropriate facility location is outranking method ELECTRE (Maciej Serda et al. 2011, Uysal 2014), as well as for other sustainable supply chain decisions (Komsiyah et al. 2019, Lu et al. 2018, Sevkli 2009). In the literature, ELECTRE II (Roy and Bertier 1973) and ELECTRE III (Roy 1978) are widely used versions of ELECTRE for MCDM problems (Sevkli 2009).

To the best of our knowledge, there is no study that combines the BWM and ELECTRE III methods for manufacturing location selection. Our goal is to develop a new decision-making approach, considering both the strengths and weaknesses of the techniques, and apply it to solve a real-case scenario MCDM problem.

3. Methodology

In the following section, we present the step-by-step process followed in order to carry out this research.

3.1 Best Worst Method (BWM)

In this section, we present the steps of the linear BWM, a pairwise comparison-based method, that is followed in order to obtain the weight of the criteria (Rezaei 2015, 2016) as follows:

Step 1: The decision-makers choose the set of relevant criteria $(c_1, c_2, \ldots, c_n)$ based on the literature study presented to them.

Step 2: The decision-makers determine the best and the worst criteria from the chosen set of relevant criteria $(c_1, c_2, \ldots, c_n)$, according to their preferences.

Step 3: The decision-makers assign values between 1 and 9 to express their preference of the best criterion over all the other criteria. This results in the following Best-to-Others vector:

$$A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn})$$

here, a_{Bj} is the preference of the best criterion (B) over criterion j.

Step 4: The decision-makers assign values between 1 and 9 to express their preference of all the criteria to the worst criterion. This results in the following Others-to-Worst vector:

$$A_W = (a_{1W}, a_{2W}, \ldots, a_{nW})^T$$

where, a_{jW} is the preference of the criterion j over the worst criterion (W).

Step 5*:* The optimal weights $(w_1^*, w_2^*, \ldots, w_n^*)$ are calculated, where. we have to find a solution by which the maximum differences of $|w_B - a_{Bj}w_j|$ and $|w_j - a_{jW}w_W|$ should be minimized. This is translated to the following mathematical model:

$$\min max_j\{ |w_B - a_{Bj}w_j|, |w_j - a_{jW}w_W| \}$$

such that

$$\sum_j w_j = 1,$$

$$w_j \geq 0, for\ all\ j.$$

This model is equivalent to the following model:

$$\min \xi,$$

such that

$$|w_B - a_{Bj}w_j| \le \xi, for\ all\ j,$$

$$|w_j - a_{jW}w_W| \le \xi, for\ all\ j,$$

$$\sum_j w_j = 1,$$

$$w_j \ge 0, for\ all\ j.$$

Solving this model results in the optimal weights $(w_1^*, w_2^*, \dots, w_n^*)$ and ξ^*.

Step 6: The consistency ratio is calculated by making use of the following formulas for input based BWM (Liang et al. 2020):

$$CR = \max_j CR_j$$

where

$$CR_j = \begin{cases} \frac{|a_{Bj} \times a_{jW} - a_{BW}|}{a_{BW} \times a_{BW} - a_{BW}}, & a_{BW} > 1, \\ 0, & a_{BW} = 1. \end{cases}$$

The calculated consistency ratio is then compared to the threshold values presented in Table 2 (Liang et al. 2020).

Table 2.Thresholds for the consistency ratio for input-based (Liang et al. 2020).

	Criteria						
Scales	**3**	**4**	**5**	**6**	**7**	**8**	**9**
3	0.1667	0.1667	0.1667	0.1667	0.1667	0.1667	0.1667
4	0.1121	0.1529	0.1989	0.2206	0.2527	0.2577	0.2683
5	0.1354	0.1994	0.2306	0.2546	0.2716	0.2844	0.2960
6	0.1330	0.1990	0.2643	0.3044	0.3144	0.3221	0.3262
7	0.1294	0.2457	0.2819	0.3029	0.3144	0.3251	0.3403
8	0.1309	0.2521	0.2958	0.3154	0.3408	0.3620	0.3657
9	0.1359	0.2681	0.3062	0.3337	0.3517	0.3620	0.3662

3.1 ELECTRE III

ELECTRE is a family of multi-criteria decision analysis methods proposed by Roy (1990), and various versions are used for different aims, such as ELECTRE I for selection, and ELECTRE III for ranking problems. ELECTRE III is convenient while quantifying the relative importance of criteria for outranking the alternatives while the available data is inaccurate or uncertain (Marzouk 2011, Hashemi et al. 2016). The alternative set is evaluated using ELECTRE III steps, as Roy (1990) presented in the following.

Step 1: The decision-makers express their preference (p_j), indifference (q_j) and veto (v_j) thresholds (for the definitions see Roy (1990)).

Step 2: The concordance indices $C(a, b)$, where a and b represent the alternatives, are calculated for every pair of alternatives, by making use of the following formulas:

$$C(a,b) = \frac{1}{W}\sum_{j=1}^{n} w_j c_j(a,b)$$

where;

$$W = \sum_{j=1}^{n} w_j$$

$C(a,b)$ holds a value between 0 and 1. If it is equal to 0, this indicated that the alternative a is worse than b, with respect to all the criteria. The comparison index for each criterion is denoted as $c_j(a,b)$, which is calculated based on alternative performance, for which there are 3 cases, namely:

Case 1. If alternative a is either equivalent to or better than alternative b minus the indifference threshold for criteria j:

$$c_j(a,b) = 1 \; if \; \mathrm{g_j}(a) + q_j(g_j(a)) \geq \mathrm{g_j}(b)$$

where $\mathrm{g_j}(i)$ shows the performance of alternative i with respect to criterion j.

Case 2. If the performance of alternative a plus the performance threshold is less than the performance of alternative b, then alternative a is not better than b with respect to this selected criterion:

$$c_j(a,b) = 0 \; if \; g_j(a) + p_j(g_j(a)) \leq g_j(b)$$

Case 3. In all other cases:

$$c_j(a,b) = \frac{g_j(a) - g_j(b) + p_j(g_j(a))}{p_j\left(g_j(a)\right) - q_j(g_j(a))}$$

Step 3*:* The discordance index ($D(a,b)$) makes use of the veto threshold (v_j) and serves to take into account cases where one alternative is better than the other in general, but there is one or more (veto) criteria where it performs worse than the other one. The calculations are performed according to the following cases:

Case 1 If alternative b is not better than alternative a by a more than v_j:

$$D_j(a,b) = 0 \; if \; g_j(b) \leq g_j(a) + p_j(g_j(a))$$

Case 2 If alternative b is better than alternative a by a more than v_j:

$$D_j(a,b) = 1 \; if \; g_j(b) \geq g_j(a) + v_j(g_j(a))$$

Case 3 In all other cases:

$$D_j(a,b) = \frac{g_j(b) - g_j(a) - p_j(g_j(a))}{v_j g_j(a) - p_j(g_j(a))}$$

Step 4: The credibility ($S(a,b)$) is computed by combining the results obtained from the concordance and discordance calculations, and there are two cases:

Case 1 If there is no discordance or veto threshold present:

$$S(a,b) = C(a,b) \; if \; D_j(a,b) \leq C(a,b), \forall_j$$

Case 2 In all other cases:

$$S(a,b) = C(a,b)\prod_{j=1}^{n}\frac{1-D_j(a,b)}{1-C(a,b)}$$

Step 5: The final ranking is computed based on how the alternatives performed in each of the previous steps. Namely, every time that alternative a outranks alternative b, it gets a +1 score, while alternative b gets a -1 score. When all the scores are added, a final score that determines the ranking is obtained.

4. Application

The following diagram presents the steps followed for the application of the approach of the two MCDM methods, as described in Methodology, for the Greek company FIBRAN S.A.

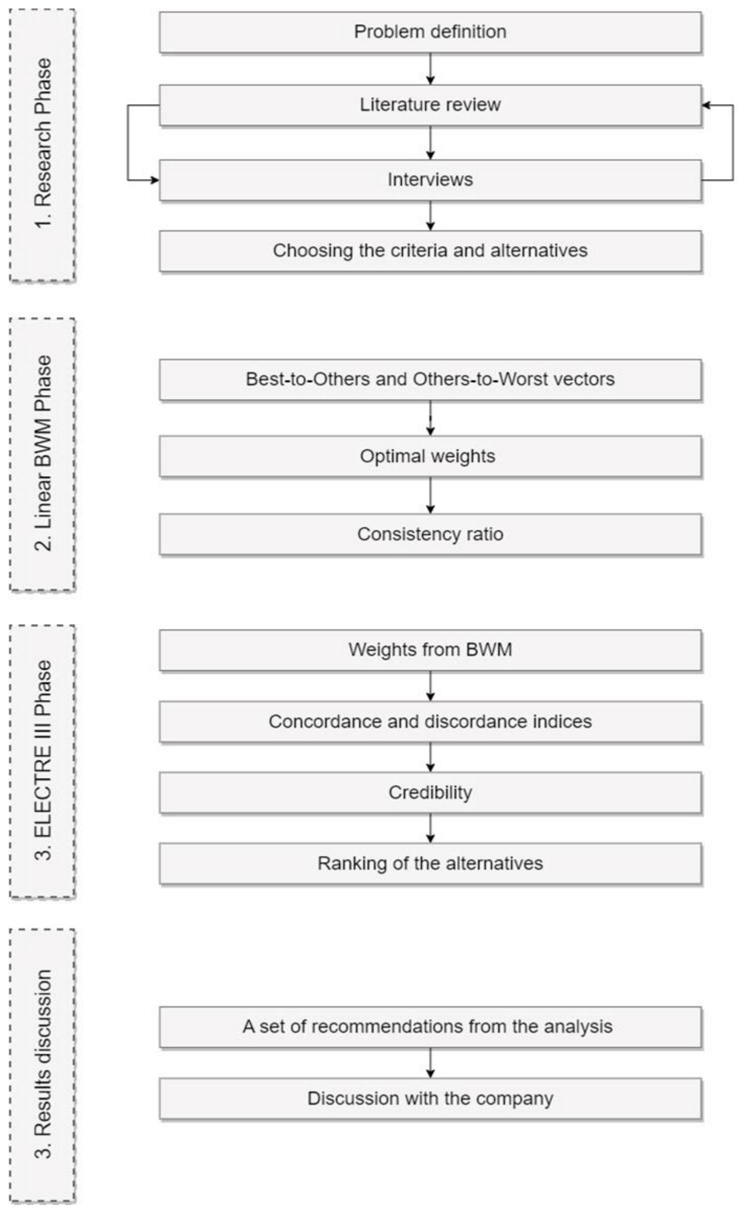

Figure 1. Scheme of the framework used for the application.

4.1 The company

In this study, we evaluated the manufacturing location selection problem for FIBRAN S.A., a multi-national insulation company, founded in 1974 in Greece. The company has expanded to different European countries and has commercial activities in more than 60 countries worldwide. Its 13 production lines produce a variety of insulation products, for thermal, and sound insulations, as well as fire protection. Some of these products are extruded polystyrene (FIBRANxps), stone wool (FIBRANgeo), and expanded polystyrene (FIBRANeps). Its product expertise is regarding extruded polystyrene and mineral wool, which provide FIBRAN S.A. with a competitive advantage over other international insulation companies (FIBRAN 2022).To capitalize on its competitive edge, the firm is constantly on the lookout for new market opportunities for its tried-and-true products. FIBRAN S.A. invests in new production units around the EU, therefore increasing its network and corporate image.

Regarding FIBRAN's past activities and future goals, the company's value proposition is to provide innovative, high-quality insulation products, by implementing an agile and flexible strategy. It operates mainly in Business to Business (B2B) channels, and its strategy for value creation is the effort of expansion to foreign markets. By following this strategic approach FIBRAN S.A. aims at achieving economies of scale by expanding the number of customers, and production levels, increasing profits and compensating for customer loss in the domestic market (Kotler et al. 2019). During the first years after the foundation, the company's main activities were in Greece, but after a few years, it started expanding internally by exporting products not only to the neighboring countries, but also through EU. However, the high transportation costs were an important barrier to the company's profits and sustainable competitive advantage. Although the quality of the products was competitive, their price could not be lower than those of the local partners, because having a pricing model considering both the high transportation costs and a competitive price, would not be advantageous for the viability and profitability of the company. Pricing decisions are of paramount importance for the profitability and competitiveness of the company and do not depend only on the customer's perceived value, but also on the competitor's prices (de Toni et al. 2017). Moreover, a major strategic focus of the company is market creation in areas where the competition is low. Specifically, FIBRAN constantly searches for new market opportunities for its established products. New markets are not only created by the introduction of new products but also by the acquisition of new clients, that could not be served through the local market, and the increase of the market share (Ménard and Shirley 2005). Therefore, the company can leverage its competitive advantage and lower the threat of new entrants in the area by being the first to develop a brand identity, and network with suppliers, and distributors (Porter 1990).

Due to the strategic insights mentioned above, FIBRAN's aim is the expansion to other EU countries to increase its market share and profits. Therefore, the objective of selecting the best alternative location for a new manufacturing facility could be formulated as a multi-criteria decision-making problem.

4.2 Data collection

The data for the analysis were collected from FIBRAN's three decision-makers[2]:

- The Chairman of the Board & CEO of the company, Maria Anastasiadou, who graduated from the Department of Organization and Business Administration of the University of Macedonia. She has been working in the company since 1986. Her initial position was assistant in the Economic Department, and after years of experience she became the manager of the Department. In 2019 she became the CEO of the company.
- Alkmini Kontou, the HR Manager of FIBRAN, who graduated from Aristotle University of Thessaloniki. She has been working in the HR Department of the company since 2014, and in 2021 she became the manager.
- Dimitrios Kontos, is the Channel Sales Manager for the region of Greece. He graduated from the Civil Engineer Department of Aristotle University of Thessaloniki and started working in the company in 2018. He is working in his current position since 2022.

[2] We have permission from the company to disclos all the collected data, including the name of the interviews.

The authors of the paper have acted as analysts and facilitators for the whole process of data collection. First, we conducted a literature review on location selection within supply chains. The objective for this was to acquire relevant information about the topic before conducting interviews with the decision-makers so that we could be aware of the problem and debate and propose suggestions for the attribute's generation. Having all the necessary information regarding the challenges and the factors and considerations behind selecting the most appropriate location, also helped us formulate the problem statement, understand why the issue arose, and what the current market trends are.

During our first interview, we addressed the company's overall strategy, the difficulty of picking a new nation for their new investment plan, and the options they are contemplating investing in with our three decision-makers. They also provided extensive information about their previous activities and investments. Following that, we informed them of our results from the literature analysis and they provided us with feedback regarding the company's primary criteria for selecting an optimal location, as well as the countries they are interested in. The discussion was not a one-sided process, but rather a dynamic one that required considerable input and deliberation until we reached a consensus on the final attributes to include in the study. We made use of semi-structured interviews (Kallio et al. 2016), in order to leave room for follow-up questions and discussions and to make sure that we have a full picture of the preferences of the decision-makers.

Following the first interview, we continued our literature research to finalize the criteria of location selection and find the relevant data regarding each alternative country. During our second interview, we presented to the decision-makers the data for their feedback and asked them to provide us with an approximate demand from these countries, as they informed us that they have already collected data on this topic. After reaching to a set of relevant attributes, we continued with the next steps of the BWM. We asked them to express their preference collectively regarding the best and worst criteria, and then assign values for the pairwise comparisons on a scale of 1 to 9, first comparing the best criterion to all the other criteria, and then comparing all the criteria to the worst one. Moreover, for the outranking method of ELECTRE III, we asked our decision makers to express their veto v_j, preference threshold p_j, and indifference threshold q_j regarding the attributes.

We managed to obtain just one set of values by having the decision-makers sit down together in a meeting with us and have an elaborate discussion about their preferences and the answers to our questions. As all three of them normally work closely together, there were no significant disagreements, so they were able to produce the data about their preferences and reach a consensus.

4.3 Alternatives

The country selection by the headquarters of FIBRAN was developed by a marketing analysis by the company taking into consideration the competition in the insulation market, and the company’s expansion strategy, and previous customer relationships. These are Germany, Romania, France, the Czech Republic, Austria, Portugal, Italy, Spain, and Poland.

4.3.1 Attributes

For the case application, the criteria found in the literature and mentioned in Section 2.2 were altered, as all the final ones were decided in agreement with the decision-makers of the company, so the criteria that are considered relevant and important for them would be used. This also helped us have a common language for the interpretation of the data given and the results. Particularly, the factors used for the case study of FIBRAN S.A. are Competition, Labor, Utilities, Transportation and distribution logistics, Market, Business and Investment freedom. The values of the attributes assigned to each alternative are summarized in Table 3. Each attribute, as well as the data, are further described in the following sections.

4.3.2 Competition

Based on the data collected by FIBRAN S.A., their key competitors in Germany are BASF SE, Knauf Insulation, Wacker Chemie AG, CBG Composites, DBW Advanced Fiber Technologies, Korff Isolmatic, ROCKWOOL Group, THERMO Feuerungsbau, Baumit GmbH, and Armacell GmbH. Paroc GmbH also has sales offices in Germany. In Germany are located most mineral wool manufacturing units, 11 in total. Poland also has eight manufacturing units by major key players such as ROCKWOOL, Saint-Gobain Construction Products, and Paroc. In France, there exist around 6 units and the major competitors are again Saint-Gobain, URSA SAS, BASF SE, Knauf Insulation, and ROCKWOOL, who are building a new production facility in Soissons (Rockwool, 2022). Spain has two major competitors, Saint-Gobain, URSA Ibérica Aislante, with four units in total, while the Czech Republic follows with three units by Knauf Insulation. Moreover, both Italy and Romania have two units, by Saint-Gobain, and ROCKWOOL for the first one, and Knauf Insulation, and ROCKWOOL for the second one. Finally, in Austria FinMach has one unit and TERMOLAN Isolamentos has one unit in Portugal. Table 3 presents the number of competitors in the countries FIBRAN is aiming at building a new manufacturing unit. The number of competitors represents the number of their manufacturing units in those countries.

4.3.3 Labor

Another key consideration for the site of a manufacturing unit is the labor profile in a nation, with two major sub-criteria being labor cost and the availability of a skilled labor force. During our interview with our decision makers, it became evident to us that the cost of labor is a major consideration for FIBRAN S.A. A skilled workforce is substantial for manufacturing companies for sustainable, balanced growth. An adept labor force can reassure successful operations and adjustments regarding future technological and marketing changes (International Labour Office 2011). As such, the strategic approach of the company toward its labor is the training of the new workers by the experienced ones, who are relocated to the new manufacturing unit for a short period, and then come back to their initial positions. Hence, the degree of knowledge is not a serious concern. Column 3 in Table 3 presents the data obtained from Eurostat, regarding the estimated hourly labor costs, in 2021. The numbers correspond to wages, salaries, and other labor costs (Statista 2022, Statistics Explained 2022). We are aware that these are average wage rates that are not specified according to the specialization that the company is looking for. However, after discussing this matter with FIBRAN, it was concluded that it is most important for them to be aware of the differences in wages among the countries, as opposed to the exact salaries they would be paying to the workers.

4.3.4 Utilities

In terms of the utility criteria, availability and cost are major elements that influence location selection. Water and electricity are the most crucial utilities for FIBRAN S.A. It should be mentioned that almost all the units of the company are utilizing only electricity and not natural gas. Electricity prices are a key indicator of overall production costs. Hence, it is critical for the firm to choose a region with lower indirect manufacturing expenses. The manufacture of stone wool requires a huge amount of power since the raw materials that are mostly rocks, must melt at temperatures that reach 1500 ^{0}C. Column 4 of Table 3 displays the volatile electricity prices for businesses per kWh, including all items in the electricity bill (Global Petrol Prices 2022). The volatility of electricity prices is taken into account, and as the focus is on comparing different alternatives, this data is still relevant, as it serves as an overview of the pricing differences in the chosen countries.

4.3.5 Transportation and distribution logistics

The availability of transportation and logistics expenses are one of the crucial sub-criteria for FIBRAN's logistic operations. Because of the product's significant volume, low weight, and low price, transportation costs are high for the corporation. Each truck has a specified volume, and costs have a predetermined fee for each run. As a result, the lower the value of the commodity being transported, the lower the profit for the firm. To decide how to quantify transportation costs, we did a study of transportation fees throughout the EU and discovered that the greater a country's diesel fuel prices, the higher the charge for the transfer. Therefore, with the approval of the decision-makers, we decided to utilize data for diesel fuel prices in the countries where FIBRAN S.A. is considering investing. Even though fuel price is very volatile, we expect the ratios between fuel prices of the alternatives to remain considerably similar, even if there are significant variations in fuel prices. The diesel fuel prices data are presented in Column 5 of Table 3.

4.3.6 Market

As mentioned above, a key component of FIBRAN's strategy is the search for new market opportunities for its established products by acquiring new clients. However, in terms of profitability and growth, the firm also used customer retention techniques to boost client loyalty and reduce the number of consumers lost. That is why FIBRAN S.A. wishes to establish a new production plant near loyal clients in locations where demand is high. The approximated data about consumer demand provided by the decision-makers are displayed in Column 6 of Table 3. The data were derived through a market analysis the company made, regarding the total demand for mineral wool from those countries.

4.3.7 Business and Investment Freedom

Regarding the governmental policy and incentives criterion, before having the interview with the head of our decision-makers, we studied and discussed how this criterion could be measured. Clearly, our literature review yielded several sub-criteria that influence the main one, such as the tax level, the codes and regulations, potential incentives, and the general political conditions in each country. Because the criterion indicated above cannot be measured directly, we recommended to the decision-makers that the Business Freedom and the Investment Freedom indicators be used as proxies for measuring the level of governmental policy for the countries on FIBRAN's agenda. After examining the Economic Freedom Index, together with FIBRAN S.A., we determined that these metrics are acceptable for their problem. Business Freedom is a wide measure of the efficacy of government control of the business, and its quantitative score is generated using a range of criteria pertaining to the difficulty of starting, operating, and closing a corporation. Moreover, Investment Freedom defines the number of constraints, if any, on international and domestic investments, foreign currencies, payments, and transfers. Labor restrictions, the extent of corruption, the lack of infrastructure, and political and security concerns all have an impact on this form of freedom. The more freedom a country has, the higher its score will be on a scale from 0 to 100 for both indicators (Heritage.org 2022) The data for Business Freedom and Investment Freedom is presented in Columns 7 and 8 of Table 3, respectively.

Table 3. Alternative countries and their performance with respect to different criteria.

Country	Number of competitors	Estimated hourly labor costs (euro)	Cost of electricity (kWh, euro)	Diesel fuel prices (euro)	Demand (thousand tons)	Business freedom	Investment freedom
Germany	11	37.2	0.442	2.183	139	87.2	80
Romania	2	8.5	0.188	1.812	79	71.4	70
France	6	37.9	0.184	1.944	182	81.9	75
Czech Republic	3	15.3	0.295	1.909	64	80.6	70
Austria	1	37.5	0.311	2.073	102	82.3	80
Portugal	1	16	0.238	1.982	90	76.2	70
Italy	2	29.3	0.307	1.906	147	73.8	80
Spain	4	22.9	0.323	1.977	100	75.2	85
Poland	8	11.5	0.165	1.694	82	78.7	80

5. Results

In this section, we present the collected data used for the calculations, as well as the results obtained.

5.1 Best Worst Method Results

Following the steps of the BWM, the decision-makers deemed demand as the best criterion and estimated hourly labor costs as the worst criterion. The Best-to-Others table was found as follows:

Table 4. Best to others table according to FIBRAN.

Best to Others	Number of competitors	Estimated hourly labor costs	Cost of electricity	Diesel fuel prices	Demand	Business Freedom	Investment Freedom
Demand	2	9	4	7	1	5	5

The values assigned to the comparison of the criteria to the worst criterion (estimated hourly labor costs) are presented in the Others-to-Worst table as follows:

Table 5. Others to worst table according to FIBRAN.

Others to the Worst	Estimated hourly labor costs
Number of competitors	8
Estimated hourly labor costs	1
Cost of electricity	6
Diesel fuel prices	3
Demand	9
Business Freedom	5
Investment Freedom	5

The weights computed by the BWM Solver (bestworstmethod.com 2022) are presented below. Demand has the highest weight of 0.3758, whereas the estimated hourly labor cost, has the lowest one 0.0327.

Table 6. Weights of the criteria.

Weights	Number of competitors	Estimated hourly labor costs	Cost of electricity	Diesel fuel prices	Demand	Business Freedom	Investment Freedom
	0.2288	0.0327	0.1144	0.0654	0.3758	0.0915	0.0915

The consistency ratio (CR) is 0.2222, which is deemed acceptable according to Liang et al. (2020).

5.2 ELECTRE III Results

The ranking was derived using ELECTREE III (Roy, 1991). For the credibility index, the cut-off value λ=0.7 is assigned. The veto v_j, preference p_j, and indifference q_j thresholds were provided by the decision-makers, who supplied one set of values that they had agreed upon. The values are presented in Table 7.

Table 7. Preference, Indifference, and Veto Thresholds from FIBRAN.

	Number of competitors	Estimated hourly labor costs	Cost of electricity	Diesel fuel prices	Demand	Business Freedom	Investment Freedom
p	5	20	0.3	1.5	100	30	30
q	2	10	0.2	1	80	10	10
v	10	30	0.4	2	150	80	80

The credibility matrix calculated following the ELECTRE III is provided in the following Table 8.

Table 8. Credibility matrix.

	Germany	Romania	France	Czech Republic	Austria	Portugal	Italy	Spain	Poland
Germany	1	1	1	1	1	1	1	1	1
Romania	0.65	1	0.44	1	0.96	1	0.97	0.96	0.77
France	0.7	1	1	1	1	1	1	1	1
Czech Republic	0.74	1	0.52	1	0.97	1	0.93	0.96	0.77
Austria	0.77	1	0.77	1	1	1	1	0.92	0.77
Portugal	0.73	1	0.51	1	0.97	1	0.99	0.9	0.77
Italy	0.76	1	0.85	1	1	1	1	1	0.77
Spain	0.75	1	0.95	1	0.99	1	1	1	0.85
Poland	0.8	1	0.59	1	0.97	1	0.97	1	1

The final ranking obtained based on the credibility matrix is as follows: (1) France, (2) Germany, (3) Austria, (4) Italy, (5) Spain, (6) Czech Republic, (7) Portugal, (8) Poland, (9) Romania.

6. Discussion

As can be seen from Section 5, the criterion of demand has the highest weight of 0.3758, whereas the estimated hourly labor cost, the worst criterion, has the lowest one at 0.0327. The number of competitors has the second-highest weight namely 0.2288, making it quite an important criterion as well. Demand and number of competitors together take up more than 50% of the total weight of the seven criteria. With this in mind, it makes sense that France was ranked as the best alternative, as it holds the first place when it comes to demand, while also having a reasonably low number of competitors compared to the other alternatives. The criterion with the third highest weight is the cost of electricity at 0.1144, closely followed by business freedom and investment freedom both at 0.0915, as the decision-makers assigned the same values to them in the interview.

When discussing possible inconsistencies, it is worth mentioning that we used proxies since the criteria determined for the selection of the best locations cannot be measured by a particular fundamental objective. According to Keeney and Raiffa (1979), determining the direct measurement of an attribute is a complicated issue. So, proxy attributes can be used as an indirect measurement of a decision objective when a natural property is difficult to be measured else how. However, each decision-maker and the analyst should be mindful of the possibility of biased judgments of the link between a proxy and a basic trait due to decision-makers' cognitive capabilities and heuristics (Fischer et al. 1987). Also, it should be mentioned that each selected attribute should be characterized as unambiguous, comprehensive, direct, operational, and understandable (Keeney and Gregory 2005). One solution to overcome proxy biases is the replacement of proxy attributes with fundamental objectives, but this requires our decision-makers to take a more time-consuming, objective, and nuanced approach to the problem (Montibeller and von Winterfeldt 2015).

Furthermore, we are aware of possible cognitive and motivational biases regarding the elicitation of the weights and attributes by our decision-makers. Particularly, proxy bias can exist in our analysis due to the use of proxy attributes, due to sophisticated inferences that transcend the human ability for consistent assessments. Regarding the anchoring bias, it is assumed that the BWM is a possible debiasing strategy to mitigate it. Therefore, the consideration of the opposite-worst attribute by our decision-makers could have increased their consistency during our interviews, as well as the group decision-making for the provided data (Rezaei et al. 2022). In terms of motivational biases, confirmation bias may have happened as our decision-makers expressed their preferences for the criteria to support their beliefs and previous strategic judgments (Montibeller and von Winterfeldt 2015). Confirmation bias can be controlled by using more decision-makers with different points of view in the same or similar companies (Montibeller and von Winterfeldt 2015).

Finally, another method could have been considered for computing the weights and ranking, for instance, AHP. However, we concluded that this was not the optimal choice for us, as there are three decision-makers present for the company and the complexity of the problem is already high. Namely, it would be quite challenging to explain exactly what information is needed from the decision makers and to conduct these elaborate interviews within the limited timeframe in which the research was conducted, as well as the limited time that the company allocated for the interviews. Moreover, AHP works with fractional numbers which can be problematic, whereas BWM uses integers (Kheybari et al. 2019).

Finally, our recommendation for FIBRAN S.A. is to build a new manufacturing unit in France. Taking into account the different scores, in case of future expansions, i.e. after expanding to France, we think that it would be beneficial to reevaluate other options again, as many of the criteria are subject to change. For instance, diesel fuel prices and the cost of electricity are quite volatile in nature, and although these criteria are not as important to FIBRAN S.A., they could still make a difference. The volatility should also be considered for this decision. This could be done by conducting a thorough financial analysis to mitigate possible (financial) risks. After all, the decision-maker should make the final choice (Brans and Mareschal 1994).

7. Conclusion

This paper investigates the application of two different Multi-criteria Decision-making (MCDM) methods, ELECTRE III and Best-Worst Method (BWM) on solving a problem of location selection in supply chain management. These methods were applied on a real-life problem, namely for a new manufacturing unit for stone wool production, by a multi-national insulation manufacturing company FIBRAN. To gather the necessary information, we conducted interviews with decision-makers, accompanied by a literature review. The method used for the generation of the weights was Linear BWM, and the ranking of the alternative countries was derived using ELECTREE III. This analysis yielded useful results that were used to formulate recommendations in form of which alternative is the most suitable for the company, according to their preferences. The alternative that was ranked as the best one was France, so this was the recommendation that was made to the company.

References

Alam, K. M. S., Wali, F. I., Hossain, S., and Wali, M. M. I. (2015) 'Use of multi-criteria decision analysis for location decision: Developing a risk reaction spectrum', *The Journal of Developing Areas*, 49(6), 505-516.

Alimoradi, A., Yussuf, R. M., and Zulkifli, N. (2011) 'A hybrid model for remanufacturing facility location problem in a closed-loop supply chain', *International Journal of Sustainable Engineering*,4(01), 16-23.

Arunyanart, S., Sureeyatanapas, P., Ponhan, K., Sessomboon, W., and Niyamosoth, T. (2021) 'International location selection for production fragmentation', *Expert Systems with Applications*, 171, 114564.

Arya, V., Garg, N., Khandekar, R., Meyerson, A., Munagala, K., and Pandit, V. (2004) 'Local Search Heuristics for k-Median and Facility Location Problems', *In Proceedings of the thirty-third annual ACM symposium on Theory of computing* (pp. 21-29).

Athawale, V. M., and Chakraborty, S. (2010) 'Facility Layout Selection Using PROMETHEE II Method', *IUP Journal of Operations Management*, 9(1/2), 81.

Best Worst Method (2022) 'BWM Solvers', available at: https://bestworstmethod.com/software/

Boutkhoum, O., Hanine, M., Agouti, T., and Tikniouine, A. (2015) 'An improved hybrid multi-criteria/multidimensional model for strategic industrial location selection: Casablanca industrial zones as a case study', *Springer Plus*, 4(1), 1-23.

Brans, J. P., and Mareschal, B. (1994) 'The PROMCALC and GAIA decision support system for multicriteria decision aid', *Decision Support Systems*, 12(4-5), 297-310.

Ceballos, B., Lamata, M. T., and Pelta, D. A. (2016) 'A comparative analysis of multi-criteria decision-making methods', *Progress in Artificial Intelligence*, 5, 315-322.

Chan, F. T. S., and Chung, S. H. (2004) 'Multi-criteria genetic optimization for distribution network problems', *The International Journal of Advanced Manufacturing Technology* 24(7), 517-532.

Chang, P. Y., and Lin, H. Y. (2015) 'Manufacturing plant location selection in logistics network using Analytic Hierarchy Process', *Journal of Industrial Engineering and Management*, 8(5), 1547-1575.

Chu, T.C. (2002) 'Selecting Plant Location via a Fuzzy TOPSIS Approach', *The International Journal of Advanced Manufacturing Technology*, 20(11), 859-864.

Chuang, P. T. (2002) 'A QFD approach for distribution’s location model', *International Journal of Quality and Reliability Management*, 19(8), 1037-1054.

de Toni, D., Sperandio Milan, G., Saciloto, B., and Larentis, F. (2017) 'Pricing strategies and levels and their impact on corporate profitability', *Revista de Administração,* 52, 120-133.

Duchemin, R., and Matheus, R. (2021) 'Forecasting customer churn: Comparing the performance of statistical methods on more than just accuracy', *Journal of Supply Chain Management Science*, 2(3-4), 115-137.

Dey, B., Bairagi, B., Sarkar, B., and Sanyal, S. K. (2017) 'Group heterogeneity in multi member decision making model with an application to warehouse location selection in a supply chain', *Computers and Industrial Engineering*, 105, 101-122.

Ertuğrul, I. (2010) 'Fuzzy Group Decision Making for the Selection of Facility Location', *Group Decision and Negotiation*, 20(6), 725-740.

Ertuğrul, I., and Karakaşoğlu, N. (2008) 'Comparison of fuzzy AHP and fuzzy TOPSIS methods for facility location selection', *The International Journal of Advanced Manufacturing Technology*, 7–8(39), 783-795.

Farahani, R. Z., SteadieSeifi, M., and Asgari, N. (2010) 'Multiple criteria facility location problems: A survey', *Applied Mathematical Modelling*, 34(7), 1689-1709.

FIBRAN (2022). Home - Fibran International. https://fibran.com/

Figueira, J. R., Greco, S., Roy, B., and Słowiński, R. (2013) 'An overview of ELECTRE methods and their recent extensions', *Journal of Multi-Criteria Decision Analysis*, 20(1-2), 61-85.

Fischer, G. W., Damodaran, N., Laskey, K. B., Lincoln, D., Fischer, G. W., Damodaran, N., Laskey, K. B., and Lincoln, D. (1987) 'Preferences for Proxy Attributes', *Management Science*, 33(2), 198-214.

Frost and Sullivan (2022) 'European Building Insulation Materials Market Driven by Energy-efficiency Targets', https://store.frost.com/european-building-insulation-materials-market-driven-by-energy-efficiency-targets.html

Global Trends in the Thermal Insulation Market (2021).available at https://www.lucintel.com/lucintelBriefFile/210702%20-%20Trends%20and%20Opportunities%20in%20the%20Thermal%20Insulation%20Market%20-%20Lucintel-07-02-2021.pdf

Global Petrol Prices (2022). Electricity prices around the world |. https://www.globalpetrolprices.com/electricity_prices/

Govindan, K., Jha, P. C., Agarwal, V., and Darbari, J. D. (2019) 'Environmental management partner selection for reverse supply chain collaboration: A sustainable approach', *Journal of Environmental Management,* 236, 784-797.

Hale, T., and Moberg, C. R. (2005) 'Improving supply chain disaster preparedness: A decision process for secure site location', *International Journal of Physical Distribution and Logistics Management*, 35(3), 195-207.

Hashemi, S. S., Hajiagha, S. H. R., Zavadskas, E. K., and Mahdiraji, H. A. (2016) 'Multicriteria group decision making with ELECTRE III method based on interval-valued intuitionistic fuzzy information', *Applied mathematical modelling*, 40(2), 1554-1564.

heritage.org. (2022) 'Index of Economic Freedom: Promoting Economic Opportunity and Prosperity by Country', https://www.heritage.org/index/

Kalantari, A.H. (2013) 'Facility Location Selection for Global Manufacturing', *Theses and Dissertations*.

International Labour Office (2011) 'A Skilled Workforce for Strong, Sustainable and Balanced Growth A G20 Training Strategy', www.ilo.org/publns

Kahraman, C., Ruan, D., and Doğan, I. (2003) 'Fuzzy group decision-making for facility location selection', *Information Sciences*, 157, 135-153.

Kallio, H., Pietilä, A. M., Johnson, M., and Kangasniemi, M. (2016) 'Systematic methodological review: developing a framework for a qualitative semi-structured interview guide', *Journal of Advanced Nursing,* 72(12), 2954-2965.

Keeney, R. L., and Gregory, R. S. (2005) 'Selecting Attributes to Measure the Achievement of Objectives', *Operations Research*, 53(1), 1-11.

Keeney, R. L., and Raiffa, H. (1979) 'Decisions with Multiple Objectives: Preferences and Value Trade-Offs', *IEEE Transactions on Systems, Man and Cybernetics*, 9(7), 403.

Kheybari, S., Kazemi, M., and Rezaei, J. (2019) 'Bioethanol facility location selection using best-worst method', *Applied Energy*, 242, 612-623.

Kirkwood, C. W. (1982) 'A Case History of Nuclear Power Plant Site Selection', *The Journal of the Operational Research Society*, 33(4), 353.

Komsiyah, S., Wongso, R., and Pratiwi, S. W. (2019) 'Applications of the Fuzzy ELECTRE Method for Decision Support Systems of Cement Vendor Selection', *Procedia Computer Science*, 157, 479-488.

Koopmans, T. C., and Beckmann, M. (1957) 'Assignment Problems and the Location of Economic Activities' *Econometrica*, 25(1), 53.

Kotler, P., Keller, K. L., Brady, M., Victor Goodman, M. R., and Hansen, T. (2019) 'Marketing management', *Soldering & Surface Mount Technology*, 13(3), 842.

Liang, F., Brunelli, M., and Rezaei, J. (2020) 'Consistency issues in the best worst method: Measurements and thresholds', *Omega*, 96, 102175.

Liang, F., Verhoeven, K., Brunelli, M., and Rezaei, J. (2021) 'Inland terminal location selection using the multi-stakeholder best-worst method', *International Journal of Logistics Research and Applications*, 1-23.

Liang, G. S., and Wang, M. J. J. (2007) 'A fuzzy multi-criteria decision-making method for facility site selection', *International Journal of Production Research*, 29(11), 2313-2330.

Lu, H., Jiang, S., Song, W., and Ming, X. (2018) 'A Rough Multi-Criteria Decision-Making Approach for Sustainable Supplier Selection under Vague Environment', *Sustainability* 10(8), 2622.

MacCarthy, B. L., and Atthirawong, W. (2003) 'Factors affecting location decisions in international operations – a Delphi study', *International Journal of Operations & Production Management*, 23(7), 794-818.

Gundogdu, C. E. (2011) 'Selection of facility location under environmental damage priority and using ELECTRE method', *Journal of Environmental Biology*, 32(2), 221-226.

Marzouk, M. M. (2011) 'ELECTRE III model for value engineering applications', *Automation in construction*, 20(5), 596-600.

Ménard, C., and Shirley, M. M. (2005) 'Handbook of New Institutional Economics', Springer.

Montibeller, G., and von Winterfeldt, D. (2015) 'Cognitive and Motivational Biases in Decision and Risk Analysis,' *Risk Analysis*, 35(7), 1230-1251.

Mousavi, S. M., Tavakkoli-Moghaddam, R, Heydar, M, Ebrahimnejad, S, Mousavi, S. M., Heydar, M., and Ebrahimnejad, S. (2013) 'Multi-Criteria Decision Making for Plant Location Selection: An Integrated Delphi-AHP-PROMETHEE Methodology', *Arabian Journal for Science and Engineering*, 38(5), 1255-1268.

Norese, M. F. (2006) 'ELECTRE III as a support for participatory decision-making on the localisation of waste-treatment plants,' *Land Use Policy*, 23(1), 76–85.

Office for National Statistics (2022) Energy prices and their effect on households - Office for National Statistics. https://www.ons.gov.uk/economy/inflationandpriceindices/articles/energypricesandtheireffectonhouseholds/2022-02-01

Pavel, C. C., and Blagoeva, D. T. (2018) 'Competitive landscape of the EU's insulation materials industry for energy-efficient buildings', PUBSY No. JRC108692 EUR, 28816.

Porter, M. E. (1990) 'The Competitive Advantage of Nations Harvard Business Review', *Harvard business review*,*73*, 91.

Precedence Research (2022). OEM Insulation Market Size, Trends, Growth, Report 2030. https://www.precedenceresearch.com/oem-insulation-market

Rahmawati, D. U., and Salimi, N. (2022) 'Sustainable and resilient supplier selection: the case of an Indonesian coffee supply chain', *Journal of Supply Chain Management Science*, 3(1-2), 16-36.

Raut, R. D., Narkhede, B. E., Gardas, B. B., and Raut, V. (2017) 'Multi-criteria decision making approach: a sustainable warehouse location selection problem', *International Journal of Management Concepts and Philosophy*, 10(3), 260.

Research and Markets. (2020). Germany Active Insulation Market https://www.researchandmarkets.com/reports/5190170/germany-active-insulation-market-2020-2026

Revelle, C. S., and Laporte, G. (1996) 'The Plant Location Problem', *Operations Research*, 44(6), 864-874.

Rezaei, J. (2015) 'Best-worst multi-criteria decision-making method', *Omega*, 53, 49-57.

Rezaei, J. (2016) 'Best-worst multi-criteria decision-making method: Some properties and a linear model', *Omega*, 64, 126-130.

Rezaei, J., Arab, A., and Mehregan, M. (2022a) 'Analyzing anchoring bias in attribute weight elicitation of SMART, Swing, and best-worst method', *International Transactions in Operational Research*.

Rezaei, J., Arab, A., and Mehregan, M. (2022b) 'Equalizing bias in eliciting attribute weights in multiattribute decision-making: experimental research', *Journal of Behavioral Decision Making*, 35(2), e2262.

Rezaei, J., Nispeling, T., Sarkis, J., and Tavasszy, L. (2016) 'A supplier selection life cycle approach integrating traditional and environmental criteria using the best worst method', *Journal of Cleaner Production*, 135, 577-588.

Rockwool. (2022). Rockwool stone wool insulation. https://www.rockwool.com/group/

Roy, B. (1978) 'ELECTRE III: Un algorithme de classements fondé sur une représentation floue des préférences en présence', de critères multiples'ELECTRE III: Un algorithme de classements fondé sur une représentation floue des préférences en présence'.

Roy, B. (1990) 'The Outranking Approach and the Foundations of Electre Methods', *Readings in Multiple Criteria Decision Aid*, 155-183.

Roy, B. (1991) 'The outranking approach and the foundations of electre methods', *Theory and Decision*, 31(1), 49-73.

Roy, B.,and Bertier. P. (1973) 'La méthode ELECTRE II – Une application au média-planning'.

Saaty, T. L. (1977) 'A scaling method for priorities in hierarchical structures', *Journal of Mathematical Psychology*, 15(3), 234-281.

Saha, R., Bose, J. C., and Gothwal, S. (2015) 'Plant location selection of a manufacturing industry using analytic hierarchy process approach', *International Journal of Services and Operations Management*, 22(2), 235-255.

Schmenner, R. W., Huber, J. C., and Cook, R. L. (1987) 'Geographic differences and the location of new manufacturing facilities', *Journal of Urban Economics*, 21(1), 83-104.

Sehra, S. K., Brar, Y. S., and Kaur, N. (2012) 'Multi Criteria Decision Making Approach for Selecting Effort Estimation Model', *International Journal of Computer Applications* 39(1).

Sevkli, M. (2009) 'An application of the fuzzy ELECTRE method for supplier selection', *International Journal of Production Research*, 48(12), 3393-3405.

Sriniketha, D., Diwakar Reddy, V., and Phaneendra, A. N. (2014) 'Plant location selection by using MCDM methods', *Journal of Engineering Research and Applications*, 4(12), 110-116.

Statista (2022) EU hourly labor cost by country 2021. https://www.statista.com/statistics/1211601/hourly-labor-cost-in-europe/

Statistics Explained. (2022). Labour cost index - recent trends -. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Labour_cost_index_-_recent_trends

Terouhid, S. A., Ries, R., and Fard, M. M. (2012) 'Towards sustainable facility location–a literature review', *Journal of sustainable development*, 5(7), 18-34.

Towhidur Rahman, S. M., and Kabir, A. (2019) 'Factors influencing location choice and cluster pattern of manufacturing small and medium enterprises in cities: evidence from Khulna City of Bangladesh', *Journal of Global Entrepreneurship Research*, 9(1), 1-26.

Tscheikner-Gratl, F., Egger, P., Rauch, W., and Kleidorfer, M. (2017) 'Comparison of Multi-Criteria Decision Support Methods for Integrated Rehabilitation Prioritization', *Water*, 9(2), 68.

Ulutaş, A., and Karakuş, C. B. (2021) 'Location selection for a textile manufacturing facility with GIS based on hybrid MCDM approach', *Industria Textila*, 72(2), 126-132.

Uysal, H. (2014) 'Selection of Logistics Centre Location via ELECTRE Method : A Case Study in Turkey',*International Journal of Business and Social Science*, 5(9)

Vassoney, E., Mammoliti Mochet, A., Desiderio, E., Negro, G., Pilloni, M. G., and Comoglio, C. (2021) 'Comparing Multi-Criteria Decision-Making Methods for the Assessment of Flow Release Scenarios From Small Hydropower Plants in the Alpine Area', *Frontiers in Environmental Science*, 9, 104.

Velasquez, M., and Hester, P. T. (2013) 'An Analysis of Multi-Criteria Decision Making Methods', *International journal of operations research*, 10(2), 56-66.

Wątróbski, J., Jankowski, J., Ziemba, P., Karczmarczyk, A., and Zioło, M. (2019) 'Generalised framework for multi-criteria method selection', *Omega*, 86, 107-124.

Weber, A., and Friedrich, C. J. (1929) 'Theory of the location of industries', *Simplifying Assumptions.*

Wu, Y., Zhang, T., Xu, C., Zhang, B., Li, L., Ke, Y., Yan, Y., and Xu, R. (2019) 'Optimal location selection for offshore wind-PV-seawater pumped storage power plant using a hybrid MCDM approach: A two-stage framework', *Energy Conversion and Management*, 199, 112066.

Yang, T., and Hung, C. C. (2007) 'Multiple-attribute decision making methods for plant layout design problem', *Robotics and Computer-Integrated Manufacturing*, 23(1), 126-137.

Yong, D. (2006) 'Plant location selection based on fuzzy TOPSIS', *The International Journal of Advanced Manufacturing Technology*, 28(7), 839-844.