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A DECISION MODEL FOR THE ASSESSMENT OF ENVIRONMENTAL SUSTAINABILITY RISKS OF THE AUTOMOTIVE INDUSTRY[1]

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ABSTRACT

The automotive industry is increasing its competitive power by undergoing more and more technological and digital changes every day. Along with this competitiveness, the concepts of sustainability, ethics, and reputation come to the fore. Sustainability includes social, economic, and environmental issues that meet all the needs of future generations and use limited resources efficiently. In this study, the environmental and sustainable supply chain risks of the automotive industry are examined through automotive industry reports, expert opinions, and a literature review. After nine risks were identified, 14 alternatives were developed to prevent them. In the study, a multi-level risk assessment method using Failure Modes and Effects Analysis and Entropy-based EDAS method was introduced and an application was carried out in the automotive sector. According to the entropy-based EDAS method, the most important alternative has been "The top management's determination of sustainability commitments and targets".

Keywords: *Supply Chain, Sustainability, Risk Analysis, FMEA, EDAS, Multi-Criteria Decision Making.*

JEL lassification: *D7, D81, K32, Q01, Q2.*

OTOMOTİV SEKTÖRÜNÜN ÇEVRESEL BOYUTTAKİ SÜRDÜRÜLEBİLİRLİK RİSKLERİNİN DEĞERLENDİRİLMESİNE YÖNELİK BİR KARAR MODELİ[2]

ÖZET

Otomotiv sektörü her geçen gün daha fazla teknolojik ve dijital değişime uğrayarak rekabet gücünü artırmaktadır. Bu rekabet gücü ile birlikte sürdürülebilirlik, etik ve itibar kavramları ön plana çıkmaktadır. Sürdürülebilirlik, gelecek nesillerin tüm ihtiyaçlarını karşılayan ve sınırlı kaynakları verimli kullanan sosyal, ekonomik ve çevresel konuları içermektedir. Bu çalışmada, otomotiv

[1] Bu çalışma doktora tezinden üretilmiştir.

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sektörünün çevresel ve sürdürülebilir tedarik zinciri riskleri, otomotiv sektörü raporları, uzman görüşleri ve literatür taraması yoluyla incelenmiştir. Dokuz risk belirlendikten sonra bunları önlemek için 14 alternatif geliştirildi. Çalışmada Hata Türleri ve Etkileri Analizi ve Entropi tabanlı EDAS yöntemi kullanılarak çok düzeyli bir risk değerlendirme yöntemi tanıtılmış ve otomotiv sektöründe bir uygulama gerçekleştirilmiştir. Entropi tabanlı EDAS yöntemine göre, en önemli alternatif, "Üst yönetimin sürdürülebilirlikle ilgili taahhüt ve hedeflerini belirlemesi" olmuştur.

Anahtar Kelimeler: *Tedarik Zinciri, Sürdürülebilirlik, Risk Analizi, HTEA, EDAS, Çok Kriterli Karar Verme.*

JEL Sınıflandırması: *D7, D81, K32, Q01, Q2.*

1. INTRODUCTION

The concept of sustainability was the focus of the Brundtland Report published in 1987 by the World Commission on Environment and Development (WCED, 1987) under the Kyoto Protocol. Sustainability according to WCED; It is an interdisciplinary approach that examines social, environmental and economic dimensions (Brundtland et al., 1987). Sustainability is about fulfilling the current generation's requirements without undermining the future generations' needs while also striking a balance between economic progress, environmental protection, and social well-being. A sustainability risk refers to an occurrence or situation related to the environment, society, or governance that might cause a negative impact, either currently or in the future. Sustainability risks includes risk factors associated with the social, environmental and economic aspects of sustainability. There are many studies and different methods applied regarding sustainability risks. Bathrinath et al. (2022), Huang et al. (2020), Torres-Ruiz and Ravindran (2018), Awasthi et al. (2018), and Oduoza (2020) investigated sustainability risks by considering the AHP method or the hybrid AHP method. Liu et al. (2020) discussed the risk assessment method related to the smart logistics ecological chain by using the TOPSIS method. Trubetskaya et al. (2021), Giannakis and Papadopoulos (2016), Valinejad and Rahmani (2018), Bai et al. (2017) discussed the sustainability risk with the method of failure mode and effects analysis (FMEA). Ak and Türedi (2022) conducted a research on the Turkish banking sector for the evaluation of corporate sustainability reports. In the application area, they used the TOPSIS method, which is one of the decision-making methods.

The environmental dimension is undoubtedly the most extensively studied area among all aspects of sustainability. Joyce and Paquin (2016) listed the following as objectives under the environmental dimension: to create a healthy environment for people, to protect natural resources, to ensure that resources are used in a way that does not harm the environment, to produce as little waste as possible, and to use resources at a minimum level. Environmental sustainability has become increasingly important in the automotive industry, which is an important part of the global industry. For this reason, it is clear that global environmental problems will become important for the automotive industry in the future and will have a great impact. Petroleum products are used in 96% of the world's transportation systems. Today, 1,696.6 billion barrels of oil are used in the world. As of 2021, there are a total of 25,249,119 cars and trucks registered in Turkey (TUIK, January 26 2022). As the number of cars on the roads and the amount of oil used increase, the need for fuel, material needs, and air pollution will also increase. It is therefore important to make major changes in how cars around the world affect the environment so that the automotive industry can be used without harming the environment. With these changes, it has become commonplace for business leaders and design engineers in the automotive industry to try new things (McAuley, 2003).

The main purpose of this study is to determine the most important environmental risks and risk measures faced by the automotive industry in the supply chain. In the study, after determining the environmental sustainability risks and measures, Failure Mode and Effects Analysis (FMEA), which is one of the risk assessment method, was used and a risk-based decision model developed for prioritizing environmental sustainability risks in the automotive industry.

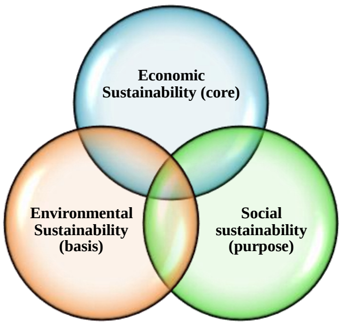
The study analyzed the environmental sustainability risks and risk measures associated with the automotive industry. The opinions of five experts from a major logistics company in Turkey and an extensive literature review were used to identify these risks and measures. The necessary precautions for the risks are explained in detail. The FMEA method was utilized to determine the levels of risks after analyzing the probability and severity of each risk with the help of experts. This method was chosen for the study owing to its capability of identifying risk levels, analyzing system functionality, and its adaptability across various industries. The developed decision model includes the evaluation of the measures of these risks with the EDAS method, taking into account the highest priority risks obtained as a result of the FMEA method. The study presented a technique to assess risks at multiple levels by employing Failure Modes and Effects Analysis and EDAS Methods. The method was demonstrated through an application in the automotive industry. The ultimate goal is to contribute to the literature by creating a decision model that evaluates the environmental sustainability risks in the automotive industry's supply chain.

2. LITERATURE REVIEW

The concept of sustainability, as introduced by Amabile (1979), involves meeting the requirements of environmental, social, and economic factors while ensuring their long-term performance. This concept can be analyzed in three parts: economic, environmental, and social sustainability. Economic sustainability pertains to a business's ability to maintain a stable financial structure and generate profits. Environmental sustainability involves the utilization of natural resources by a business without causing any harm to the environment. It also includes taking the necessary measures to prevent resources from damaging the environment. Social sustainability refers to enhancing the working and living conditions of employees, customers, society, and future generations (Gençoğlu and Aytaç, 2016:52).

According to Elkington (1999), a sustainable supply chain perspective is to take into account the economic, environmental and social objectives of sustainable development as well as meeting the demands of the stakeholders in the supply chain. It is also the regular provision of materials, information and money in supply chain flows. Nur and Hidayatno (2020) sustainable supply chain; They expressed it as supply chains that achieve sustainable growth by maintaining environmental, economic and social stability. The relationship between the triple baseline and the sustainable supply chain is illustrated in Figure 1. Accordingly, the three dimensions are inseparable and form an organic whole. In Figure 1, economic sustainability (core), social sustainability (purpose) and environmental sustainability (basis) are expressed as a schema.

Figure 1. The Relationship Between The Triple Bottom Line And The Sustainable Supply Chain



Some studies on sustainable supply chain are as follows: Majumdar et al. (2021) determined sustainable supply chain risk reduction strategies in the textile industry and evaluated 12 risks and alternatives and criteria. Valilai and Sodachi (2020) made a case study with markov decision processes by addressing the sustainability assessment in the context of industry 4.0. Sirisawat et al. (2018) addressed the issue of reverse logistics in the electronics industry and used fuzzy AHP and fuzzy TOPSIS methods. Deng et al. (2019) discussed sustainable supply chain risk spillovers in perishable food products with tropos target-risk analysis.

The automotive industry is one of the largest and most complex industries in the world. Although the automotive industry is a key sector influencing the sustainability of the global economic system, the environmental and social performance of major automakers and other companies in the automotive supply network does not always comply with regulations or expectations. Despite all these difficulties, the issue of sustainability has received considerable attention (Orsato and Wells, 2007).

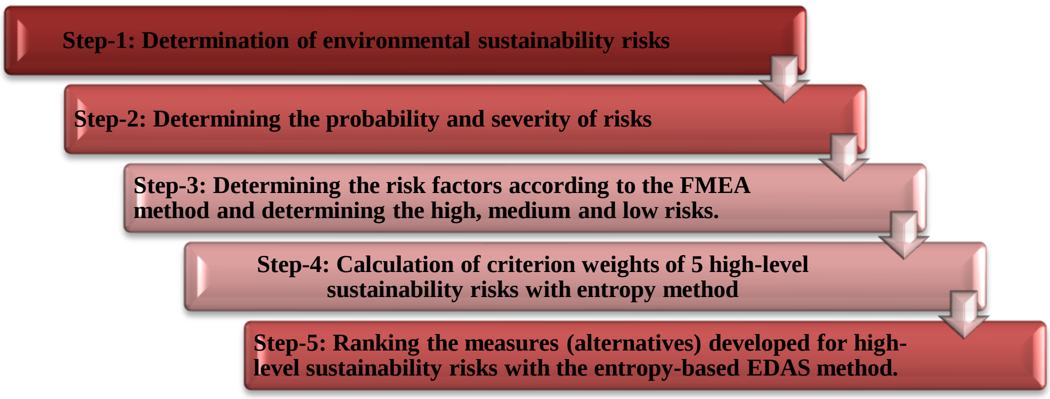
Several studies have been conducted on sustainability in the automotive industry's supply chain. Stoycheva et al. (2018) used a multi-criteria decision analysis method to tackle the issue of sustainable production in the industry. They found that material alternatives can be selected quantitatively based on sustainability goals. Yousefi and Tosarkani (2022) developed a comprehensive approach to managing the risks of logistics processes in an automotive supply chain. They identified the critical risks of each logistics process and proposed effective, sustainable risk reduction measures to improve their performance. Lenort et al. (2023) discussed the factors affecting target prioritization related to sustainable development in the automotive sector. In their studies, they determined the performance related to sustainable development using frequency analysis and the PROMETHEE method. There are also studies in the literature on risk assessment methods in the automotive industry, such as the proportional risk assessment (PRA) technique and preliminary hazard analysis (PHA) discussed by Domínguez et al. (2023) and the Monte Carlo method used by De Oliveira and Lourenço (2021). Thun and Hoenig (2011) discuss a case study on supply chain risk management in the German automotive industry.

3. METHODOLOGY

3.1. A Decision Model for the Assessment of Environmental Sustainability Risks

In the study, a risk-based decision model for sustainability risks in the automotive supply chain has been developed and is illustrated in Figure 2. The model begins by identifying environmental sustainability risks through a review of literature and industry reports. The severity of these risks is then determined by expert opinion and assessed using the FMEA method. Weightings for high-level risks are calculated using the entropy method. Finally, the entropy-based EDAS method is applied to high-level risks identified by FMEA, and risk reduction measures are recommended.

Figure 2. The Methodology Developed For Environmental Sustainability Risk In The Automotive Industry



3.2. Failure Mode Effects Analysis (FMEA)

The FMEA technique facilitates the calculation of risk levels and the identification of high-priority risks. FMEA is an effective method used to calculate the effects of potential risks and to develop recommendations-improvements to reduce risks (Akın et al., 1998). The reason why FMEA method differs from classical risk analysis is that there is a detectability factor when calculating risk levels. The usage area of FMEA method is very wide and it has increased even more today. The usage of this technique is widespread across various industries, including food, agriculture, manufacturing, design, and particularly the automotive sector (Scipioni et al., 2002).

FMEA comprises of three main components that are probability, severity, and detectability, and all these elements are considered collectively to calculate the Risk Priority Number (RPN). One of the three factors used to determine the priority of risks is probability, which is defined as the likelihood of a risk occurring. Probability values range from 1 to 10. Severity is used to indicate how significant an error or a risk is, with an estimated effect between 1 and 10. Detection, or detectability, is a measure of a risk or an error's ability to be detected (Pillay and Wang, 2003). As a risk becomes easier to detect, its degree decreases. The degree of risk that is difficult to detect is also high. RPN, or risk criticality level, is obtained by multiplying the three risk factors: probability of occurrence (O), severity (S), and detection (D) for each risk or error; RPN = O * S * D (Wang et al., 2009; Yılmaz, 1997).

In the RPN value, the probability, severity and detectability value is a value between 1 and 10. For example, if the probability of a risk is very high, it is grade 10, if there is no risk effect, grade 1, if it is not possible to detect error or risk, grade 10. It takes the value 1 if it is certain to detect the risk or error. If the severity of a risk is very high, it takes the value of 10, if the severity is very small, it takes the value of 1. (Durmuş et al., 2021).

For the RPN value; If RPN<40, the risk level is low and no need to take precautions. If 40≤RPN≤100, the risk level is medium and It is useful to take precautions. Finally, if RPN is >100, the risk level is high and Precautions must be taken (Pillay and Wang, 2003).

3.3. Entropy Method

The criterion weights to be found in the entropy method will be used in the EDAS method. The steps of the entropy method are as follows (Wang and Lee, 2009; Li et al., 2011).

Step 1: The decision matrix denoted by : E = $[z_{ij}]_{m*n}$ is standardized. Equation (1) is used when the criteria are utility-based. Equation (2) is used when the criteria are cost-oriented.

$$r_{ij} = \frac{z_{ij}}{maxj(zij)} \quad (1)$$

$$r_{ij} = \frac{minj(zij)}{z_{ij}} \quad (2)$$

Step 2: In this step, the standardized decision matrix is normalized using equation.

$$t_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} \quad (3)$$

Step 3: For the entropy values of the criteria, equation (4) below is used.

$$H_j = -\frac{\sum_{t=1}^{m} t_{ij} \ln(t_{ij})}{\ln(m)} \tag{4}$$

Step 4: Finally, the weight of the criteria is calculated according to the equation (5) below.

$$W_j = \frac{1 - H_j}{\sum_{j=1}^{n}(1 - H_{j)}} \tag{5}$$

3.4. EDAS Method

The Evaluation based on Distance from Average Solution (EDAS) method is a decision making technique developed by Ghorabaee et al. (2015). The steps of the EDAS method are as follows:

Step 1: The first step is to create the decision matrix. In the decision matrix below,

Xij = i. alternative j. represents the performance according to the criteria. Xij decision matrix is seen in equation (6).

$$X_{ij} = [X_{ij}]_{m*n} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \tag{6}$$

Step 2: In this step, the average solution (AV: Average Solution matrix) is created by taking the average of each criterion.

AVj: j. Expressed the mean matrix of the criteria

$$AV = [AV_j]_{1xn} \tag{7}$$

$$AV_j = \frac{\sum_{i=1}^{m} X_{ij}}{m} \tag{8}$$

Step 3: For each criterion, the positive distance matrix from the mean (PDA) and the negative distance matrix from the mean (Negative Distance From Average-NDA) are calculated. Equation (11) and equation (12) are used when metrics are of benefit type, while equation (13) and equation (14) are used when metrics are cost types. The PDA and NDA formulas that need to be calculated according to the types of benefits and costs vary.

$$PDA= [PDA_{ij}]_{mxn} \tag{9}$$

$$NDA=[NDA_{ij}]_{mxn} \tag{10}$$

$$PDA_{ij}=\frac{\max(0,(X_{ij}-AV_j))}{AV_j} \tag{11}$$

$$NDA_{ij}=\frac{\max(0,(AV_j-X_{ij}))}{AV_j} \quad (12)$$

$$PDA_{ij}=\frac{\max(0,(AV_j-X_{ij}))}{AV_j} \quad (13)$$

$$NDA_{ij}=\frac{\max(0,(X_{ij}-AV_j))}{AV_j} \quad (14)$$

Step 4: In this step, for each alternative, the weighted total positive value (SPi) and the weighted total negative value (SNi) are calculated. Equation 15 and 16 are used for SPi and SNi. Here wj = j. indicates the weight of the measure.

$$SP_i=\sum_{j=1}^{n} w_j * PDA_{ij} \quad (15)$$

$$SN_i=\sum_{j=1}^{n} w_j * NDA_{ij} \quad (16)$$

Step 5: Equation 17 and equation 18 below are used to normalize the SP and SN values found in the previous step.

$$NSP_i=\frac{SP_i}{max_i(SP_i)} \quad (17)$$

$$NSN_i=1-\frac{SN_i}{max_i(SN_i)} \quad (18)$$

Step 6: The following equation 19 is used to find the evaluation scores of the alternatives, called ASi (Evaluation score).

$$AS_i=\frac{1}{2}-(NSP_i+NSN_i) \quad (19)$$

Step 7: The evaluation score is used to sort all the available options in a descending order. The top-ranked option, which has the highest value, is chosen as the best alternative.

Some studies on the EDAS method are as follows: He et al. (2019) discussed the EDAS method for green supplier selection. Barauskas et al. (2018) used the EDAS method for the most effective processing of public transport systems. Alioğulları and Tüysüz (2020) examined foreign trade activities in Istanbul between 2013 and 2018 and discussed which sector is better with EDAS and CODAS methods. Karabasevic et al. (2018) discussed EDAS and SWARA methods for evaluating the quality of websites in the textile industry.

4. SUSTAINABILITY RISK ASSESSMENT IN THE AUTOMOTIVE INDUSTRY

In this section, the applications of the steps in the methodology section are explained. Environmental sustainability risks and risk reduction measures in automotive logistics were determined by taking the opinions of 5 experts from Turkey's leading logistics companies and the literature in this field as reference.

4.1. Sustainability Risks And Risk Mitigation Measures

The main purpose of risk control is to stop the occurrence of the risk and to take the necessary measures to reduce the risk. The environmental sustainability risks of the automotive industry are as in Table 1. A total of 9 environmental risks have been identified here. The sub-dimensions and definitions of risks are given in Table 1 and these were obtained through a large literature search. Environmental sustainability includes strategic sustainability activities that businesses create to prevent any action that harms the nature.

Table 1. Environmental Sustainability Risks of the Automotive Industry

Environmental Dimension – (Code : R-1)			
Sub-Dimensions	**Code**	**Description & Risks**	**Reference**
Increasing energy consumption	SR-1	Energy efficiency is about providing the desired environmental conditions while consuming the minimum amount of energy. If energy cannot be used effectively, efficiency cannot be achieved in production.	Diesendorf (2007), Omer (2008), Hoffmann et al. (2014)
Increasing greenhouse gas	SR-2	The increase in the emission of greenhouse gases such as CO2 resulting from transportation in logistics activities and the formation of global warming problems are a risk. This risk creates negative consequences for human health. Excessive and inefficient stock management and storage can pose a threat to greenhouse gases.	Bailey and Solomon (2004), Mesjasz-Lech (2016), Blackburn (2007), Dey et al. (2011), Çamlıca and Akar (2014), Giannakis and Papadopoulos (2016), Hoffman et al. (2013), Koberg and Langoni (2019), Hoffmann et al. (2014)
Pollution increase: Light-air-water-noise-soil impurities	SR-3	It relates to light, water, soil or noise pollution from operations at the facility or from the environment. At the same time, air emissions from chemical storage are examples of pollution.	Bailey and Solomon (2004), Mesjasz-Lech (2016), Blackburn (2007), Dey et al. (2011), Çamlıca and Akar (2014), Hoffman et al. (2013), Koberg and Langoni (2019), Hoffmann et al. (2014)
Increase in accidents	SR-4	In the logistics sector, they are accidents caused by transportation or any reason during the production phase. Fire, explosion or various work accidents can be given as examples. Accidents affecting the environment can result from a firm's operations, machinery or personnel.	Song et al. (2017), Gouda and Saranga (2018), Marshall et al. (2014), Giannakis and

			Papadopoulos (2016)
Water and Wastewater Risks	SR-5	With the climate crisis, threats occur on existing water resources. At the same time, water scarcity threatens a significant portion of the world's population. In addition, global water use is increasing.	Turkey Automotive Main Industry Sustainability Report (2020)
Climate crisis and risk of global warming	SR-6	Climate change is an issue that people and businesses have to deal with today. The World Economic Forum (WEF) has published a report on global risks for 2021. Weather events that occur more frequently and have greater effects, the inability to combat climate change and the fact that environmental risks from humans are at the top show how serious this problem is.	FORD (2021) Doğuş Automotive (2021)
Occurrence of natural disasters	SR-7	Earthquake, fire, flood, hurricane etc. are external factors.	Wagner and Bode (2008), Jüttner et al. (2003), Giannakis and Papadopoulos (2016), Song et al. (2017), Nakandala et al. (2016)
Excessive product wastage	SR-8	It consists of product waste that may occur in excessive amounts due to faulty processing and transportation system in logistics activities. Product wastes such as plastics, chemicals and oils cause negative damage to the environment.	Khan and Islam (2015), Dey et al. (2011), Çamlıca and Akar (2014)
Excessive or unnecessary packaging	SR-9	Packaging (and packaging waste: stretch film) are risks from non-compliance or overpacking.	Panigrahi et al. (2018), Blackburn (2007), Giannakis and Papadopoulos (2016), Dey et al. (2011), Çamlıca and Akar (2014)

Risk assessment; analyzes what dangers exist in the workplace or what dangers may come from outside. It also shows which of these hazards have become risks, how the risks arising from the hazards should be analyzed and how the risks should be ranked. Risk control measures can also be determined by risk assessment. Carrying out a risk assessment; It does not mean that the employer's responsibilities regarding occupational health and safety in the workplace are over. The employer also learns all necessary information and documents related to risk assessment from the authorized person or persons.

Risks are generally addressed in three aspects of risk assessment (Dnv, 2001). Unacceptable Risks: It is in the high risk group. Risks that are deemed unacceptable regardless of their contribution, except in exceptional circumstances. Precautions must be taken against such risks. Tolerable Risks: It is in the moderate risk group. The severity of such risks is tolerable. An appropriate risk control should be carried out for such risks. Acceptable Risk: It is in the low risk group. Considering the legal regulations and procedures of the enterprises, they create acceptable risks (Dnv, 2001).

Alternatives (AL) or measures developed in response to risks in the automotive industry are as in Table 2. The alternatives here have been created by taking into account the expert opinions of a leading logistics company in Turkey. At the same time, Ford automotive, Doğuş automotive and Turkey Automotive Main Industry Sustainability reports were obtained by examining.

Table 2. Measures Developed Against Sustainability Risks in the Automotive Industry

Code	Definition
AL-1	Investing in efficient vehicles, equipment and machinery. For example, R&D studies and innovations in electrification, battery technologies, autonomous driving, alternative fuels, driver support and safety systems and interface development, weight reduction, material technologies and digitalization. To use clean fuel for logistics transport vehicles.
AL-2	Developing electric or hydrogen vehicle technologies. Investing in electric vehicle charging stations. Along with new electric vehicle models; product and service range, creating new markets and competitive opportunities. Being carbon neutral, having low and zero emission vehicles, reducing dependence on fossil fuels.
AL-3	Carrying out activities related to the reduction of energy consumption and energy efficiency policy. For example: Minimizing fossil fuel consumption, using renewable energy sources, Investing in efficient energy, using ISO 50001 Energy Management System Standards, Contributing to reducing the effects of global warming by increasing energy efficiency. To use natural resources efficiently, to produce environmentally friendly and energy efficient new and technological products.
AL-4	To design and develop processes taking into account environmental impacts. For example, involving suppliers in greenhouse gas emission reduction programs.
AL-5	Placing the plant away from the urban area. Soundproofing. To design green buildings in a way that will not reflect light pollution. Reducing the flue gas effect. To perform regular maintenance of ventilation and cooling systems. To prepare regular reports on air, soil, light and water quality. Developing new technologies and improving business processes to eliminate harmful substances and improve air quality in operations. Reducing the air emissions of cars and other vehicles and improving their performance with investments in R&D and innovation.
AL-6	Creating an emergency action plan for potential accidents. To provide continuous training on the reduction of accidents. Making field trips and setting goals in this direction. To determine accident frequency rate (TAR), accident severity rate (ASR), lost day accident frequency rate (LTAR) and set targets. To arrange and design working environments in a way that prevents environmental accidents.
AL-7	To determine approaches for water management and water reuse in the production activities of companies and to develop practices in this direction. To purify the industrial wastewater generated as a result of the production processes and the domestic wastewater generated in the facilities in the treatment plants.
AL-8	To use energy efficiently to reduce the effects of global warming. To make the environmentalist perspective traditional by increasing awareness within the institution. To ensure that living things and nature are not affected by the negative effects of products and activities. To align with the Paris agreement on climate crisis prevention. To determine and implement the environmental and energy management policy of the enterprise well. To set goals such as reducing emissions in the fight against global climate change, in logistics processes and supply chain, operations and products. To promote processes that reduce emissions throughout the entire supply chain. To ensure the transition of the automotive industry to a low-carbon economy with the EU green agreement.
AL-9	To prepare a disaster action plan and to provide training in this direction. Using fire prevention/retardant systems and fire alarms, Using seismic isolators in buildings for earthquakes. Making earthquake studies, using smart systems to prevent natural disasters. Earthquake/fire drill. Earthquake, fire, flood, etc. to secure the losses that may occur in the event of the realization of the risks, with the insurances it has taken out within the scope of the policy limits. To position the enterprise on suitable lands against the risk of flooding.
AL-10	To ensure proper disposal or recycling of waste. To produce and use the product in a way that does not harm the environment. To produce environmentally friendly, eco-sustainable products. Optimizing the process. To prepare the industrial waste management plans of the companies and to provide the necessary training to the maintenance personnel. To support zero waste practices. Reducing idle capacity.

AL-11	Optimizing packaging. To do R&D in terms of saving packaging. Developing packaging suitable for the product. To increase environmental awareness and reduce single-use plastics by reducing the packaging of products and raw materials from suppliers with the green packaging project. Buying recycled packaging.
AL-12	Complying with all kinds of laws, regulations and legislations related to occupational health and safety of companies and providing trainings in this direction. Establishment of occupational health and safety committees. These boards regularly monitor the current work flow of the company and provide a safe and healthy working environment. To take precautions against dangerous situations by making risk analysis in the workplace. To find the root causes of work accidents and occupational diseases by investigating. Keeping the emergency teams up to date and following up. Performing periodic machine and equipment maintenance. Performing periodic health care for employees. To provide preventive and preventive medical services. To carry out high-level hygiene practices in production facilities and offices.
AL-13	Determination of the commitments and targets of the top management related to sustainable targets. Establishing plans for business continuity and continuity.
AL-14	To develop sustainable supply chain management and logistics infrastructure. To strengthen the competitiveness of our country and to ensure its development in the changing automotive ecosystem.

4.2. Assessing Sustainability Risks with FMEA

In Table 3, sustainability risks in the environmental dimension in the automotive industry are examined and a total of 9 risk levels, that is, criteria, are determined. The average of the results obtained with the expert opinions is given in the table, and the RPN values are given in the result column.

Table 3. Risks Obtained as a result of the Application and Risk Degrees

Code	Risk	Possibility	Severity	Detection	Result
SR-1	Increased energy consumption - High energy consumption	**10**	**10**	**2**	**200**
SR-2	High greenhouse gas emissions	**10**	**10**	**2**	**200**
SR-3	Pollution increase: Light-air-water-noise-soil impurities	**4**	**10**	**2**	**80**
SR-4	Increase in accidents	**4**	**10**	**2**	**80**
SR-5	Water and Wastewater Risks	**6**	**10**	**4**	**240**
SR-6	Climate crisis and risk of global warming	**8**	**10**	**4**	**320**
SR-7	Occurrence of natural disasters	**10**	**10**	**7**	**700**
SR-8	Excessive product wastage	**4**	**3**	**5**	**60**
SR-9	Excessive or unnecessary packaging	**6**	**2**	**5**	**60**

According to the FMEA method, while there is no risk for risks with an RPN value less than 40, there are 4 risks with an RPN value between 40 and 100, which are expressed as medium level. Risks with an RPN greater than 100 are considered "high-level" risks. Precautions must be taken against high-level risks. The risks that absolutely need to be taken are as follows: Increasing energy consumption - High energy consumption, High greenhouse gas emissions, Water and wastewater risks, Climate crisis and global warming risk, and natural disasters.

4.3. Risk Assessment with Entropy-Based EDAS Method

The decision matrix containing the criteria and alternatives, including 5 high-level risks in the FMEA method and 14 measures developed for the environmental sustainability risks of the automotive industry, is as follows. The decision matrix in Table 4 was created by taking the opinions of 5 experts from a leading logistics company. The criteria in the decision matrix are as follows: C1: Increasing energy consumption – High energy consumption, C2: High greenhouse gas emissions, C3: Water and wastewater risk, C4: Climate crisis and global warming risk, C5: Natural disaster risk. In the survey section asked to the experts, the criteria were considered as beneficial, as they were asked to what extent the alternatives reduce the existing risks. In the survey section, experts were asked to provide their insights on the extent to which the alternatives reduce existing risks. This criteria-based approach was considered highly beneficial in determining the effectiveness of the alternatives under consideration. By focusing on the reduction of existing risks, the survey aimed to evaluate the potential impact of each alternative and identify the most effective solution. The inclusion of experts in this process allowed for a comprehensive analysis of the risks and the potential mitigating factors that each alternative offered. This criteria-based survey approach not only provided valuable insights but also ensured that the decision-making process was informed by expert opinions and expertise.

Table 4. Decision Matrix

	C1	C2	C3	C4	C5
AL1	9	9	7	8	3
AL2	9	9	7	9	1
AL3	9	8	6	9	1
AL4	9	9	8	9	6
AL5	8	6	8	7	3
AL6	7	1	6	5	7
AL7	6	7	9	8	6
AL8	7	9	9	9	6
AL9	6	1	5	4	9
AL10	6	9	9	9	2
AL11	6	8	7	8	2
AL12	6	5	7	7	7
AL13	8	9	7	8	8
AL14	6	7	7	8	6

The values in Table 4 were created according to the level of relationship between criteria and measures. For example, the 3rd Alternative (AL3) affects the high greenhouse gas emission, which is the C2 criterion, at a very high level. The linguistic expressions of the numerical values in the table are as follows: 1: Definitely low, 2: Very low, 3: Low, 4: Below average, 5: Average, 6: Above average, 7: High, 8: Very high, 9: Definitely high

Table 5. Standardized Decision Matrix According To The Entropy Method

	C1	C2	C3	C4	C5
A1	1,000	1,000	0,778	0,889	0,333
A2	1,000	1,000	0,778	1,000	0,111
A3	1,000	0,889	0,667	1,000	0,111
A4	1,000	1,000	0,889	1,000	0,667
A5	0,889	0,667	0,889	0,778	0,333
A6	0,778	0,111	0,667	0,556	0,778
A7	0,667	0,778	1,000	0,889	0,667

A8	0,778	1,000	1,000	1,000	0,667
A9	0,667	0,111	0,556	0,444	1,000
A10	0,667	1,000	1,000	1,000	0,222
A11	0,667	0,889	0,778	0,889	0,222
A12	0,667	0,556	0,778	0,778	0,778
A13	0,889	1,000	0,778	0,889	0,889
A14	0,667	0,778	0,778	0,889	0,667

In Table 5, the decision matrix is brought into standardized form. For this, equations (1) and (2) from the title of Entropy method are used.

Table 6. Decision Matrix Normalized According To The Entropy Method

	C1	**C2**	**C3**	**C4**	**C5**
A1	0,088	0,092	0,068	0,074	0,044
A2	0,088	0,092	0,068	0,083	0,014
A3	0,088	0,082	0,058	0,083	0,014
A4	0,088	0,092	0,078	0,083	0,089
A5	0,078	0,061	0,078	0,064	0,044
A6	0,068	0,010	0,058	0,046	0,104
A7	0,058	0,072	0,088	0,074	0,089
A8	0,068	0,092	0,088	0,083	0,089
A9	0,058	0,010	0,049	0,037	0,134
A10	0,058	0,092	0,088	0,083	0,029
A11	0,058	0,082	0,068	0,074	0,029
A12	0,058	0,051	0,068	0,064	0,104
A13	0,078	0,092	0,068	0,074	0,119
A14	0,058	0,072	0,068	0,074	0,089

The standard decision matrix in Table 6 is normalized in this step. Calculations are made using equation (3) in the title of entropy method.

Table 7. Weights Of Criteria According To Entropy Method

	C1	**C2**	**C3**	**C4**	**C5**
Wj	0,047	0,328	0,040	0,064	0,518

In Table 7, the weights of the criteria are calculated using equation (5). Here, the criteria weights are between 0 and 1. The criteria weights found at this stage are transferred to the EDAS method.

Table 8. Positive And Negative Distance Matrix From The Mean

	Positive distance matrix from the mean					**Negative Distance Matrix from Mean**				
	C1	**C2**	**C3**	**C4**	**C5**	**C1**	**C2**	**C3**	**C4**	**C5**
A1	0,235	0,299	0,000	0,037	0,000	0,000	0,000	0,039	0,000	0,373
A2	0,235	0,299	0,000	0,167	0,000	0,000	0,000	0,039	0,000	0,791
A3	0,235	0,155	0,000	0,167	0,000	0,000	0,000	0,176	0,000	0,791
A4	0,235	0,299	0,098	0,167	0,254	0,000	0,000	0,000	0,000	0,000
A5	0,098	0,000	0,098	0,000	0,000	0,000	0,134	0,000	0,093	0,373
A6	0,000	0,000	0,000	0,000	0,463	0,039	0,856	0,176	0,352	0,000
A7	0,000	0,010	0,235	0,037	0,254	0,176	0,000	0,000	0,000	0,000
A8	0,000	0,299	0,235	0,167	0,254	0,039	0,000	0,000	0,000	0,000
A9	0,000	0,000	0,000	0,000	0,881	0,176	0,856	0,314	0,481	0,000
A10	0,000	0,299	0,235	0,167	0,000	0,176	0,000	0,000	0,000	0,582
A11	0,000	0,155	0,000	0,037	0,000	0,176	0,000	0,039	0,000	0,582
A12	0,000	0,000	0,000	0,000	0,463	0,176	0,278	0,039	0,093	0,000

A13	0,098	0,299	0,000	0,037	0,672	0,000	0,000	0,039	0,000	0,000
A14	0,000	0,010	0,000	0,037	0,254	0,176	0,000	0,039	0,000	0,000

The positive and negative distance matrix from the mean in Table 8 is calculated with the help of the equations in Step 3 under the heading EDAS method.

Table 9. SP, SN, NSP, NSN and AS Values

	SPi	SNi	NSPi	NSNi	ASi
A1	0,111	0,195	0,244	0,532	0,388
A2	0,120	0,411	0,263	0,013	0,138
A3	0,072	0,417	0,159	0,000	0,079
A4	0,255	0,000	0,560	1,000	0,780
A5	0,008	0,243	0,018	0,416	0,217
A6	0,240	0,313	0,525	0,250	0,388
A7	0,146	0,008	0,321	0,979	0,650
A8	0,250	0,001	0,547	0,995	0,771
A9	0,456	0,333	1,000	0,201	0,601
A10	0,118	0,310	0,259	0,256	0,257
A11	0,053	0,311	0,116	0,252	0,185
A12	0,240	0,107	0,525	0,742	0,634
A13	0,453	0,001	0,993	0,996	0,995
A14	0,137	0,009	0,300	0,976	0,638

Table 9 is calculated with the help of equations (10), (11), (12) and (13) in Step 4 and Step 5 under the title of EDAS method. The ASi evaluation score in the table was calculated with the help of the formula (14) in the same step. Here, the 13th alternative with the highest evaluation score is "Determining the commitments and targets of the top management regarding sustainability. Putting forward plans for business continuity and continuity." has been selected. In other words, the first precautionary measure against the identified risks is the 13th Alternative. The order of the alternatives, from largest to smallest, is as follows:

13>4>8>7>14>12>9>1>6>10>5>11>2>3

5. CONCLUSION AND SUGGESTIONS

The increasing use of natural resources has made sustainability a crucial concept in today's world. This study focuses on sustainability risks in automotive logistics and evaluates 9 risk factors using expert opinions and FMEA risk assessment method. Out of the 9 risks, 5 are considered high risks, including energy consumption, greenhouse gas emissions, water and wastewater risk, climate crisis, and natural disasters. Immediate action is required to address these risks. Additionally, moderate risks such as pollution, accidents, product waste, and excessive packaging are also notable. These risks need to be addressed as quickly as possible. There is no risk with an RPN value less than 40, that is, the risk level is low. Low-level risks are those for which businesses accept these risks and do not need to take action. Since there is no low level risk, it is seen that environmental sustainability risks in automotive logistics consist of medium or high risks. In the second application part of the study, Entropy-based EDAS method was applied for 5 high-dimensional risks found by FMEA method. In the decision matrix determined by expert opinions, the criteria constitute risks and alternatives measures. In the study, a total of 14 measures to be taken against environmental sustainability risks in the automotive industry were developed. In the results obtained from the entropy-based EDAS method, the first alternative in the ASi evaluation score is: "Determining the commitments and targets of the top management regarding sustainability. It has put forward plans for business continuity and continuity". Businesses should develop procedures compatible with sustainability to eliminate existing risks. It is very important to plan and set goals in order to ensure business continuity and increase sustainability performance. In this way, the basis for eliminating all risks is formed. The approach of management in enterprises is very important for the success of sustainability. All work can be considered risky if an enterprise does not have goals for planning and future work. Therefore, the most important thing for the management and employees is to adopt a sustainable understanding of sustainability and to follow appropriate procedures and laws. The second alternative was "Designing and developing processes, taking into account environmental effects". Considering environmental risk mitigation measures, this alternative seems to be important. By designing and developing an environmental process, existing risks can be prevented. For example, suppliers can be included in a greenhouse gas emission reduction program. It is of great importance to design and develop environmental impacts accurately and consciously, especially due to the high energy consumption and the negative effects of greenhouse gas emissions. Another alternative that comes in the 3rd place among the alternatives is AL8 alternative. In this alternative, energy should be used efficiently in order to reduce global warming, and trainings should be given within the institution for efficient use of energy. Awareness should be increased and environmental risks should be eliminated.

It may not be possible to try to prevent or reduce all risks with existing resources in businesses. Therefore, prioritization of risks and studies on risks with high risk levels should be started. In addition, some risks with very high RPN values may not be included in the scope of improvement studies due to insufficient resources or operational capabilities of the enterprises. Risk transfer is generally the preferred strategy for these risks. Therefore, in this study, after determining the risk levels with FMEA, a multi-level risk assessment method has been proposed in which the measures of risks with very high RPN values are examined with the EDAS method. In this way, it is aimed to evaluate risk-reducing measures in the most accurate way by experts, taking into account business capabilities and strategies. In future studies, it may be possible to obtain more effective results with more different decision methods and studies involving a larger number of evaluators. The interaction of sustainable environmental risks in the automotive industry with other sustainability risks can be discussed in detail, and a more comprehensive risk assessment model can be put forward for hybrid models.

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Tartışma ve Yorum / *Discussion and Interpretation*	Bulguların değerlendirilmesinde ve sonuçlandırılmasında sorumluluk almak / *Taking responsibility in evaluating and finalizing the findings*	Ecenur ALİOĞULLARI Assoc. Prof. Yusuf Sait TÜRKAN Asst. Prof. Emre ÇAKMAK
Literatür Taraması / *Literature Review*	Çalışma için gerekli literatürü taramak / *Review the literature required for the study*	Ecenur ALİOĞULLARI Assoc. Prof. Yusuf Sait TÜRKAN Asst. Prof. Emre ÇAKMAK

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