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Analysis of Sustainable Supply Chain Risks: An Application in the Food Industry

Sürdürülebilir Tedarik Zinciri Risklerinin Analizi: Gıda Sektöründe Bir Uygulama

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Abstract

Limited production resources and high competition expose supply chains in the food industry to various risks. Therefore, it is crucial to manage the risks implement sustainable supply chain in the food industry. The objective of this study is to determine the importance weights of sustainable supply chain risks in the food industry (confectionery and chocolate). The results are expected to help food industry managers better manage a sustainable supply chain. In this document, the process was managed with four experts to prioritize nine sub-risk factors, including supply, demand and internal risks as the main criteria. Sub-risk factors were created with both literature review and expert opinions. BWM, one of the multi-criteria decision making methods, was used in the study. Findings show that the most important risk factors are finding sustainable suppliers and using sustainable technology. The least important risk factor in the sustainable supply chain was determined as the stock shortage due to demand change. In addition, the consistency ratio of the findings was less than 0.1, which also demonstrates the reliability of the results.

Keywords: Sustainable Supply Chain, Sustainable Supply Chain Risks, Risk Factor, BWM, MCDM.

Paper Type: Research Article

Öz

Sınırlı üretim kaynakların ve rekabetin yüksek olması gıda endüstrisindeki tedarik zincirlerini çeşitli risklerle karşı karşıya bırakmaktadır. Bu nedenle, gıda endüstrisinde sürdürülebilir tedarik zincirini uygulamak için karşılaşılan riskleri yönetmek çok önemlidir. Bu çalışmada gıda endüstrisindeki (şekerleme ve çikolata) sürdürülebilir tedarik zinciri risklerinin önem ağırlıklarının belirlenmesi amaçlanmaktadır. Sonuçların, gıda endüstrisi yöneticilerinin sürdürülebilir bir tedarik zincirini daha iyi yönetebilmesine yardımcı olması beklenmektedir. Bu belgede tedarik, talep ve iç riskler ana kriterler olmak üzere dokuz alt risk faktörünü önceliklendirmek için dört uzman ile çalışılmıştır. Alt risk faktörleri hem literatür taraması hem de uzman görüşleri ile oluşturulmuştur. Uzmanlar şekerleme ve çikolata sektöründe en az beş yıl deneyime sahip tecrübeli kişilerden seçilmiştir. Çalışmada çok kriterli karar verme yöntemlerinden biri olan BWM kullanılmıştır. Karar verici poziyonunda olan yöneticiler kriterleri ağırlıklandırmak için bulanık ortamda dilsel değişkenler kullanmış ve kriterleri sübjektif ifadelere göre değerlendirmiştir. Bulgular en önemli risk faktörlerinin sürdürülebilir tedarikçi bulma ve sürdürülebilir teknoloji kullanımı olduğunu göstermektedir. Sürdürülebilir tedarik zincirinde en düşük öneme sahip risk faktörü ise talep değişimine bağlı olarak oluşan stok sıkıntısı olarak belirlenmiştir. Ayrıca bulguların tutarlılık oranının 0.1'den düşük olması sonuçların güvenirliğini de ortaya koymuştur.

Anahtar Kelimeler: Sürdürülebilir Tedarik Zinciri, Sürdürülebilir Tedarik Zinciri Riskleri, Risk Faktörü, BWM, ÇKKV.

Makale Türü: Araştırma Makalesi

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Introduction

While firms have implemented strategies such as competitive pricing and product differentiation in traditional supply chains, there is increasing pressure to implement sustainable behaviors in today's supply chains. Increasing awareness of stakeholders, customers and government about environmental issues is forcing businesses to integrate sustainability into their supply chain management (Fritz, 2019). As supply chains become global and emerging economies grow, businesses need to become more sustainable in managing the world's resources and the environment. Sustainable supply chain differs from traditional supply chain and it implements the environmental management system (Curkovic & Sroufe, 2011).

Sustainable supply chain aims to minimize environmental damage with the supply chain partners of businesses. On the one hand, consumer awareness of environmental issues is increasing. On the other hand, sustainability is seen as an important strategy for companies to monitor long-term performance on social, environmental and economic targets (Li, Liu & Wei, 2020). Therefore, it is critical for companies to address sustainability issues in supply chain management. From this point of view, many companies are transitioning to a sustainable supply chain by adopting sustainable practices in traditional supply chain models.

A sustainable supply chain can give businesses competitive advantages such as cost savings and reduction in energy consumption by processing waste (Zhu, Sarkis, Cordeiro & Lai, 2008). These situations help companies gain more opportunities in the market and improve their performance (Abdel-Basset & Mohamed, 2020; Burki, Ersoy & Najam, 2019). However, various risks may arise in the sustainable supply chain due to market uncertainties, outsourcing and the development of advanced technologies, and this may even cause disruption of various activities (Song, Ming & Liu, 2017). There are various risk factors in supply chains, such as supply, demand, production, logistics, flexibility. The realization of risks and their consequences are often uncertain. Failure to cope with these risks results in poor performance for companies (Nazam, Xu, Tao, Ahmad & Hashim, 2015).

Sustainable supply chain management is increasingly becoming a strategic requirement for companies. In order to manage sustainable supply chain risks, companies must react quickly to uncertainties in their supply chains and use their resources correctly. Therefore, it is crucial to anticipate and manage these risks in order to fully implement the sustainable supply chain. Especially when production resources are limited, managers need to identify critical risk factors. In the literature, prioritization of risks encountered in sustainable supply chains has been studied. However, the sectors in which the studies were carried out were mostly on the automotive industry (Hudin, Hamid, Habidin & Mustaffa, 2019; Tobescu & Seuring, 2015) and the textile industry (Oelze, 2017). Research in the food industry (confectionery and chocolate) for risk management are in its infancy and, to the author's knowledge, the only study in the food industry is Abadi and Darestani (2023).

The food industry is one of the most important sectors facing significant environmental, economic, social and political challenges (Kuwornu et al., 2023; Mastos & Gotzaman, 2022). Due to the increases in the global population, the demand for different and better quality food has made the food sector more important (Molotoks, Smith & Dawson, 2020). Recently, the sustainable food supply chain has also been a major concern among stakeholders and it has contributed to the unprecedented development of management (Kuwornu et al., 2023). On the other hand, consumers began to be careful about the origin of food, production methods and whether food is environmentally friendly (Mastos & Gotzaman, 2022). For this reason, the food industry all over the world is characterized by advanced supply chain relationships aimed at achieving high sustainability performance (Beske, Land & Seuring, 2014).

The food industry is directly related to evaluating agricultural products, supplying raw materials to the industry and contributing to employment. Therefore the food industry is of strategic socio-economic importance in all countries. The food sector in Turkey is one of the sectors with the highest share in the manufacturing industry (Ministry of Industry and Technology, 2022). Many different types of products have the potential to be produced in Turkey. Many different types of products such as meat and meat products, fish varieties, milk and dairy products, bakery and bakery products, oils, chocolate and confectionery, beverages and ready-to-eat foods can be produced. Most of the raw materials in the food industry are processed as raw materials in the industry and produced in the form of packaged foods.

The first objective of this study is to determine the most common risks related to the implementation of a sustainable supply chain in the confectionery and chocolate food sector. The second aim is to prioritize or rank the identified risks. This study contributes to the literature in many ways. Although many previous studies have provided valuable insight into the risk factors of traditional supply chain management, less attention has been paid to analyzing risks in the context of sustainable supply chains. On the other hand, traditional risk assessment methodologies assume that risk factors have the same importance (Can & Toktas, 2018). Determining the importance weights of these risks is seen as the most important issue of the sustainable supply chain (Moktadir, Dwivedi, Khan, Paul & Khan 2021). This study contributes to the limited literature by dynamically combining expert opinions with multi-criteria decision making and determining the importance weights of risks. Finally, the most important limitation of the study is at the point of data collection. It is very difficult to reach businesses that implement or plan to implement a sustainable supply chain in the food industry. In addition, the narrowing of the application in the confectionery and chocolate sector is effective in this situation.

This document first provides a theoretical background on sustainable supply chain risks and their management. In the next section, the steps of the BWM (Best Worst Method) used in the study are explained. In the application part of the study, the evaluations of the decision criteria made by the experts are analyzed by the BWM and the results are given. In the last part, the results are discussed and suggestions are made for researchers who are interested in the subject.

1. Theoretical Background

Supply chain risks are one of the important issues that have been studied especially in recent years (Chen, 2018). However, it is said that the issues that supply chain risks and sustainability are studied together have received little attention by researchers (Abdel-Basset & Mohammed, 2020; Rostamzadeh, Ghorabaee, Govindan, Esmaeili & Noba, 2018; Syed, Li, Junaid, Ye & Ziaullah, 2019). It is important to define and understand the risks correctly, as these risks can affect the performance of the firm. Businesses' ignoring risk management can lead to failure. Therefore, it is important for organizations to evaluate risk factors (Cervantes-Cabrera & Briano-Turrent, 2018). Deciding on the most important risks plays a necessary role in the industry.

A risk factor is considered to be the uncertainty and unexpected situation related to the occurrence of any event (Gurnani, Mehrotra & Ray, 2012). Uncertainties in the evaluation process are one of the biggest problems that decision makers can face. Identifying risks in a sustainable supply chain is the first step in identifying all the risks of a sustainable supply chain. A team of experts, senior engineers and supply chain managers from different departments of a company perform to identify relevant risk factors (Prakash et al., 2022).

Sustainable supply chain risks are related to events that affect companies economically, socially and environmentally (Giannakis & Papadopoulos, 2016; Zarbakhshnia, Govindan, Kannan & Goh, 2022). At the top of the economic risks are factors such as decreased market share (Afgan & Carvalho, 2004), loss of reputation or brand damage (Abadi & Darestani, 2023; Sodhi, Son & Tang, 2012) and price and cost fluctuations (Tang & Musa, 2011). In economic terms, firms should determine their competitors by controlling costs and price fluctuations and they try not to lose their market share (Abadi & Darestani, 2023). Environmental risks, one of the second largest risk types, are one of the important areas of sustainable supply chain. Purchasing, operations and implementing services in a sustainable supply chain are quite complex. Each of these processes requires environmental commitment. Environmental pollution (Blackburn, 2007), packaging waste (Atherton, 2011), inefficient use of resources (Diesendorf, 2007), hazardous waste generation (Dües, Tan & Lim, 2013), energy use (Atherton, 2011) and CO^2 emissions are among the main environmental risks. Another risk class is defined as social risks. Social risks are often caused by human rights violations (Clift, 2003), failing to fulfill social commitment (Maloni & Brown, 2006), dangerous and unhealthy working environment (Halldórsson, Kotzab & Skjøtt-Larsen, 2009), unfair wages, employment policies (contract, insurance policies) (Abadi & Darestani, 2023).

Sustainable supply chain risk factors have been a topic. It has been addressed in many different ways in current studies. There are constant risks at different levels of the supply chain, such as the supply of materials, the production process and distribution. In the literature, it is seen that many researchers group risk factors in different ways. In addition, in the literature, the main risk factors related to the supply chain have been defined by researchers such as Chopra and Sodhi (2004); Cagliano, De Marco, Grimaldi and Rafele, (2012); Govindan and Fattahi (2017); Prakash, Kumar, Soni, Jain and Rathore, (2020); Soni and Kodali (2013). Chopra and Sodhi (2004) defined risks as system risks such as supply disruption, supply delay, price fluctuations, demand fluctuations, exchange rate fluctuations, deterioration of information infrastructure, forecast risks due to inaccuracies, supply and inventory risks, capacity risks, and intellectual property risks. Cagliano et al. (2012) defined risks within the class of internal risks, strategic, tactical, operational, and within the class of external risks, catastrophic, economic, social, political, legal, cultural, industrial risks. Zhao, Huo, Sun and Zhao (2013) classified supply chain risk into three categories: internal risks, supply-based risks, and demand-driven risks. Internal risks are risks that occur within the firms themselves. Sustainable supply risks and sustainable demand risks are external risks. Aqlan and Lam (2015) classified risks as supplier risks, customer risks, process and control risks, technology risks, product risks, occupational risks, culture risks, transportation risks, stock risks. Rogers, Srivastava, Pawar and Shah (2015) examined risks as cultural, operational, infrastructure, economic, forecasting and supplier-related risks.

In general classifications, risks are separated as supply risk, process risk and demand risk. Problems arising from supply concern both companies and customers. For this reason, supply risks are very critical and important for businesses. Supply risks can be evaluated in terms of availability of materials (Prakash et al., 2022), supplier delivery delays (Abadi & Darestani, 2023; Ortegoli & Ghadim, 2016; Rostamzadeh et al., 2018) and poor quality at the source of supply (Abadi & Darestani, 2023; Nazam et al., 2015; Ortegoli & Ghadim, 2016; Rostamzadeh et al., 2018; Tummala & Schoenherr, 2011). In addition, supply risks include the flexibility of supply sources (Kumar Sharma & Bhat, 2014), information sharing risks (Dubey et al., 2017), supplier financial instability (Rostamzadeh et al., 2018), supplier uncertainty/lack of appropriate supplier selection (Abadi & Darestani, 2023; Luthra, Garg & Haleem, 2015; Rostamzadeh et al., 2018; Song et al, 2017) can be given as examples. In the sustainable supply chain, it is vital to find especially sustainable suppliers. Selection of the right suppliers is important in providing raw materials on time and at appropriate quality. Choosing suppliers with better sustainability performance on social, environmental and economic goals plays a major role (Jharkharia & Shankar, 2007).

Demand risks are also an important issue in a sustainable supply chain. The main demand risks include the inability of businesses to respond quickly to changes in demand (volume, variety, location) and with reasonable cost (Simchi-Levi, 2010), demand uncertainty that causes unexpected or incorrect demand forecasts (Tang & Musa, 2011) are important demand risks. In addition, stock shortages and market price uncertainties due to demand changes (Zhao et al., 2013) can be shown as the main demand risks.

All identified risks are critical to a business. Because the risks that arise in the supply chain will cause the production process to deteriorate (Kosasih & Brintrup, 2021). The robustness of the supply chain can only be achieved through the reduction of uncertainty and the implementation of activities that limit the occurrence of risks. Sustainable supply chain risk management is recommended as a holistic approach for risk management that requires the supply chain to be durable, robust or agile (Andrea & Wallenburg, 2012). The main tasks of risk management in the supply chain are to identify all risks in the production cycle, analyze risks, control, track and provide solutions for accountability (Rostamzadeh et al., 2018). Risk management in sustainable supply chains also helps companies be more confident in their performance. Firms need to develop operational approaches such as risk avoidance, risk transfer, risk mitigation or risk acceptance to manage supply chain risk (Syed et al., 2019). However, after identifying the risks, determining the importance weights of the risks is necessary for the management of a sustainable supply chain.

2. Method

In this study, multi-criteria decision making technique is used to determine the importance weights of sustainable supply chain risk factors. In recent years, multi-criteria decision making techniques have been used frequently for applications in different sectors within supply chain risk management. In a study published by Wang, Chan, Yee and Diaz-Rainey (2012), Fuzzy AHP (Analytical Hierarchy Process) method was used to evaluate supply chain risks in the fashion industry. The fuzzy AHP method was also used in the studies of Ganguly and Guin (2013), Mangla, Kumar and Baru (2015) for a similar purpose. The DEMATEL (The Decision Making Trial and Evaluation Laboratory) method, which is one of the multi-criteria decision-making methods, was included in the studies of Rajesh and Ravi (2015), Su et al. (2016) and Song et al. (2017), which were also made for risk assessment. The studies of Su et al. (2016) and Song et al. (2017) were prepared directly on sustainable supply chain risks. Junaid et al. (2020) used both the Analytical Hierarchy Process and the TOPSIS (Technique For Order Preference By Similarity To An Ideal Solution) method for risk research in the auto industry field. Risk assessment studies with fuzzy TOPSIS were conducted by Samvedi, Jain and Chan (2013) and Prakash et al. (2022). Finally, Moktadir et al. (2021) used the BWM approach, while Wang, Lin, Fu and Wang (2022) used the VIKOR approach.

In this study, BWM, one of the multi-criteria decision-making methods, was preferred for the evaluation of sustainable supply chain risk factors. There are many important reasons for choosing the method. One of these reasons is to have a basically structured data collection method. Secondly, since there are nine criteria in the application, the method can provide high efficiency according to the amount of data. In addition, other important reasons are that the method is user-friendly due to the ease of operation and especially the ability to calculate the consistency of the analysis results. In this way, the concern about the reliability of the study results can be eliminated.

BWM was first developed in 2015 by Razaei. The BWM method is a widely used method to improve the consistency ratio by showing precise values and allowing less pairwise comparisons (Rezaei, Wang & Tavasszy, 2015). BWM method gives more reliable results than methods such as AHP, Analytic Network Process (ANP) and Simple Multi-Attribute Rating Technique (SMART) (Rezaei, 2015). The BWM, which is used in the weighting of the criteria, is based on a systematic comparison between the best criterion and other criteria, and between the worst criterion and other criteria. This method is much easier, more precise and eliminates unnecessary comparisons (Akbari et al., 2021).

The steps of the method are as follows (Razei, 2015), (van de Kaa, Fens & Rezaei, 2019):

1. Stage: Determine the criteria (C_j) for decision analysis.

2. Stage: Identify the most important/best criterion and the least desirable/worst criterion together. The values of the criteria are not taken into account at this stage and no comparison is made.

3. Stage: Prioritize the best criterion using a 1 to 9 pairwise comparison scale (see Table 1). (Here 9 indicates that best is most preferred over the other criterion.)

$A_{(best)}=(\alpha_{(best(1))}, \alpha_{(best(2))},\ldots, \alpha_{(best(n))})$

4. Stage: Express the worst preference for all criteria using a 1 to 9 pairwise comparison scale (see Table 1). (Here 9 indicates that the criterion is least preferred.)

$A_{(worst)}=(\alpha_{(worst(1))}, \alpha_{(worst(2))},\ldots, \alpha_{(worst(n))})$

Table 1. Pairwise comparison scale with BWM

Important Level	Explanation
1	Equally important
2	Equally moderately important
3	Moderately more important
4	Moderately much more important
5	Strongly important
6	Very important as strong
7	Important as very strong
8	More important as very strong
9	Quite very important

Reference: Rezaei, 2015

5. Stage: Calculate the optimum weights. Optimal weights can be obtained by solving the linear optimization problem, which finds the weights for which the maximum deviation of pairwise comparisons and their corresponding weight ratios (for all j's) are minimized.

Min ξ

$|w_{(best)} - \alpha_{(best(j))} \cdot w_j| \leq \xi$ and $\forall_j$ (1)

$|w_j - \alpha_{jw} \cdot w_{(best(j))}| \leq \xi$ and $\forall_j$ (2)

$\Sigma_{j=1}^{n} w_j = 1$ (3)

$w_j \geq 0$

$w_{(best)}$ shows the relative weight of the best criterion, $w_{(worst)}$ shows the relative weight of the worst criterion.

6. Stage: The optimal weights and the optimal objective function value, which are defined as the consistency indicator of the binary comparison system, are found. This step is to check the consistency of the comparisons and to see if the results are reliable. The consistency value, which is close to zero, shows that the pairwise comparison system has consistent and reliable results. The Consistency Index (CI) values used in BWM are given in Table 2.

Table 2. CI values used in BWM

a_{BW}	1	2	3	4	5	6	7	8	9
CI	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

Reference: Rezaei, 2015

The Study Consistency Ratio (CR) is calculated using ξ and CI as follows:

Consistency ratio(CR)= ξ / Consistency Index(CI) (4)

In general, if the consistency ratio is ≤ 0.1, this value shows that the obtained vector is acceptable.

3. Implementation

This section includes the implementation of BWM to assess sustainable supply chain risks in the food industry. In the study, a total of 14 criteria were evaluated by four experts.

3.1. Deciding on Criteria

The criteria in this study were decided by making use of expert opinions and previous studies in the literature. Firstly, the classification made for the sustainable supply chain by Zhao et al. (2013) was taken into consideration in the selection of the criteria. Three main risk classes were used in the study; internal risks, supply risks and demand risks. The adaptation of Zhao's study to the sustainable supply chain was carried out by Syed et al. (2019). Syed's study used a total of 14 criteria. However, Syed et al. was interested in the "green" factors. However, the criteria used by Syed with the theme of "green" were adapted to "sustainable" in this study. From this point of view, seven criteria in Syed's study were used for this study. These criteria are "finding sustainable suppliers", "supplier quality issues for sustainable raw materials", "major changes in demand for sustainable products", "out of stock due to demand changes", "market price decline uncertainties", "sustainable package design" and "long delivery times due to sustainable process". The sector in which the research was conducted and the opinions of experts working in these sectors were particularly effective in selecting the criteria. Interviews with experts took place in the form of group discussions based on brainstorming. In line with expert opinions, the "supplier price increase for sustainable raw materials" (C_{13}) and "use of sustainable or green technology" (C_{31}) criteria were included in the study.

In this study, there are three risks in the internal risks class, three risks in the demand risks class and three risks in the supply risks class. From this point of view, there are a total of nine criteria in this study.

C_1 (Supply Risks):

C_{11}: Finding sustainable suppliers

C_{12}: Supplier quality issues for sustainable raw materials

C_{13}: Supplier price increase for sustainable raw materials

C_2 (Demand Risks):

C_{21}: Major changes in demand for sustainable products

C_{22}: Out of stock due to demand changes

C_{23}: Market price decline uncertainties

C_3 (Internal risks):

C_{31}: Use of sustainable or green technology

C_{32}: Sustainable package design

C_{33}: Long delivery times due to sustainable process

3.2. Deciding on Experts

Evaluations from the experience of experts in fuzzy environments are very practical and useful. In this study, experts working in the confectionery and chocolate industry were interviewed to assess the critical risks in sustainable food supply chain. Since the employees in the managerial position in the sector can reach this position after having at least 5 years of experience, the selected people are experienced people in the sector. Two of the decision makers have been working full-time in the relevant sector for 5 years, one for 7 years and one for 10 years. Experts were expected to evaluate “sustainable supply chain risks” on the prepared form. Experts evaluated the criteria according to subjective expressions using linguistic variables in a fuzzy environment.

3.3. Results

In the traditional risk assessment procedure, risk factors are evaluated predictively before the risk occurs. It is difficult to give direct numerical values to risk factors in real applications. For this reason, they use linguistic variables such as "more important, much more important or less important" rather than numerical values in the assessment of risks. In this study, the implementation was carried out by experts using linguistic variables. The analysis of the evaluations made by the experts was carried out with BWM. It is based on linear programming model based on BWM. In this study, the findings were easily obtained by placing the criteria in the cells on Microsot Excel, entering the preference levels made by the decision makers (according to Table 1), and writing the related equations (Equations 1, 2 and 3) with the help of the solver.

Initially, all decision criteria were listed for experts to evaluate. Then, each of the expert determined the best criterion and then the worst criterion and compared it with the other criterion, which is binary. Table 3 shows the comparisons made by the decision-making group according to the best criteria. The scale shown in Table 1 was used for these comparisons.

Table 3. Evaluation chart by best criterion

Experts	The Best	C_{11}	C_{12}	C_{13}	C_{21}	C_{22}	C_{23}	C_{31}	C_{32}	C_{33}
E_1	C_{31}	2	7	5	4	9	5	1	5	7
E_2	C_{11}	1	9	4	5	7	4	2	5	6
E_3	C_{11}	1	8	5	4	9	4	3	7	5
E_4	C_{31}	2	7	4	6	9	5	1	5	6

According to Table 3, while the first and fourth decision makers considered the green technology criterion to be the most important, the other two decision makers stated the finding sustainable suppliers criterion as more important than the others.

After this step, each of decision maker compared the criteria just as in the previous step. However, the biggest difference here is that they decided on the worst criterion first and they compared the criteria accordingly (Table 4). The experts made the comparison in line with the scale shown in Table 1.

Table 4. Evaluation table by worst criterion

	E_1	E_2	E_3	E_4
Criteria	The worst:C_{22}	The worst:C_{12}	The worst:C_{22}	The worst:C_{22}
C_{11}	7	9	9	8
C_{12}	2	1	2	2
C_{13}	3	4	3	4
C_{21}	5	3	4	3
C_{22}	1	2	1	1
C_{23}	3	4	4	3
C_{31}	9	7	4	9
C_{32}	3	3	2	3
C_{33}	2	2	3	2

According to Table 4, the criterion, which is seen as less important than the others, is seen as stock shortage due to demand changes. In addition, an even more unimportant criterion for one of the experts was supplier quality issues for sustainable raw materials. After the pairwise comparison of the worst criterion with all other criteria was completed, the final weights of the criteria were calculated. For this purpose, a model was established for the Simple LP method with the help of solver parameters in Excel. Weight values were calculated separately for each decision maker. For example, Figure 1 shows the Excel program output of Expert 1.

Figure 1. Program inputs and outputs in Excel (for E_1)

Criteria Number = 9	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	Criterion 7	Criterion 8	Criterion 9
Names of Criteria	C_{11}	C_{12}	C_{13}	C_{21}	C_{22}	C_{23}	C_{31}	C_{32}	C_{33}

Select the Best	C31
Select the Worst	C22

Best to Others	C11	C12	C13	C21	C22	C23	C31	C32	C33
C31	2	7	5	4	9	5	1	5	7

Others to the Worst	C22
C11	7
C12	2
C13	3
C21	5
C22	1
C23	3
C31	9
C32	3
C33	2

Weights	C11	C12	C13	C21	C22	C23	C31	C32	C33
	0,1945582	0,0555881	0,0778233	0,0972791	0,0307197	0,0778233	0,332797	0,0778233	0,0555881

Input-Based CR	**0,0694444**	The pairwise comparison consistency level is acceptable
Associated Threshold		

The simple LP model was the same for every decision maker. The program was run separately for all decision makers. Simple LP model in Excel solver:

Min \$C\$26

\$C\$32: \$K\$33 ≤ \$C\$26

\$C\$35: \$K\$36 ≤ \$C\$26

SUM(C24:K24)= 1

\$C\$24: \$K\$24≥ 0   (The model was set up this way.)

In order to express the equations more clearly, the following equations have been established as an example.

\$C\$26 = ξ,

\$C\$32=IF(\$C\$10=1;\$C\$24;IF(\$D\$10=1;\$D\$24;IF(\$E\$10=1;\$E\$24;IF(\$F\$10=1;\$F\$24;IF(\$G\$10=1;\$G\$24;IF(\$H\$10=1;\$H\$24;IF(\$I\$10=1;\$I\$24;IF(\$J\$10=1;\$J\$24;IF(\$K\$10=1;\$K\$24)))))))))-C10*C24

\$D\$32=IF(\$C\$10=1;\$C\$24;IF(\$D\$10=1;\$D\$24;IF(\$E\$10=1;\$E\$24;IF(\$F\$10=1;\$F\$24;IF(\$G\$10=1;\$G\$24;IF(\$H\$10=1;\$H\$24;IF(\$I\$10=1;\$I\$24;IF(\$J\$10=1;\$J\$24;IF(\$K\$10=1;\$K\$24)))))))))-D10*D24

\$E\$32=IF(\$C\$10=1;\$C\$24;IF(\$D\$10=1;\$D\$24;IF(\$E\$10=1;\$E\$24;IF(\$F\$10=1;\$F\$24;IF(\$G\$10=1;\$G\$24;IF(\$H\$10=1;\$H\$24;IF(\$I\$10=1;\$I\$24;IF(\$J\$10=1;\$J\$24;IF(\$K\$10=1;\$K\$24)))))))))-E10*E24 etc.

\$C\$33 = -C32, \$D\$33 = -D32, \$E\$33 = -E32 etc.

\$C\$35=C24-\$C13*IF(\$C\$13=1;\$C\$24;IF(\$C\$14=1;\$D\$24;IF(\$C\$15=1;\$E\$24;IF(\$C\$16=1;\$F\$24;IF(\$C\$17=1;\$G\$24;IF(\$C\$18=1;\$H\$24;IF(\$C\$19=1;\$I\$24;IF(\$C\$20=1;\$J\$24;IF(\$C\$21=1;\$K\$24)))))))))

D35==D24-$C14*IF($C$13=1;$C$24;IF($C$14=1;$D$24;IF($C$15=1;$E$24;IF($C$16=1;$F$24;IF($C$17=1;$G$24;IF($C$18=1;$H$24;IF($C$19=1;$I$24;IF($C$20=1;$J$24;IF($C$21=1;$K$24)))))))))

E35=E24-$C15*IF($C$13=1;$C$24;IF($C$14=1;$D$24;IF($C$15=1;$E$24;IF($C$16=1;$F$24;IF($C$17=1;$G$24;IF($C$18=1;$H$24;IF($C$19=1;$I$24;IF($C$20=1;$J$24;IF($C$21=1;$K$24))))))))) etc.

C36 = -C35, D36 = -D35, E36 = -E35 etc.

The outputs of the problem modeled with linear programming were obtained with the Excel program solver. These data are shown in Table 5.

Table 5. Weights and Consistency Ratios of Criteria

	C_{11}	C_{12}	C_{13}	C_{21}	C_{22}	C_{23}	C_{31}	C_{32}	C_{33}	CR	
E_1	0.194	0.055	0.077	0.097	0.030	0.077	0.332	0.077	0.055	0.069	
E_2	0.331	0.032	0.093	0.074	0.053	0.093	0.186	0.074	0.062	0.041	
E_3	0.360	0.050	0.080	0.100	0.035	0.100	0.134	0.057	0.080	0.083	
E_4	0.194	0.055	0.097	0.064	0.031	0.077	0.335	0.077	0.064	0.041	
W_j	0.270	0.048	0.087	0.083	0.037	0.087	0.247	0.071	0.065	0.059	$\sum \cong 1.0$
Rank	1	8	3	5	9	4	2	6	7		

Table 5 shows the weight value of each criterion and the consistency rates according to the evaluations made by decision makers. The values in the table were reached with the solver of the Excel Program. According to Table 5, the consistency rate of the first decision maker was 0.069, the consistency rate of the second and fourth decision makers was 0.041, and the consistency rate of the third decision maker was 0.083. Finally, the final consistency rate of the study was 0.059. These data indicate that the weight values of the risk factors in the study can be trusted. Because the rates are consistent.

Conclusion and Evaluation

Industries must recognize potential risk factors and threats in the business environment to improve their sustainability practices. Supply chain risks have a significant impact on the short and long-term performance of businesses. These risks need to be managed effectively in order to reduce the possible performance losses.

This study is an attempt to identify a comprehensive assessment of sustainable supply chain risk factors, considering the state of the food industry. The critical importance of this study is that it can reveal different findings since the application was conducted in a specific area of the food industry. Because the prioritization of sustainable supply chain risks has only been studied a few times in the food industry. Based on the literature review and experts reviews, nine critical risk factors were identified. The suitability of nine risk factors for sustainability was provided by experts.

The risk factors identified for the successful execution of sustainable supply chain management practices were divided into three groups as supply, demand and internal risks. Supply risks in the study were determined as finding sustainable suppliers, supplier quality problems for sustainable raw materials and supplier price increase for sustainable raw materials. Demand risks were determined as large changes in the amount of demand for sustainable products, stock shortage due to demand changes, and market price decline uncertainties. Finally, internal risks were long delivery times due to sustainable process, sustainable use of technology and sustainable package design. The BWM was applied to evaluate the importance of each relevant risk factor in order to decide on the most important criteria. It is important that the method is user-friendly and gives consistent results.

When the findings obtained from the study are evaluated; finding sustainable suppliers, one of the supply risks, is seen as the most important risk. The risk of finding sustainable suppliers is the most critical risk with a value of 0.270, in other words, with a rate of 27% among the total risks. This result shows that sustainable supplier selection is the most obvious risk factor for sustainable supply chain. Initiatives that increase the sustainability performance of suppliers are becoming increasingly important for the supply chain risk management of enterprises (Fan, Xiao, Zhang & Guo 2021). Because supplier selection plays an important role in achieving the social, environmental and economic benefits of sustainable supply chain management. (Luthra et al., 2015; Song et al., 2017). For this reason, supplier selection should always be evaluated in the risk management and it should ultimately be rated as a decision-making tool (Tavakoli Haji Abadi & Avakh Darestani, 2023).

The second most important risk criterion has resulted in the use of sustainable or green technology, which is one of the internal risks. The risk of using sustainable technology is the second most critical risk with a value of 0.247, in other words with an average of 25% among the total risks. According to this result, clean technology strategies should be considered in order to design a sustainable supply chain. From this point of view, it can be stated that the interviewed experts are also in this awareness. Adopting green technology is often more costly than non-green technologies, and this situation challenges emerging businesses (Fathollahi-Fard et al., 2021). Even the presence of such an effect may be influential in experts' opinion of being one of the most critical risks. In many studies in the literature, the weakness of green technology systems is seen as one of the most important risks that organizations should consider (Chaleshigar Kordasiabi, Gholizadeh, Khakifirooz & Fathi, 2023; Ozkan-Ozen, Sezer, Ozbiltekin-Pala & Kazancoglu 2022; Rostamzadeh et al., 2018; Xu & Zhan, 2021).

The third and fourth criteria with the highest weighting of sustainable supply risks are in the same weight ratio. One of them is supplier price increase for sustainable raw material. The other is market price decline uncertainties from demand risks. These two criteria have a weight of 0.087 and they have a lower weight ratio compared to the other two criteria. What is remarkable for the two criteria is that they are related to the economic dimension. Both market uncertainty and price change of suppliers are very important on the economic power of the businesses. The economic uncertainty that businesses face can be a cause for concern in many ways. In the literature, economic risks have an important place in studies where sustainable supply chain risks have been evaluated. Many researchers indicate that economic risks are among the dominant risks (Abadi & Darestani, 2023; Alshehri, Jun, Shah & Solangi, 2022; Elmsalmi, Hachicha & Aljuaid, 2021; Ozkan-Ozen et al., 2022;). On the other hand, two of the first four risks are demand risks. This result shows that the risk group that businesses in the food sector are most concerned about is demand risks.

When the other criteria are examined, the big changes in the amount of demand for sustainable products and sustainable package design are among the criteria with the highest weight. Major changes in demand for sustainable products are also seen as one of the important risk factors. It is important for businesses to balance supply and demand. Businesses that achieve this can expand into new markets, increase revenues and gain momentum for sustainable economic performance (Piprani, Jaafar, Ali, Mubarik & Shahbaz, 2022).

As a result of the evaluations of the experts, the sustainable packaging risk has a share of 7.1% in the total of the sustainable supply chain risks. Currently, food packaging constitutes the largest share (85%) in the total packaging industry (Silva, Dourado, Gama & Poças, 2020). This is a very high rate. Product packaging is one of the most critical components of the food industry. The purpose of product packaging is to protect foods in a cost-effective manner until the products reach consumers, complying with legal requirements (Sangroniz et al., 2019). The food industry demands environmentally friendly packaging materials with improved physical and mechanical properties, and the use of unsustainable materials raises environmental concerns (Silva et al., 2020). Sustainable packaging practices generally have positive consequences for supply chain sustainability performance (Zailani, Jeyaraman, Vengadasan & Premkumar, 2012). For this reason, the industry is trying to develop renewable and sustainable alternatives with competitive features (Mondal, 2018). On the other hand, consumers expect and demand sustainable packaging materials that will reduce the environmental problems associated with plastic waste (Omerović et al., 2021). Businesses are also trying to improve their packaging in this direction.

The criterion with the lowest weight, with a weight ratio of 0.037, is that the enterprise has stock shortages due to demand changes. In other words, the situation that the experts consider the least important in terms of sustainable supply chain risks is the stock problem. This is similar to the study findings of Dang and Chang (2023). Although the immediate stock holding strategy is often recommended in this study, it is not always preferred to reduce the negative impact of demand changes (Dang & Chang, 2023). According to the findings of our study, businesses in the food sector do not have stock concerns.

Finally, it can be said that the criterion weight values expressed so far are reliable. Because it is seen that the consistency rate in the findings is 0.059 (see Table 5). As can be seen, the consistency rate is below the 0.1 limit in the evaluations made by four experts. These ratios are a measure of the consistency of results. For this reason, it can be stated that the research findings are valid.

It is important that the study was applied in the food industry. However, the implementation is possible to repeat the application both in different sectors and in different sub-business lines of the food sector by using the relevant criteria. For researchers who are interested in this field, the study can be repeated in different business areas. In addition, the study can be enlarged by adding different demand, supply and internal criteria apart from the nine criteria used in the study. On the other hand, researchers can carry out different implementations by including different environmental criteria such as energy, water consumption and CO_2 emission, which are not included in this study. If this is the case, it is likely that the study will make different contributions.

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ETİK ve BİLİMSEL İLKELER SORUMLULUK BEYANI

Bu çalışmanın tüm hazırlanma süreçlerinde etik kurallara ve bilimsel atıf gösterme ilkelerine riayet edildiğini yazar(lar) beyan eder. Aksi bir durumun tespiti halinde Afyon Kocatepe Üniversitesi Sosyal Bilimler Dergisi'nin hiçbir sorumluluğu olmayıp, tüm sorumluluk makale yazarlarına aittir. Yazarlar etik kurul izni gerektiren çalışmalarda, izinle ilgili bilgileri (kurul adı, tarih ve sayı no) yöntem bölümünde ve ayrıca burada belirtmişlerdir.

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