SUSTAINABILITY CRITERIA REFLECTION IN THE SELECTION OF LOGISTICS CENTER LOCATION WITH SIMILARITY-BASED TOPSIS USING OWA OPERATORS

Lappeenranta–Lahti University of Technology LUT

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Examiners: Professor Pasi Luukka

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ABSTRACT

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Sustainability criteria reflection in the selection of a logistics center location with Similarity-based TOPSIS using OWA operators

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Keywords: Logistics centers, Location Selection, Sustainability, Similarity-based TOPSIS, OWA operator.

This study proposes a framework that incorporates sustainability criteria and employs the Similarity-based TOPSIS with the OWA operator to support the decision-making process. The framework aims to reflect sustainability considerations in the selection of logistics center locations.

The Similarity-based TOPSIS with OWA operators is applied to evaluate and rank the alternatives. It is also utilized to calculate the Proximity to key customer centers score for the considered municipalities. The approach offers a flexible and customizable method that allows decision makers to express their preferences and requirements by selecting appropriate linguistic requirements for similarity calculations. The results obtained from the case study in Finland demonstrate the effectiveness of the proposed method in reflecting the decision maker's preferences. The study contributes to the field by offering a new approach that considers different stakeholder interests regarding dimensions of sustainability through multiple models with different sets of criteria. Overall, the proposed framework enhances the understanding of sustainability considerations in logistics center location selection and offers a new approach for practitioners and researchers in addressing the problems of logistics center location with sustainability criteria.

ABBREVIATIONS

A1	Alternative 1
A2	Alternative 2
A3	Alternative 3
A4	Alternative 4
A5	Alternative 5
A6	Alternative 6
A7	Alternative 7
A8	Alternative 8
A9	Alternative 9
A10	Alternative 10
A11	Alternative 11
A12	Alternative 12
A13	Alternative 13
A14	Alternative 14
AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
C1	Criterion 1
C2	Criterion 2
C3	Criterion 3
C4	Criterion 4
C5	Criterion 5
C6	Criterion 6
C7	Criterion 7
C8	Criterion 8
C9	Criterion 9
C10	Criterion 10
C11	Criterion 11
DEA	Data Envelopment Analysis
ELECTRE	Elimination and Choice Translating Reality
GIS	Geographic Information Systems
GHGs	Greenhouse Gases
MCDM	Multi-Criteria Decision-Making
NIS	Negative Ideal Solution
OWA	Ordered Weighted Aggregation
PIS	Positive Ideal Solution
ROC	Rank-Order Centroid
RC	Relative Closeness
TBL	Triple Bottom Line
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution

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1. Introduction

Over the last few years, the growth of ecommerce has emerged as a significant trend, transforming the global business landscape in both local and international markets. With the help of digital technology, businesses can now reach out to new markets and customers without the need for a physical presence. This has led to an expansion of their customer base and an increase in revenue streams. The rise of the internet and mobile devices has further facilitated this trend, making it easier for businesses to offer their products and services to a global audience, regardless of their geographical location.

The impact of globalization has been a critical driver in the development of ecommerce. The harmonization of trade regulations and economic integration has opened up new opportunities for businesses to engage in cross-border commerce, resulting in the potential expansion of customer bases beyond national borders. This development has also led to the growth of international payment systems and logistics infrastructure, enabling businesses to sell and deliver products to customers in different parts of the world.

The COVID-19 pandemic has had a significant influence on the e-commerce industry in several countries as people have been avoiding going out and practicing social distancing, thereby resorting to purchasing goods from home. The global retail ecommerce sales have witnessed a significant increase from 2019 to 2020, primarily due to the pandemic's impact on the ecommerce market and this trend is expected to persist, with a steady growth rate of 8 percent for all worldwide retail ecommerce sectors sales until 2024 (International Trade Administration, 2021). For example, the e-commerce market in Euro, which ranked as the third largest market in 2019 with revenues amounting to US $351.9 billion, experienced a significant boost of 10 percent in e-commerce revenues in 2020 due to the pandemic (Jílková and Králová, 2021). According to Bhatti et al. (2020), retail sales of e-commerce have been significantly impacted by COVID-19, and the global e-commerce sales are projected to reach US $6.5 trillion by the year 2023. This trend has been observed both in developed countries and developing countries, resulting in a rise in the number of online buyers. The pandemic has caused a significant shift towards domestic and neighboring region online stores for buyers in many areas (Perera et al., 2021; Helsinki Times, 2022). In Finland, there has been a marked increase in interest in Finnish online stores during the pandemic, which has continued to grow. As an example, a Posti survey conducted in 2022 indicated that almost all Finns favored Finnish online stores on popular shopping days such as Black Friday (Posti, 2022a).

Since the rise of ecommerce and the shift towards online shopping promote the transportation of goods around the world and delivery of goods in cities (Cano, Londoño-Pineda and Rodas, 2022), businesses are facing increasing pressure to deliver goods quickly and cost-effectively to customers across the globe. The complexity of global operations can lead to greater uncertainty for a company, resulting in longer lead times and increased inventory levels. To address these challenges, the establishment of extensive worldwide logistics networks that incorporate logistics centers can be a critical factor in ensuring successful global logistics operations (Eckhardt and Rantala, 2012). Logistics centers serve as vital hubs within the global logistics system, augmenting the value of logistics services throughout the logistics value chain and optimizing the efficiency of terminal operations. A new logistics center can provide businesses with the ability to store, manage, and distribute their products more efficiently, allowing them to improve their supply chain operations, reduce costs, and meet the evolving needs of customers. (Eckhardt and Rantala, 2012)

Given the critical importance of logistics centers, many businesses are investing in them to enhance their supply chain operations, reduce costs, and meet the evolving needs of customers. For example, in Finland, Posti, one of the largest delivery and fulfillment companies in Finland, has announced its plan to invest in a new logistics center within the country, as the company foresees that the e-commerce market in Finland will grow twofold by the end of the current decade. The company aims to support the growth of this market by enhancing its ability to provide efficient and optimized services that cater to the requirements of customers throughout the entire e-commerce logistics value chain. (Posti, 2022b)

The process of strategic decision-making involved in the planning of a new logistics center for logistics businesses places great emphasis on the location of the facility. This has become a critical aspect in the logistics and supply chain management field (Rao et al., 2015), as it directly impacts the efficiency of delivery and costs of the entire system. Logistics centers serve as a crucial infrastructure in supply chains, and locating them appropriately is key to ensuring the efficiency of the freight system and supply chain (Pham, Ma and Yeo, 2017). Properly placed facilities can effectively reduce costs and promote the balanced development of the logistics system. However, an unfavorable logistics center location can lead to additional costs (Kayikci, 2010), for the business, such as increased transportation costs, as well as social consequences, including greater traffic congestion, higher emissions, compromised road safety, and a negative impact on the urban landscape (Rao et al., 2015).

The selection of an appropriate location for locating logistics centers is a complex and dynamic decision-making process, which requires a significant investment. Historically, logistics location selection has primarily revolved around minimizing financial costs or maximizing customer service levels (Rao et al., 2015; Terouhid, Ries and Fard, 2012). This is reflected in the traditional criteria that are predominantly used in evaluating logistics location problems.

However, solely prioritizing financial or profitability aspects is no longer sufficient. The growing concerns over sustainability issues such as the depletion of natural resources, global warming, greenhouse gases (GHGs) emission, and consumer health, have significantly heightened the importance of integrating sustainability into organizational strategies (Dey, LaGuardia and Srinivasan, 2011). Environmental problems, including emissions, energy consumption, pollution, and climate change, have a direct impact on human beings who rely on the environment in their daily lives and cannot be ignored (Wichaisri and Sopadang, 2013). Social issues, such as unemployment, should also be considered. As a result, sustainability has become a critical issue that all organizations, including those in the business and logistics sectors, should prioritize while making decision alongside profitability. Consequently, in logistics management, the selection of a logistics center location should constitute from a sustainable development perspective, and sustainability criteria should be incorporated into decision-making processes while selecting the logistics center's location.

Despite the growing recognition of the importance of sustainability in logistics center location problem, few studies specifically emphasize sustainability within the context of location problems. To address this gap, this thesis proposes framework that utilizes a multi-criteria decision-making approach to assess potential logistics center locations based on sustainability factors from a logistics business perspective by using objective numerical data. The framework will be practically applied using data from the Finnish logistics industry to demonstrate its effectiveness.

This thesis aims to provide a novel and practical approach for both academic researchers and practitioners in the field of sustainable logistics by incorporating sustainable principles into the multi-criteria decision-making process for selection of a logistics center location. By considering factors in relation to sustainability in the multi-criteria decision-making process, the proposed framework will deepen the understanding of the logistics location selection problem for academic researchers and provide a structured approach for practitioners to select the most appropriate logistics centers that not only maximize profitability for the logistics firm but also support the sustainability of their supply chains in the long term.

The subsequent sections of this study commence by providing a clarification of the problem definition. This encompasses the logistics center definition, the concept of sustainability, sustainability in logistics and selection of logistics center location with sustainability criteria. Following this, a literature review is presented, including an examination of past methods, the criteria employed in previous studies, and an exploration of sustainability within the logistics center location problem. Subsequently, the methodology employed in this research is explicated. Followed the methodology section, an illustrative case study conducted in Finland is presented. This section outlines the step-by-step implementation of the study, and subsequently delves into the obtained result summary, providing insightful discussions to facilitate a comprehensive understanding of their implications. Lastly, a sensitivity analysis is given, followed by a conclusive section that summarizes the key outcomes and offers critical insights into the limitations of the study, as well as potential avenues for future research.

2. Problem definition

2.1 Logistic center definition

The logistics industry is rapidly advancing in conjunction with advancements in the fields of industry and commerce. Therefore, it is imperative to have a globally competitive strategy that can effectively meet the demands of these sectors. Logistics centers, which originated during the industrial revolution in the United States and were established in Europe in the 1960s, are a key element of this strategy that plays a significant role for the improvement of logistics. (Uyanik, Tuzkaya and Oğuztimur, 2018) Logistics centers have emerged as a result of the globalization of business processes, the pursuit of innovative business solutions, and the potential for collaboration (Meidute, 2005). However, there is no agreed-upon name for this term, and it is often referred to by various names such as distribution center or distribution-storage center, logistics park, transport center etc. (Meidute, 2005; Uyanik, Tuzkaya and Oğuztimur, 2018).

The analysis of Meidute (2005), suggests that there are two viewpoints on the concept of a logistics center. The first is that it is a part of the transportation infrastructure (supported by Tsamboulas and Kapros, 2003; Konings, 1994; Krzyzanowski, 1999; Krzyzanowski, 2000), which integrates various modes of transportation, making it a node or area where activities related to transport, logistics, and goods distribution take place. For this approach, intermodal transport is emphasized as a key element (Tsamboulas and Kapros, 2003; Konings, 1994; Krzyzanowski, 1999; Krzyzanowski, 2000). The second viewpoint is that a logistics center is a generator of business, providing integrated logistics services and promoting the reduction of depots in urban areas, regions, and countries. (Meidute, 2005)

The most extensive and refined definition of a logistics center has been significantly developed and refined by EUROPLATFORMS, a prominent association comprising around 80 Transport and Logistics Centers across Europe. This definition is widely accepted and utilized by various entities, including the EU, UNECE, OECD, and national authorities. According to EUROPLATFORMS, a logistics center is defined as follow.

“A Logistics Centre is a center in a defined area within which all activities relating to the transport, logistics and distribution of goods, both for national and international transit, are carried out by various operators on a commercial basis.” (EUROPLATFORMS, no date)

Within the context of this thesis, the definition put forth by EUROPLATFORMS for a logistics center is being adopted. While a logistics center may also be viewed as a generator of business, this perspective is not being considered in this study's scope, particularly in relation to the center's location selection.

2.2 Concept of Sustainability

The ongoing confusion surrounding the concept of sustainability is not primarily due to a scarcity of proposed definitions, but rather stems from the multitude of approaches that lack clear interrelationships and require further clarification. (Bretzke and Barkawi, 2013, 12)

The report named "The Limits to Growth", which was published by the Club of Rome in 1972, has been widely recognized as a significant catalyst for the current discourse surrounding sustainability (Club of Rome, 2022). The report's authors projected that, even by the turn of the millennium, we already consumed 1.2 times the amount of resources that our planet can sustain. This means that we are currently living as though we have 1.2 earths at our disposal. (Bretzke and Barkawi, 2013, 13) Given the continuously rising rate of population growth, the planet's natural resources will eventually be depleted, rendering it incapable of supporting the world society indefinitely.

The report might raise a question regarding the extent to which current utilization of the Earth's resources should be curtailed to ensure future generations have access to those resources. As a response to this inquiry, the term sustainability has been defined by the United Nations' Our Common Future report (1987) as, "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." This widely cited definition of sustainability acknowledges the need to consider the long-term impacts of present-day decision-making and emphasizes the importance of striking a balance between present and future needs. Without doubt, if the current generation persists in surpassing the Earth's environmental limits and appropriating crucial resources from future generations, the capability of those future generations to fulfill their requirements will inevitably be restricted.

Another definition of sustainability is rooted in the concept of corporate social responsibility, as exemplified by John Elkington's Triple Bottom Line (TBL) framework (1994). The TBL framework identifies three interrelated aspects of sustainability - economic, environmental, and social - which should be considered by companies to ensure long-term viability. According to this framework, companies should strive to maximize their economic value for shareholders, while also contributing to the preservation of the natural environment and promoting equitable living and working standards for all. This framework has gained widespread acceptance among firms, governments, and non-governmental organizations as a guiding principle for sustainable business practices. (Grant, Trautrims and Wong, 2023, p32)

In this thesis, the three fundamental components of sustainability, namely economic, environmental, and social considerations, are employed as the central concept for evaluating the problem of logistics center location selection. The interdependence of the three components can be observed in Figure 1. These components are not distinct and can strengthen each other (Abbasi and Nilsson, 2016).

Many researchers argue that the goal of sustainable development is to achieve a harmonious balance among these three pillars, which entails balancing resource utilization with its impact on the environment (Purvis, Mao and Robinson, 2019). However, according to Hansmann, Mieg and Frischknecht (2012) the approach of balancing these three pillars has faced criticism as it involves different types of values, such as biodiversity and landscape beauty versus costs and profits versus equity, that are not directly comparable. Moreover, conflicts of interest between different stakeholders often arise within a single sustainability dimension, such as social, economic, or environmental conflicts or preferences, making it challenging to balance their interests regarding one pillar over the others (Hansmann, Mieg, and Frischknecht, 2012). To address this issue, this thesis proposes to consider sustainability from two different approaches. The first approach involves integrating all criteria under the three pillars of sustainability and evaluate them in a single model. The second approach involves considering interests of different stakeholders regarding sustainability, which includes profitability, social and environmental concerns with various set of criteria, each of which will be evaluated in a separate model. The final decision will be made based on the evaluation and comparison of results of the integration of Profitability and Social-Environmental models and the integration of all sustainability criteria in one single model.

In the present thesis, the terms "sustainable development" and "sustainability" are used synonymously. While there may be slight differences in the usage of these two terms in various contexts, in this thesis, they are used to denote the same concepts.

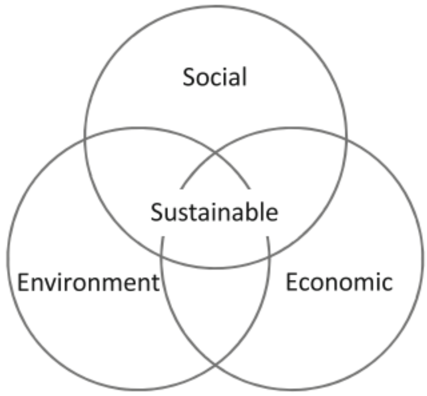

Figure 1. Three components of sustainability (Purvis, Mao and Robinson, 2019, 682)

2.3 Sustainability concept in Logistics

In the current discourse on sustainability, logistics and particularly the transportation of freight, which constitutes a significant physical aspect of logistics, have garnered significant attention due to their far-reaching impact on almost every individual and the environment (Machariset et al., 2014). As stated by Abbasi and Nilsson (2016), logistical activities have several beneficial socio-economic effects, such as providing mobility and accessibility, creating job opportunities, reducing poverty, hunger, and crime, and contributing to individual and national wealth. However, these activities also adverse effects on the natural environment and society, which need to be minimized. For instance, logistical activities rely heavily on non-renewable resources and fossil fuels, and they can cause harm to people's health and safety. They can also contribute to atmospheric, land, water, noise, and visual pollution, as well as congestion, intimidation, vibration, injuries, and accidents (Abbasi and Nilsson, 2016).

Along with the development of climate change and global warming, when it comes to sustainable development in Logistics, the environmental dimension received the first attention with the concern about increased greenhouse emissions related to pollution, traffic congestion, disposal etc. (Grant, Trautrims and Wong, 2023, 31-32; Piecyk, Cullinance and Edwards, 2015, 33-45). There are those who contend that environmental sustainability should take precedence over social and economic considerations, as the environment is the largest system encompassing both the economic and social spheres. They argue that if the carrying capacity of the environment is reduced, then the social system's capacity to deliver the common good is similarly diminished, and the economic system's output is correspondingly lowered. However, focusing solely on environmental sustainability is insufficient when considering sustainability in logistics. Bretzke and Barkawi (2013), Bouchery et al. (2017), Machariset et al. (2014) agree with this view.

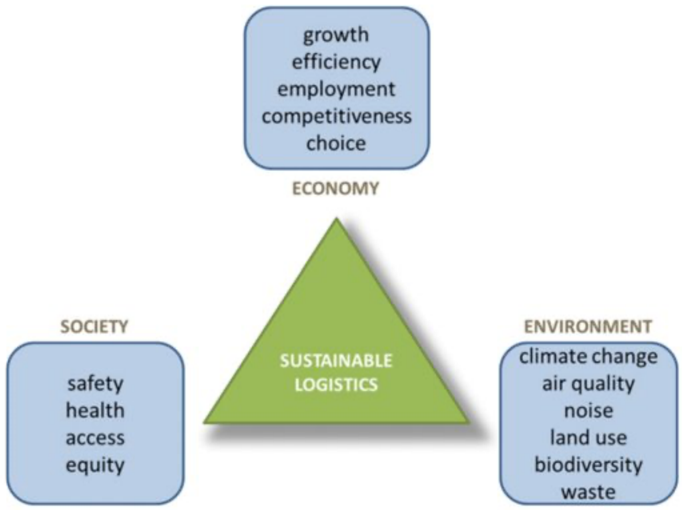

Figure 2. Framework for Sustainable Logistics (Macharis et al., 2014, xiv)

According to Machariset et al. (2014), sustainable logistics should encompass a broader concept that takes the economic and social implications of activities into consideration, aiming to enhance economic, environmental, and societal interests simultaneously as in Figure 2. Bouchery et al. (2017) argue that attaining true sustainability is challenging, even when only focusing on the already identified environmental and social factors. This is particularly true when adopting the perspective of strong sustainability that emphasizes the limited substitutability or even non-substitutability of natural capital by manufactured capital. In other words, the increase of manufactured capital cannot adequately compensate for the corresponding decline of natural capital. This perspective emphasizes the primacy of ecological considerations over economic benefits. As most supply chains rely on converting natural capital into manufactured capital to some degree, they are inherently unsustainable from this perspective. However, the weak sustainability perspective allows the depletion of natural resources as long as there is a corresponding rise in manufactured capital. For instance, deforestation may be considered acceptable as long as technological advancements provide alternatives for wood, and the increase of water pollution may be deemed acceptable as long as decontamination technology advances in parallel. From this standpoint, a supply chain could be deemed sustainable if its "net" impact on people and the planet is neutral, although this remains a challenging objective to accomplish. (Bouchery et al., 2017)

Different individuals and perspectives may have varying attitudes towards sustainability in logistics. Therefore, sustainable logistics should not be viewed as absolute states, such as weak or strong. In their book on sustainable supply chain, Bouchery et al. (2017) proposed a definition regarding sustainability in supply chain is that “a more sustainable supply chain is one that is better at identifying current and future environmental and social impacts and findings ways to mitigates those.” This definition emphasizes the importance of firms being aware of the economic, environmental, and social dimensions of the entire supply chain, including logistics, in order to succeed. It also highlights the need for active monitoring and management of these factors. (Bouchery et al., 2017)

The term "more sustainable" in the definition may indicate that there is a spectrum of sustainability within supply chains. It suggests that the goal is to move towards greater sustainability by continuously improving the identification and mitigation of environmental and social impacts. By using the term "more sustainable," Bouchery et al. (2017) may suggest that supply chains exist on a continuum, ranging from less sustainable to more sustainable. A less sustainable supply chain may have limited awareness or understanding of its environmental and social impacts and may not actively take steps to mitigate them. In contrast, a more sustainable supply chain demonstrates a greater commitment to identifying and addressing these impacts effectively. The term "more sustainable" implies a focus on progress and ongoing efforts. It suggests that sustainable supply chains are not static entities but instead should continually strive to improve their performance in terms of environmental and social responsibility. It recognizes that sustainability is a journey rather than a destination, and there is always room for further improvement and innovation.

In light of this definition, a sustainable supply chain can be understood as a supply chain that engages with and focus on the identification, understanding, and mitigation of environmental and social impacts. A sustainable supply chain is characterized by its commitment to continuously improving its sustainability performance, moving from a state of being "less sustainable" towards becoming "more sustainable." This commitment is demonstrated through the implementation of measures that address the environmental and social challenges associated with the supply chain, while also embracing responsible business practices.

Besides Bouchery et al. (2017), Bretzke and Barkawi (2013) put forth a framework that outlines the reference objects of sustainability within the context of logistics, as depicted in Figure 3. Rather than providing a definition for sustainable logistics, the authors emphasize the importance of considering three interconnected spheres: Profitability, Mobility, and Unpolluted Environment (alternatively referred to as Environment Protection) when formulating sustainable logistics concepts. Moreover, they also assert that logistics can and must play a crucial role in the development of sustainable economic strategies. By incorporating sustainability consideration into logistics practices, businesses and organizations can effectively contribute to the attainment of profitability, the efficient and effective movement of goods and service while protecting the environmental. (Bretzke and Barkawi, 2013, XVII & 32-33)

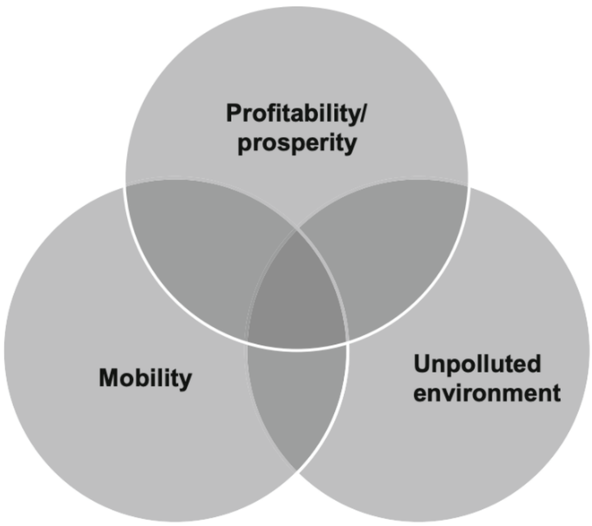

Figure 3. Reference objects of sustainability (Bretzke and Barkawi, 2013, 32)

According to these definitions and frameworks regarding sustainability concepts in supply chain and logistics, it becomes apparent that logistics firms have a significant responsibility to actively engage in sustainable development efforts. In addition to prioritizing profitability and prosperity, they need to recognize and address the environmental and social impacts associated with their operations and should strive to improve their sustainability performance. As logistics firms are the ones managing the entire logistics operation, they should be consciously aware of the potential negative consequences of their operations, such as contributing to climate change, energy consumption, and externalities, and take responsibility for their impacts.

However, it is important to recognize that logistics firms, like any other businesses, operate within financial constraints. Therefore, their involvement in sustainable development has to be limited by their financial capacity. While it is desirable for logistics firms to assume responsibility for identifying and addressing current and future environmental and social impacts, they should do so in a manner that is financially viable. This means that if a decision would not lead to invading or depleting the firm's capital, then environmental and social impacts should be taken into account.

While the arguments above suggest the need for firms to engage with their impacts on the economic, environmental, and social dimensions, there exist a limitation to the firm's sustainable responsibility, which is within the firm's financial ability. Firms should ensure their survival before acting sustainably. If sustainable solutions lead to a firm going bankrupt or being unable to pay its operational costs such as staff salary and renting payment, it would trigger many other negative effects and would obviously not lead to sustainable development. Moreover, if companies pass on the cost of sustainable practices to customers by increasing prices, customers may not be able to afford the products, leading to a decrease in sales and revenue. Firms should find ways to implement sustainable practices that do not result in financial instability, while also considering the long-term benefits to the environment and society. This approach can lead to a sustainable and prosperous future for both the company and the wider community.

The motivation for firms to adopt sustainable solutions is not only in term of morality, which is responsible for its impact, but also can be creation of competitive advantages and the pressure from governments and customer. Kazançoğlu, Özbiltekin and Özkan-Özen (2019) highlight that sustainability of logistics center becomes important given that it improves competitiveness and enhances global acceptance regarding environmental, health, and safety standards, especially in developing countries. In the context of customer preferences, while price and quality remain significant factors, convenience is no longer the only priority. Consumers are increasingly interested in socially relevant attributes such as energy efficiency and health benefits. This trend has led to the emergence of the term “conscious consumer,” referring to individuals who demands transparency and accountability from businesses across all levels of operations (Dey, LaGuardia and Srinivasan, 2011).

Furthermore, both individual customers, particularly in developed countries, and organizations in the business-to-business context, are pressuring firms to adopt sustainable practices (Bouchery et al., 2017). A survey of CEOs of large third-party logistics companies in 2008 identified that the key motivations for implementing sustainability programs were the desire to do the right thing, pressure from customers, enhancing corporate image, attracting eco-friendly customers, and competitive pressures (Dey, LaGuardia and Srinivasan, 2011). Governments are also creating policy guidelines to regulate pollutants, air transportation noise restrictions, and emissions standards in the logistics field to promote sustainability (Dey, LaGuardia and Srinivasan, 2011).

Most logistics managers acknowledge that carbon emission and other logistics regulations are not a matter of “if” but rather a matter of “when.” Therefore, the decision of whether to adopt sustainability practices across their global supply chain rests with top management, determining whether they want to implement these practices proactively, ahead of government intervention, or to wait until regulatory measures are imposed. (Dey, LaGuardia and Srinivasan, 2011)

2.4 Selection of logistics center location with sustainability criteria

The selection of a suitable location for logistics centers should constitute as a hierarchical problem with two levels of analysis. The first level, referred to as the macro-level, involves a comprehensive examination of wider areas or macro-regions to determine their potential and appropriateness for hosting a logistics center. The second level, referred to as the micro-level, involves a detailed analysis to identify the most appropriate specific locations within the region selected at the macro-level. In this thesis, the authors will focus exclusively on the macro-level analysis of the logistics center location problem. (Żak and Węgliński, 2014)

In the selection of logistics center locations under sustainability perspective, it is necessary to evaluate several criteria simultaneously (Rao et al., 2015) due to taking into account the interests of multiple stakeholders (Pham, Ma and Yeo, 2017). Moreover, the set of criteria can differ depending on the viewpoints of various decision makers. Private investors and firms seek to maximize their profitability, while public authorities aim to enhance the benefits for society and execute their broader policies and plans (Meidute, 2006). Additionally, customers may expect timely delivery, while residents in the surrounding area may desire more job opportunities and less impact on traffic congestion and the nearby environment. Environmental concerns also need to be addressed, including the expectation of lower pollution levels and emissions. Hence, it is essential to evaluate all of these factors not only in the short term but also in the long term when selecting logistics locations to ensure that the interests of all stakeholders are appropriately addressed.

From a sustainability perspective, He et al. (2017) stated that the stakeholders involved in city logistics include shippers, freight carriers, administrators, residents, receivers, leading industries in the city, and other related industries. However, when considering the location of logistics centers specifically, the author of this study argues that there are additional stakeholders that need to be taken into account. These additional stakeholders are the environment, company shareholders, and employees. In summary, the stakeholders involved in logistics center location should be logistics companies, company shareholders, the environment, municipal governments, surrounding residents, employees, customers, and other related industries. To advance towards more sustainable and habitable cities, it is essential to take into account sustainability concerns of different stakeholders because these stakeholders have varying goals and viewpoints on the selection of logistics center locations (He et al., 2017).

In light of these considerations, a framework regarding the stakeholders involved in the logistics center is proposed and illustrated in Figure 4. This framework is a combination of the author's viewpoint and the framework suggested by He et al. (2017).

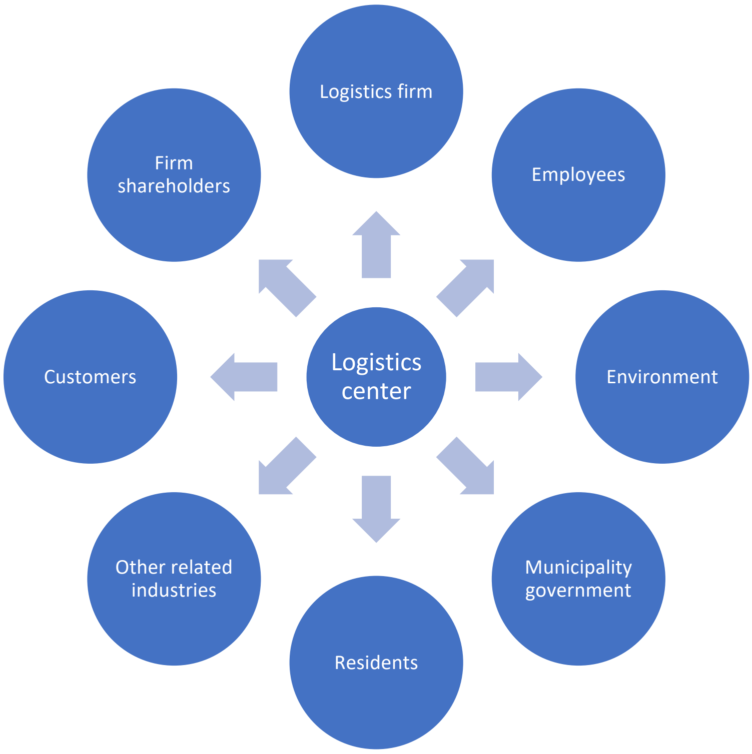

Figure 4. Stakeholders of the logistics center under sustainability

Before considering profitability, it is important for firms to balance financial ability with environmental and social considerations when selecting the location for a logistics center. In this context, financial ability refers to the capacity to acquire and sustain the requisite financial resources that enable the delivery of services to individual clients in accordance with the prescribed standards. Firms should ensure their financial ability before implementing sustainable practices, as the cost of implementing sustainable solutions may be high and potentially lead to bankruptcy or defaulting on operational costs. Therefore, when selecting the location of a new logistics center, firms should prioritize the costs of investment and operation of the new center and evaluate whether the company can sustainably operate and maintain its functionality in the long term. This means that the company's financial ability should be able to cover all estimated costs required to construct and operate the logistics center in a specific region. By taking into account these financial considerations, firms can ensure the long-term viability of their sustainable logistics practices.

From the perspective of investors and firms, profitability and costs are the primary considerations when deciding on the location of a logistics center. The term "investors" in this particular context does not include "green" investors. "Green" investors are individuals or entities who actively seek to invest in businesses that demonstrate a positive effect on the natural environment. These investors are interested in supporting companies or projects that are committed to activities such as the conservation of natural resources, reduction of pollution, or other environmentally conscious business practices. In term of costs consideration, fixed investment costs, such as land acquisition and construction costs, and variable costs, such as transportation, operation costs, are crucial factors that need to be considered. The cost of land acquisition is influenced by the logistics center location. For instance, the price of land in rural areas tends to be lower than in urban or city center areas due to the availability of land.

In addition, labor availability in the region is also a significant factor to consider when calculating the operation cost of a logistics center. The logistics industry relies heavily on labor. Even with significant advancements in technology, process mechanization, automation, and robotization, personnel and labor remain the primary resources (Kilibarda, Andrejić and Pajić, 2019). Furthermore, the availability of skilled labor in the region is becoming increasingly important due to the high level of technological development in the industry. Skilled labor is required to operate and maintain technological systems, which are prevalent in modern logistics centers. People with higher education are likely to have better technological knowledge, who can develop into skilled labor. Higher education institutions play a crucial role in equipping workers with the necessary behavioral, cognitive, and technical skills to be effective in the labor market (World Bank, 2012, xiii). Notably, empirical evidence reveals a positive relationship at the firm level between technological innovation (broadly defined) and the proportion of workers with higher education, as observed in a sample of firm surveys conducted in East Asia. Furthermore, it is acknowledged that a higher proportion of graduates with science, technology, engineering, and mathematics skills generally correlates with enhanced innovation outcomes. (World Bank, 2012, 15-16)

To minimize transportation costs, logistics centers should be located close to urban areas as more than 55 percent of the global population live in urban regions, a number projected to increase to 68 percent by 2050 (United Nations, 2018). However, the decision to locate a logistics center close to a city center is not straightforward. While some researchers argue that locating logistics centers closer to city centers will reduce heavy goods traffic, this will also limit available land for other uses. Additionally, the increased sensitivity of cities to heavy goods traffic, the development of freight transport as a result of e-commerce, the acceleration of pollution, the expected increase in energy costs, and the lack of land for expansion in the long term suggest that logistics centers should not be located near city centers (Combes, 2016). Indeed, the observed trend is that logistics centers are increasingly being located in suburban areas for example Brussels (Belgium), Paris (France) and Gothenburg (Sweden) (Heitz, Dablanc and Tavasszy, 2017; Strale, 2020; Heitz et al., 2020). This trend is due to the availability of cheaper industrial land and less impact from urban traffic congestion, which reduces costs for businesses (He et al., 2018), since road traffic congestion is one of the significant factors contributing to the rise in transportation costs.

Meanwhile the study of Heitz, Dablanc and Tavasszy (2017) in the Randstad region of the Netherlands has also suggested that logistics facilities can be located intensively within the main urban areas rather than being compelled to relocate to the suburbs. However, from the author' perspective, this may not necessarily apply to logistics centers in general. The long-term benefits of moving to exurban and suburban areas may outweigh those of locating within urban areas. Given the significant costs associated with constructing or relocating a logistics center, it is crucial to prioritize long-term advantages that will prove beneficial to logistics businesses over an extended period.

One primary reason for considering suburban locations is the comparatively lower land prices and the potential reduction in traffic congestion. Suburban areas often offer more affordable land options compared to urban areas, enabling cost savings for logistics businesses. Moreover, moving logistics centers away from densely populated urban areas can help alleviate traffic congestion, enhancing operational efficiency and reducing transportation delays. Another essential factor to consider is the potential for future expansion. Suburban locations typically provide greater possibilities for the extension of logistics facilities compared to urban areas where land availability may be limited due to urbanization and the increasing demand for accommodation and residential spaces. Given the trend of urbanization and the influx of people into urban areas, land for logistics centers may become scarce, making suburban locations more viable for long-term growth and development.

Although transportation costs may be higher due to longer transport distances, this issue can be mitigated by strategically locating logistics centers near transportation infrastructure, such as highways or intersections, in suburban areas that are still within reasonable proximity to urban centers. This proximity ensures efficient connectivity to major transport networks while benefiting from the cost advantages of suburban land.

In summary, while some cases suggest intensification of logistics facilities within urban areas, the decision regarding logistics center location should carefully consider the potential long-term benefits. Suburban areas offer advantages such as lower land prices, reduced traffic congestion, and greater expansion possibilities. Although transportation costs may be a consideration, proximity to transportation infrastructure and urban centers can alleviate this issue. Considering these factors, it can be inferred that locating a new logistics center in suburban areas, or at least avoiding urban areas, is a reasonable decision.

According to analysis of logistics activities' external impacts by Piecyk, Cullinance, and Edwards (2015, pp. 32-45) and Grant, Trautrims, and Wong (2023, 54-56), as well as the author's own perspective, Table 1 has been developed to provide an overview of the diverse impacts of logistics centers on the stakeholders involved. The table aims to shed light on the social and environmental effects associated with the establishment and operation of logistics centers, which have ramifications for a wide range of stakeholders.

Table 1. Impacts of logistic centers' location and involved stakeholders (excepting the other related industries)

Impact of logistics center location	Impacted stakeholder
Greenhouse gas emission, Air pollution, Global effect of air pollution	Environment, Residents, Customers, Employees, Firm shareholders, Municipalities governments
Noise pollution	Residents, Employees, Environment
Traffic congestion	Residents, Employees, Logistics firms, Environment
Land use demand	Environment
Profitability and cost	Firm shareholders, Logistics firms
Regional economic growth	Residents, Employees, Municipalities governments, Logistics firms
Creation of job opportunities	Employees, Residents

From Table 1, it can be seen that the social and environmental effects associated with the location of logistics centers, affect various stakeholders. It encompasses factors such as greenhouse gas emissions, air pollution, and the global effects of air pollution, which have wide-ranging effects on the majority of stakeholders involved. While there are positive impacts such as job creation and regional economic growth, the majority of the effects are negative, including greenhouse gas emissions, air pollution, global effects of air pollution, noise pollution, and increased traffic congestion. From the perspective of municipalities, communities, and the environment, the location of logistics centers should be considered under the sustainability perspective to improve economic opportunities while minimizing adverse effects on nearby residents and the environment.

In addition to locating logistics centers close to major cities and transport network to reduce transport distances, thereby reducing greenhouse gas emissions and air pollution, several other factors should also be considered. The region selected for the logistics center should have sufficient land for the center's placement and future expansion needs. Moreover, the promotion of intermodal transportation in logistics center location selection can have financial and environmental benefits (Dey, LaGuardia, and Srinivasan, 2011). Firms that use water freight and rail freight for long-distance transportation can reduce road time, resulting in lower carbon emissions. Intermodal transportation has been found to be the most efficient method for shipping goods. Furthermore, a study in logistics and inventory management has demonstrated that companies can reduce storage costs and improve response times by sending their shipments to intermodal terminals. This advance positioning of goods and services offers an opportunity for intermodal transport providers to contribute to the sustainability of the supply chain. This is because intermodal transportation has a lower environmental impact per ton mile compared to road transport. (Dey, LaGuardia, and Srinivasan, 2011)

While some individuals may favor road transport due to its flexibility and ability to provide door-to-door delivery, it is essential to consider the broader context. Road transport is often perceived as the fastest and most cost-effective option for delivering goods, particularly over long distances (European Court of Auditors, 2023). In contrast, alternative modes of transport such as rail or inland waterways are characterized by slower speeds and reduced flexibility. These modes also necessitate specific infrastructure that cannot be replicated at every shipping location. However, they offer improved safety and environmental performance and can alleviate congestion on roads. The promotion of intermodality involves leveraging the inherent strengths of different transport modes rather than imposing the use of intermodal transportation on businesses. The European Commission has underscored the importance of transitioning from unimodal road transport to a greater reliance on intermodal transport. A modal shift in transport away from roads and an increased utilization of intermodal transport can play a key role in enhancing the environmental friendliness of freight transport in Europe. (European Court of Auditors, 2023)

Moreover, the research of Zahraee et al. (2022) conducted in Victoria, Australia provides additional support for the transition to intermodal transportation. The study reveals that combining truck and train transport, coupled with larger and more capacious containers, results in a near 60 percent decrease in gaseous pollutant emissions. Modifying container capacity from light to medium and heavy leads to average reductions of 46 percent and 59 percent in cumulative emissions, respectively. (Zahraee et al., 2022) By embracing intermodal solutions, the logistics industry can advance its commitment to greener transportation and foster a more sustainable future.

With the growing emphasis on sustainability in logistics, the selection of suitable location for logistics centers has become crucial in promoting sustainable economic development, enhancing customer satisfaction, reducing investment costs and operating expenses, and facilitating future expansions while ensuring sustainability (He et al., 2017). Therefore, the location selection process should be approached as a multi-criteria decision-making problem that incorporates both profitability criteria, reflecting the consideration of cost minimization and/or customer satisfaction, and sustainable criteria.

Due to the challenge in achieving a balance among these dimensions, as some criteria may conflict with one another, this thesis proposes two different approaches to address the complexities of sustainability. The first approach involves developing a single model that integrates all criteria under the three dimensions of sustainability, which can be used to balance these factors. This approach recognizes that sustainability is a complex concept that requires a holistic approach, and that a single model can help in decision-making by providing a comprehensive understanding of the effect of different factors on sustainability. The second approach involves considering sustainability from two different perspectives: the firm's perspective and the other stakeholders' perspective. The firm's perspective focuses on profitability and cost minimization, while the other stakeholders' perspective considers social and environmental factors. These perspectives will be evaluated in two separate models to allow for a more nuanced understanding of the impact of different factors on sustainability. By comparing and contrasting these two approaches, a final decision can be made that takes into account all relevant factors and balances the economic, social, and environmental dimensions of sustainability. This approach acknowledges the complexity of sustainability and recognizes that there is no one-size-fits-all solution.

3. Literature review

The literature review is structured into two distinct sections: method and criteria. This division allows for a more organized and comprehensive presentation of the literature, enabling the author to thoroughly review methods employed in previous studies for evaluating and selecting location of logistics centers, as well as the criteria used for assessing logistics center location. By delineating these sections, the author can provide clearer information and ensure a more thorough understanding of the literature, facilitating an appropriate selection of both the methodological approach and the criteria for the logistics center location selection process.

3.1 Method

In this section, an overview of the methods utilized in previous studies logistics center location assessment is presented, shedding light on the diverse research methods employed to explore the logistics center location problem.

As a part of logistics infrastructure, the problem of selecting a location for a logistics center can be considered as a particular instance of the logistics facility location problem. Numerous studies have already been published in the academic literature, examining and validating the selection of sites for logistics facility location via various methods. Among these methods, Multi-Criteria Decision-Making (MCDM) techniques are dominantly widespread than the others, such as Geographic information systems (GIS), Center of Gravity Method or mathematical models (Uyanik, Tuzkaya and Oğuztimur, 2018; Uyanik et al., 2020) as they are believed to provide the optimal solution by evaluating and sorting the available alternatives based on specific criteria in various application areas (Pekkaya and Keleş, 2022).

Regarding MCDM methods, the utilization of fuzzy-based approaches has been extensively employed. These methods rely on expert or decision maker linguistic opinion-based evaluation information to address the decision-making problem. Ou and Chou (2009) employ a weighted Fuzzy Factor Rating System (FRS) to determine the optimal location for an international distribution center from the perspective of a foreign market. The FRS is based on the opinions of a group of decision makers. Kayikci (2010) develops a combined method of

Fuzzy Analytic Hierarchy Process (FAHP) and Artificial Neural Network (ANN) to identify the most suitable location for intermodal freight logistics centers. The decision-making process involved data collection through interviews with decision makers. Erkayman et al. (2011) propose a Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (F-TOPSIS) approach for the selection of logistics center location in the eastern Anatolia region of Turkey. Four expert groups participate in providing fuzzy evaluations and weight criteria using linguistic variables. Li, Liu and Chen (2011) developed a methodology using a combination of axiomatic fuzzy set clustering method and TOPSIS to solve logistics center location problem. Kuo (2011) introduced a new hybrid method of the fuzzy DEMATEL and the analytic hierarchy/network process (AHP/ANP) to select the optimal location for an international distribution center. Similarity, Liu et al. (2011) presented a new hybrid heuristic algorithm, combining rough set methods and fuzzy theory, to solve the distribution center problem. In order to support the planning of urban distribution centers in uncertain environment, Awasthi, Chauhan and Goyal (2011) developed a hybrid method of fuzzy theory and fuzzy TOPSIS. This method enables the quantification of criteria values and the evaluation of potential locations to determine the optimal site for establishing the distribution center. To identify the most suitable location for establishing a new logistics center in the airline industry, an integration of fuzzy TOPSIS and multichoice goal programming (MCGP) is developed and demonstrated with a case study in China by Chen, Liao and Wu (2014). The fuzzy preference ranking organization method for enrichment evaluation (fuzzy-PROMETHEE) is used to evaluate freight logistics center locations with the application in the case study of Turkey (Elevli, 2014). Aiming to assess suitable locations for logistics centers in Turkey, a multi-stage methodology was employed by Önden, Acar and Eldemir (2016), incorporating the use of fuzzy analytic hierarchy process (FAHP) and spatial statistics and analysis. Regarding the selection of city logistics center location, Rao et al. (2015) utilized a fuzzy approach based on a linguistic 2-tuple model and ordered weighted averaging to determine the most suitable location. In terms of humanitarian logistics context, Boltürk et al. (2016) implemented the FAHP method to choose a suitable warehouse location in the northwest region of Turkey. Pham, Ma and Yeo (2017) developed a benchmarking framework for identifying the optimal location of a logistics center in Vietnam by employing a combination of Delphi and TOPSIS methods with fuzzy measures. He et al. (2017) introduced a novel hybrid fuzzy MCDM technique that integrates fuzzy Analytic Hierarchy Process (AHP), fuzzy-entropy method for weight assignment, and enhanced fuzzy TOPSIS for prioritizing alternatives using expert evaluation data. The proposed method is applied in a case study conducted in Chongqing City, China. Kazançoğlu, Özbiltekin and Özkan-Özen (2019) conducted sustainability benchmarking for the selection of a logistics center location in Turkey by employing a fusion of fuzzy AHP and Preference Ranking Organization METHod for Enrichment Evaluations (PROMETHEE) based on expert evaluation data. Yazdani et al. (2020) developed a two-stage decision-making model to determine the optimal location for establishing logistics centers in Spain. The proposed approach employs Data Envelopment Analysis (DEA) to distinguish between efficient and inefficient alternatives in the first stage. In the second stage, the performance of the efficient alternatives is evaluated using the Rough Full Consistency (R-FUCOM) and Combined Compromise Solution (R-CoCoSo) methods, taking into account the input of decision makers' judgments. Recently, Bennani et al. (2022) implemented an integration of Fuzzy Stepwise Weighted Assessment Ratio Analysis (F-SWARA), Fuzzy Entropy and Fuzzy Vlse Kriterijumska Optimizacija Kompromisno Resenje (F-VIKOR) methods to determine the optimal zone for an urban distribution center in Casablanca city in Morocco based on information from expert opinions and stakeholder reviews.

In addition to fuzzy MCDM methods, a number of other MCDM methods have been employed for evaluating the location selection problem with quantitative data. Markovits-Somogyi, Gecse, and Bokor (2011) conducted a study on the suitability of DEA method for assessing the efficiency of Hungarian logistics centers. Regmi and Hanaoka (2013) employed AHP and goal programming methodologies to evaluate the logistics center location in Laos. Żak and Węgliński (2014) utilized the elimination and choice expressing reality (ELECTRE III/IV) method to rank regions based on their suitability for locating a logistics center, with the aid of fixed and known numerical data. Andrejic´ and Kilibarda (2015) introduced a combination method of principal component analysis and DEA model to measure efficiency and select distribution channels for logistics centers. Peker et al. (2016) proposed a logistics center selection model based on the analytic network process (ANP) technique in Trabzon, Turkey. Özceylan et al. (2016) developed a methodology for selecting logistics center locations in Ankara by combining the GIS, ANP, and TOPSIS methods. Özmen and Aydoğan (2019) applied a three-stage approach to present a framework for selecting the location of logistics centers within the logistics development plan of Kayseri, using the linear best-worst method (BWM) for weighting the criteria and the average solution (EDAS) method for evaluating and ranking the locations based on different distance measures.

Agrebi, Abed and Omri (2017) employed the ELECTRE method establish a ranking of the evaluated distribution center locations.

The findings of various literature reviews on the issue of logistics center location selection indicate that most research studies have relied on the utilization of MCDM techniques based on fuzzy logic, such as Fuzzy TOPSIS, Fuzzy AHP, and Fuzzy PROMETHEE methods (Yazdani et al., 2020; Uyanik, Tuzkaya and Oğuztimur, 2018). Researchers have shown significant interest in applying fuzzy sets, linguistic, and probabilistic methods due to their potential to handle imprecise and vague information during the evaluation process. Although the implementation of MCDM in a fuzzy environment can assist experts in managing uncertainty and imprecise information, it is noteworthy that the final outcome of the evaluation can be impacted by various factors, including expert experience, personal preferences, and the knowledge structure of the field (Chen, 2017). However, it is impractical to assume that an expert's knowledge and representation can be precise in an environment characterized by imprecision and uncertainty (Turskis and Zavadskas, 2010). In the past, obtaining multi-criteria information and quantifying it in a model was a challenging task, leading to the more common use of expert consultation methods for logistics center location selection in actual studies. However, with the increasing digitalization of the world, an abundance of quantitative data is now being recorded and made available. As a result, quantitative methods for dealing with the problem of logistics center location selection have the potential to advance further compared to expert consultation, which relies on qualitative analysis and may lack certain degrees of credibility in its results. This creates a demand for MCDM methods that can effectively utilize numerical data in the selection process.

As reported by Uyanik, Tuzkaya and Oğuztimur (2018), among the MCDM methods, AHP and TOPSIS are the most widely used MCDM methods for quantitative data in logistics center location problem. Both AHP and TOPSIS are considered easy to use, but AHP has been used in more studies than TOPSIS. However, AHP becomes more challenging to deal with a large number of alternatives and criteria (Özcan et al., 2011). When solving logistics center location problems with quantitative data, the number of criteria can be large, and TOPSIS is likely to be more appropriate as it can handle a large number of alternatives and criteria. Additionally, TOPSIS has the advantage of maintaining a consistent number of steps irrespective of problem size. Nevertheless, a drawback of TOPSIS is its use of Euclidean Distance, which does not take attribute correlations into consideration (Velasquez and

Hester, 2013) or any behavioral or personality traits of decision-makers (Luukka and Stoklasa, 2021). Thus, while TOPSIS is an effective tool for solving logistics center location problems with a large number of criteria, researchers should be aware of its limitations when applying it to real-world decision-making situations.

To address the existing gap and limitations of common MCDM methods for numerical data in logistics center location problems, a new method is proposed by this study. This method aims to fulfill the need for MCDM techniques that can handle numerical data while integrating the personality traits of decision-makers into the evaluation process. By addressing the shortcomings of existing methods, the proposed approach seeks to contribute to the field of logistics center location selection and enhance decision-making outcomes in practical settings.

3.2 Criteria

As MCDM techniques are mainly used in logistics center location problem, it is essential to select proper decision criteria for evaluation process, which can impact significantly on the solution. Numerous studies have investigated the logistics center location selection problem using MCDM methods from various perspectives and proposed various criteria for the problem evaluation. According to Terouhid, Ries, and Fard's (2012) research, decision-makers have traditionally concentrated on the economic factors when making facility location decisions. However, with the growing significance of sustainable development, location decisions now often consider environmental and social effects as well. A comprehensive review of the academic literature revealed 13 articles that used MCDM methods for logistics center location selection and their corresponding criteria, as presented in Table 2. The review commenced by conducting a search using the terms "logistics center" and "sustainability" in the titles of articles through Google Scholar and LUT Primo, the search service provided by LUT Academic Library. However, the search yielded a limited number of relevant articles. To expand the scope of the investigation, the keywords were broadened to include "freight village" and "distribution center," either with or without the term "sustainability." From the pool of studies identified, specific attention was given to logistics facility location studies pertaining to logistics centers. The study period for the review spanned from 2014 to 2022, encompassing a total of eight recent years. This time frame was selected purposefully to ensure that the articles included in the review could effectively reflect the most current trends and criteria utilized in the decision-making process for determining logistics center location.

Table 2. 13 recent studies regarding logistics center location selection and their used criteria

No.	Citation	Location	Main/Sub-Criteria
(1)	Chen, Liao and Wu (2014)	China	Resource availability, Location resistance, Expansion possibility, Investment cost, Information abilities
(2)	Żak and Węgliński (2014)	Poland	Condition of transportation infrastructure, Economic development, Investment cost, Level of transportation and logistics competitiveness, Investment attractiveness, Transportation and logistics attractiveness, Social attractiveness, Environmental-friendliness, Safety and security
(3)	Elevli (2014)	Turkey	Site suitability, Background activities/facilities, Access to transportation/network, Property conditions, Location and interconnected business activities
(4)	Rao et al. (2015)	_	Land price, Upside delivery flexibility, Transportation conditions, Service level, Human resources condition, Environmental protection level, Impact on ecological landscape, Natural conditions, Public facilities condition, Security, Comply with environmental laws and regulations, Impact on nearby residents, Impact on traffic congestion
(5)	Özceylan et al. (2016)	Turkey	Proximity to the existing railroad/railway system, Proximity to the existing highway system, Proximity to an airport, Proximity to industrial zone, Distance to population density, Distance to forest zone, Distance to rivers, Distance to lakes, Distance to earthquake epicenter, Slope of land, Cost of land
(6)	Pham, Ma and Yeo (2017)	Vietnam	Proximity to market, production area, and customers, Proximity to seaports, Proximity to airports, Proximity to highways, Proximity to railways, Proximity to inland waterways, Capability for expansion of area, Freight demand, Development policies for economic zone and free trade zone nearby, Land acquisition cost, Construction cost, Transportation cost, Environmental impact of construction activities, Environmental impact of transportation activities
(7)	He et al. (2017)	China	Price of acquiring land, Possibility of expansion, Access to transportation, Delivery timeliness Resource availability, Tax policy, Impact on traffic congestion, Impact on nearby residents, Role in promoting development of leading industry, Harmonization with regional economic planning, Impact on ecological landscape, Environmental protection level, Natural conditions
(8)	Karasan and Kahraman (2019)	Turkey	Transportation cost, Building cost, Capacity, Operational costs, Workforce, Transportation and distribution systems, Infrasturucture, Intermodal operations and management, International market location, Suitability to extension of land, Taxing, Workforce cost, Pollution, Noise, Logistical service level, Value-added services, Deliver costs, Accidents, Traffic congestion, Conservation of energy, Earthquake risk, Delivery time, Integration, Transportation and logistical competition level,

			Investment attraction, Origin/Destination proximities, Average traffic speed, Governmental incentive
(9)	Kazançoğlu, Özbiltekin and Özkan-Özen (2019)	Turkey	Transportationaccess, Land price, Expansion possibility, Impact on landscape, Impact on traffic congestion, Role in supporting the industry, Creating job opportunities
(10)	Özmen and Aydoğan (2019)	Turkey	Land (Size and shape of the land, Ownership and ten- ure condition of the land, Land infrastructure, Land expansion potential, Physical conditions of the land), Market (Proximity to free zone, Accessibility is the accessibility to public and private modes of transport, International consumption market, International production market, Proximity to Middle Eastern markets), Social (Urban traffic impact, Impact on disaster logistics, Social attraction, Employment contribution), Transportation (Proximity to the city, Proximity to production centers, Proximity to consumption centers, Proximity to the airport, Proximity to the railway, Proximity to the highway, Proximity to port (sea), Connectivity to other transport methods), Environmental effects (Environment-friendly, Energy use, Waste disposal), Intermodal operation and management (Operation competence, Information technology infrastructure, Service availability, Coordination, Quality, Connection, Interoperability), Cost (Basic construction/structure/building investment, Cost for users, Port fees, Transportation cost, Contribution to economic development), National stability (Customs, European corridors, Political stability, Economic stability, Social stability), Risk and safety (Safety, security, Risk of the accident)
(11)	Yazdani et al. (2020)	Spain	Accessibility, Security, Connectivity to multimodal transport, Cost, Environmental impact, Proximity to customers, Proximity to suppliers, Resource availability, Conformance to sustainable freight regulations, Possibility of expansion, Quality of service
(12)	Uyanik et al. (2020)	Turkey	Cost, Natural resources, Proximity to railroad system, Proximity to highway system, proximity to city center, Proximity to harbour, Size, Suitability to enlargement (land), Proximity to industrial zone, Macro-economic benefits/performance, Environmental impacts, Freight transport, Suitability to construction (topography, geography, ground structure), Cost of construction process, Accessibility to labour pool, Transportation and logistics attractiveness
(13)	Bennani et al. (2022)	Morocco	Availability of land, Possibility of extensions, Existence and position of potential suppliers and customers in the urban air, Infrastructure of the city, Geographical conditions, Accessibility of the information system, Environmental safety and security, Natural disaster risk, Level of development of the area, Attractiveness of the region through investment in logistics, Government policy on the development of the area

Table 3. Summary of criteria review

No.	Criteria	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	Used times
1	Costs (Construction investment, Operational cost, Labor cost etc.)	x	x				x		x		x	x	x		**7**
2	Land price				x	x	x	x		x					5
3	Proximity to customers/market	x		x			x	x			x	x		x	**7**
4	Proximity to suppliers											x		x	2
5	Proximity to industrial zone/production area					x	x				x		x		4
6	Possibility of expansion	x					x	x	x	x		x	x	x	**8**
7	Infrastructure (transportation infrastructure, traffic condition, public facility, etc.) and service level		x	x	x				x			x		x	**6**
8	Access to transportation/network			x				x		x	x	x			5
9	Human resources condition/Accessibility to workforce			x	x				x				x		4
10	Proximity to railway system					x	x						x		3
11	Proximity to highway system					x	x				x		x		3
12	Proximity to the airport					x	x				x				3
13	Proximity to port/water transportation						x				x		x		3
14	Natural environment (Weather condition, Land condition, Resource condition/availability etc.)			x	x	x		x			x	x	x	x	**8**
15	Government policy						x		x					x	3
16	Investment attractiveness		x						x					x	3
17	Tax policy							x	x						2
18	Security		x								x	x		x	4
19	Impact on landscape/Environmental impact			x	x		x	x	x	x	x	x	x	x	**10**
20	Impact on traffic (congestion)				x			x	x	x	x				5
21	Economic development		x										x	x	3

**Note: Table 3 presents a summary of the criteria review conducted across the 13 selected papers (numbered 1 to 13). The corresponding papers can be referenced in Table 2. In this table, the presence of an "x" in a specific cell signifies that the corresponding criterion is addressed in the corresponding paper. The bold numbers in "Used times" column highlight the criteria with the highest frequency of usage.*

Based on the analysis of these studies, it was found that approximately 21 criteria were commonly used in the location evaluation process, which are summarized in Table 3. According to Table 3, it can be observed that the most frequently used criteria in evaluating logistics center location in recent studies are related to the natural environment, which includes factors such as weather conditions, land condition, resource availability (e.g., water, energy supply), environmental impact (e.g., impact on landscape, environmental friendliness) as well as the potential for future expansion of logistics center. The second most popular group of criteria includes costs and proximity to customers or markets (both domestic and international). Additionally, infrastructure and service level emerge as key criteria for evaluating logistics center location. This criterion underscores the importance of assessing the quality and availability of transportation networks, communication infrastructure, and supporting services. Although criteria related to proximity to railway systems, highway systems, ports or water transport, access to transportation network, and connectivity to multimodal transport are less frequently used when considered separately, their importance increases significantly when grouped under the category of accessibility to transportation network and/or multimodal transport. Moreover, although criteria related to land price and costs exhibit relatively lower individual frequencies of use, they gain substantial importance when combined into the overarching cost criterion. This observation aligns with the findings of Uyanik, Tuzkaya, and Oğuztimur (2018), who conducted an in-depth analysis of the literature on logistics center location selection. Their research supports the significance of natural resource availability, accessibility to different transportation modes, and the need for future expansion flexibility as crucial criteria. However, the prioritization of cost-related criteria is a key difference between the findings of this study and Uyanik, Tuzkaya and Oğuztimur (2018) as the land price is emerged into cost criterion.

The criteria used in the evaluation process of the logistics center location selection are highly diverse and are influenced by many factors such as the location (country) of the case study, the characteristics of the logistics center, and the perspective of the author conducting the study. For instance, the criteria may vary depending on whether the location is for international distribution centers, urban distribution centers, or freight villages, and whether the author approaches the problem from a government, business, or financial expert perspective. Given this complexity, it is crucial to recognize that the determination of criteria for selecting the location of logistics centers should be approached on a case-by-case basis, considering the aforementioned factors. A careful consideration of these elements ensures the selection of an appropriate and tailored set of criteria that aligns with the specific requirements and objectives of the logistics center in question.

The optimal placement of facilities in logistic center location problems typically involves minimizing costs or maximizing desirability, however, economic factors alone do not suffice to address the long-term repercussions of location choices (Terouhid, Ries and Fard, 2012). In recent years, businesses and public authorities have placed a growing emphasis on adhering to the principle of sustainability, which aims to the long-term viability of installations while simultaneously achieving gains on the economic, societal, and environmental fronts (Bennani et al., 2022).

As evidenced from the analysis of recent studies, the criteria related to environmental and social impacts are commonly considered in logistics center location selection. Thus, it can be inferred that sustainability is increasingly becoming a crucial consideration in the process. The literature review focusing on sustainability in the context of logistics center location selection is presented in the following section.

3.3 Sustainability in logistics center location problem

According to the literature, there is a growing trend in research towards incorporating sustainability and green considerations in the decision-making process for selecting logistics center locations. However, while the literature has expanded to consider social and environmental criteria alongside economic criteria in location decision-making, the direct reference to sustainable development in location problems is still infrequent (Terouhid, Ries, and Fard, 2012). The majority of existing studies only incorporate a limited number of sustainability or environmental criteria in the decision-making process, and few place a significant emphasis on sustainability issues when choosing the location for implementing logistics centers.

Among these researchers that focused on sustainability in the problem of logistics center location, Rao et al. (2015), He et al. (2017) and Kazançoğlu, Özbiltekin and Özkan-Özen (2019) have contributed significantly to this area. In their study, Rao et al. (2015) investigated the location selection of city logistics centers under sustainability using the TOPSIS method. The researchers presented 12 sustainability criteria, which were grouped into sustainability dimensions of economic, environmental, and social. The economic criteria included price of acquiring land, upside delivery flexibility, transportation conditions, service level, and human resource condition. The environmental criteria included environmental protection level, impact on ecological landscape, and natural conditions, while the social criteria encompassed public facilities condition, security, compliance with environmental laws and regulations, and impact on nearby residents. He et al. (2017) also took into account sustainability in joint distribution center location selection, and organized the selected criteria into three sustainability dimensions: economy, society, and environment. Under the environmental dimension, the sub-criteria were impact on ecological landscape, environmental protection level, and natural conditions, while under the social dimension, the sub-criteria were impact on traffic congestion, impact on nearby residents, role in promoting development of leading industry, and harmonization with regional economic planning. Kazançoğlu, Özbiltekin and Özkan-Özen (2019) approached sustainability from a benchmarking perspective and identified seven sustainability criteria in their location evaluation model, which included transportation access, land price, expansion possibility, impact on landscape, impact on traffic congestion, role in supporting the industry, and creating job opportunities.

The articles authored by the aforementioned researchers employed an evaluation method that considered and assessed various sustainability criteria grouped under different dimensions in a single model based on expert opinions. However, this method may have some limitations. One significant limitation is its heavy reliance on expert subjective opinions, which could result in the overvaluation of specific criteria within one dimension over others. Moreover, even when the weights accurately represent the preferences of the experts, there can still be a tendency for bias towards certain dimensions. For example, there may be instances where the economic dimension is assigned a higher weight than the environmental and social dimensions. This prioritization of economic considerations over environmental and social factors can be reasonable and desirable when emphasizing profitability over societal and environmental impact. However, it does not imply that all criteria within the economic dimension, which are assigned higher weights than those within the environmental and social dimensions, are inherently more important than the latter.

This issue stems from the allocation of weights from the overall weight assigned to the economic dimension to the individual sub-criteria weights, particularly when the number of criteria under the economic dimension is fewer than those under the environmental and social dimensions. Consequently, the location selection process may exhibit bias towards the economic dimension, neglecting a comprehensive sustainability perspective. One potential resolution to this issue is the separate assignment of weights to each sub-criterion. However, challenges persist when dealing with a large number of criteria, as smaller weight values can make it difficult to differentiate between them during the evaluation process. Additionally, the inclusion of numerous criteria within a single model can present difficulties in interpreting and distinguishing the nuanced differences between alternatives when their values are closely similar. Conversely, if all dimensions are given equal weight, issues could arise if some dimensions have numerous criteria compared to others. In such cases, the weight values of sub-criteria can be relatively smaller, leading to incorrect reflections of criteria importance in the evaluation model.

In the group of researchers who only included some environmental and/or social criteria in their evaluation, Żak and Węgliński (2014) considered environment-friendliness criterion which defines the condition and the friendliness of the environment in each alternative in solving the logistics location problem. Similarly, Yazdani et al. (2020) and Uyanik et al. (2020) considered environmental impact as an influential criterion in the selection of a region for establishing a logistics center in urban areas. Pham, Ma and Yeo (2017) included environmental impact of construction activities and transportation activities in the evaluation process, as taking into account social and environmental responsibility. However, these criteria were given lower priority by expert opinions. Karasan and Kahraman (2019) initially included pollution, noise, accidents, and traffic congestion criteria in their evaluation process, but these were found to be minor and less effective factors and were thus eliminated from the evaluation process. In the study of Özmen and Aydoğan (2019) in the determination of optimal logistics center locations, several criteria related to environmental and social dimension are taken into consideration, such as urban traffic impact, impact on disaster logistics, social attraction, employment contribution, environment-friendliness, energy use, and waste disposal. Finally, Bennani et al. (2022) emphasized the importance of environmental safety and security in the evaluation of suitable locations for urban distribution centers in Casablanca, Morocco.

4. Methodology

In this study, a novel approach called similarity-based TOPSIS incorporating a linguistic-quantifier based aggregation method using Ordered Weighted Averaging (OWA) operators introduced by Luukka and Stoklasa (2021), is proposed for the selection of optimal logistics center locations. This method is a recent development that provides decision-makers with enhanced flexibility in integrating their preferences during the decision-making process. The flexibility in accommodating the decision maker's preferences is particularly important in the context of logistics center location selection due to the inherent variability in decision-makers' preferences. Different decision-makers may prioritize distinct factors when evaluating potential logistics center locations and have different requirements regarding how similar the considered locations are to an ideal location (PIS or NIS), leading to varying ranking orders of considered alternatives. This flexibility serves as a key motivation for the author to apply this method in the study of logistics center location selection. Notably, this research represents one of the pioneering studies to apply this approach, contributing to the existing literature by offering a more flexible and customizable approach for evaluation in the context of logistics center location selection under sustainability considerations.

The proposed approach allows decision-makers to incorporate various dimensions of sustainability and take into account multiple criteria. Importantly, the decision maker's preferences on each dimension can be reflected differently in separate models, enabling a more nuanced analysis and evaluation. This approach not only facilitates the integration of various sustainability dimensions into the decision-making process but also allows for a more detailed consideration of preferences associated with each sustainability dimension. For instance, decision-makers are able to employ different requirements regarding the potential locations being considered in terms of how similar they are to an ideal location (PIS or NIS), thus allowing for a more accurate representation of their preferences.

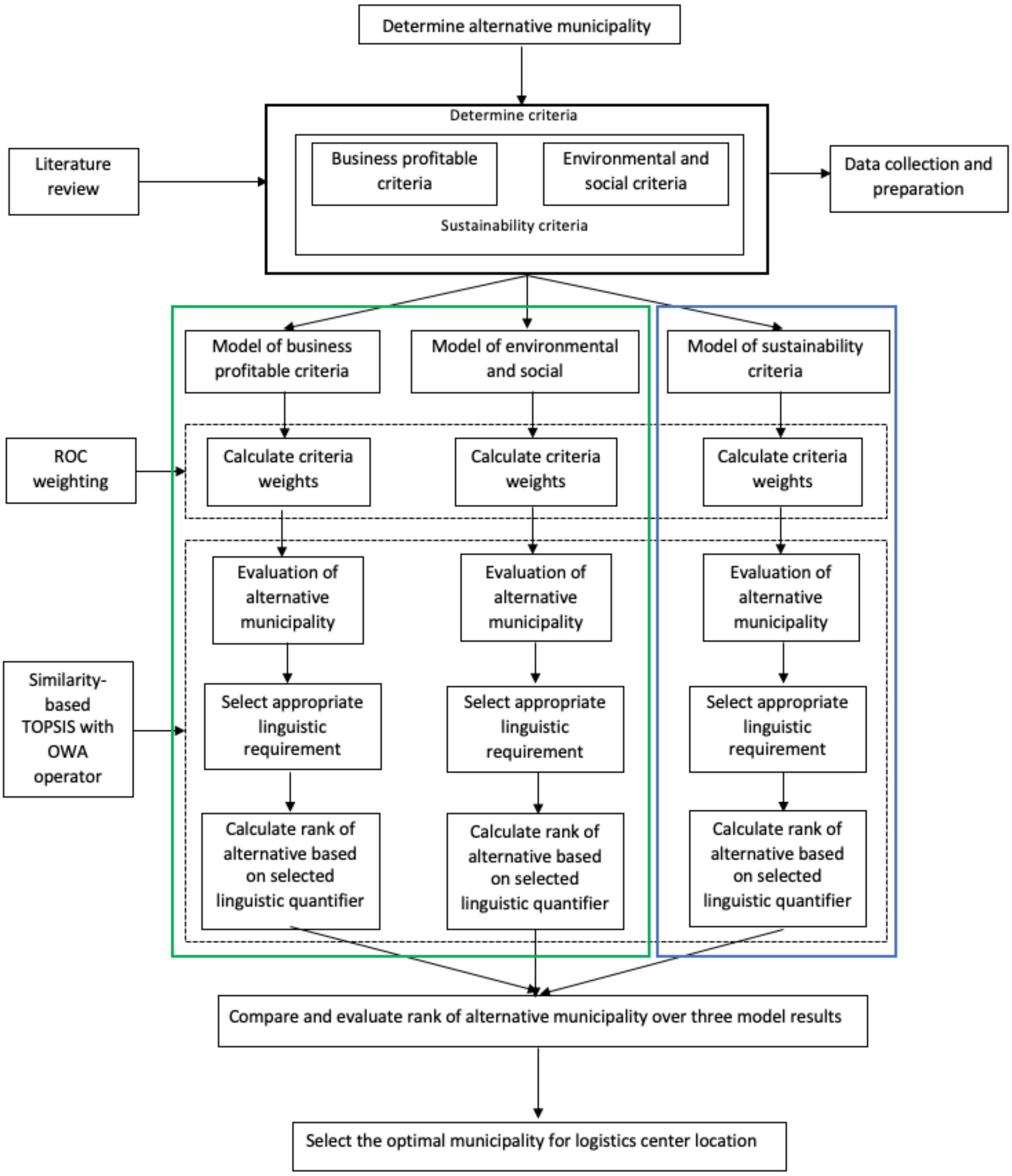

Figure 5: Framework for the evaluation and selection of logistics center sites under sustainability perspective

**Note: In this figure, the green frame represents for the integration of Profitability and Social-Environmental models, while the blue frame represents for the integration of all sustainability criteria in one single model.*

The proposed framework for selecting logistics center location under sustainability point of view is illustrated in Figure 5. Initially, alternative municipalities are selected based on pre-determined criteria obtained through logistics definition and characteristics. The criteria for the evaluation process are selected based on a literature review and should be suitable for the macro-level analysis. The identified criteria are categorized into three groups, namely, business profitability, environmental and social factors, and sustainability factors. The environmental and social group encompasses criteria related to the social and environmental dimensions of sustainability. The proposed framework’s outcomes are analyzed and interpreted through two approaches: the integration of Profitability and Social-Environmental models, and the integration of all sustainability criteria in one single model.

Data regarding the alternatives are collected from the official websites of the municipalities and national databases. Three models are established, each representing a group of criteria. In this study, the importance of the criteria within each model is determined through a ranking process, and weight values are computed using the rank-order centroid (ROC) weight method based on the ranking order of criterion importance, which is proposed by Roszkowska (2013). It is essential to acknowledge that the ROC weight method is not the compulsory weight method for the framework proposed by this study. The weight method can be selected by decision-makers based on their preference, such as expert weights, AHP, etc. In this particular study, the choice of the ROC weight method is driven by the practical constraints of the decision-making process. In certain situations, decision makers may have limited access to precise quantitative data regarding the true weights of the criteria. However, they can still provide valuable insights by establishing a rank order based on their subjective assessment of the criteria's relative importance.

By employing the ROC weight method, this study addresses this limitation and make use of the decision maker's expertise in determining the rank order of the criteria. The method allows for the derivation of weights by considering the relative positions of the criteria within the rank order. This approach enables a quantitative representation of the criteria's importance, despite the absence of specific weight values. The use of the ROC weight method is particularly relevant when the decision-making process prioritizes the criteria based on their order rather than their exact numerical values. It provides a practical and feasible solution for situations where limited information is available regarding the precise weights of the criteria.

After defining criteria weights, alternatives are evaluated using similarity-based TOPSIS, incorporating a linguistic-quantifier based aggregation method using OWA operators. The OWA operator is a specific type of aggregation operator that was introduced by Yager (1988) for use in multi-criteria decision-making evaluation. The ranking of alternative is obtained for each of the three models based on the specific linguistic requirements preferred by a selected type of decision-maker. To illustrate the functionality of the method, a sensitivity analysis is performed to examine the effects of changes in the decision-maker's attitudes. Finally, the optimal municipality is identified by comparing and evaluating the results obtained from the three models.

4.1 Alternative determination

In the context of logistics center location selection, a preselection step is necessary when businesses have not yet identified any specific municipalities for evaluation. This step involves identifying a list of municipalities that have the potential to accommodate a logistics center based on some fundamental criteria. The criteria are chosen to ensure that the logistics center can perform its basic functions, while also reducing costs for the business and mitigate negative impact on the environment and social.

The pre-selection process for municipalities for logistics center location should take into account four key factors as proposed by the author of this study. Firstly, the municipality should have easy access to at least two different transportation modes, including road transport as one of foundational element of logistics centers. Secondly, the logistics center should be located in a municipality that is close to major cities and urban areas, where there is a high concentration of population, but the municipality itself should not already be a major city. Thirdly, the municipality should have sufficient plots that meet the demand of the logistics centers' area. And finally, the municipality should have a sufficiently large population size and labor force to support the logistics center operations.

According to EUROPLATFORMS, an essential characteristic of a logistics center is its ability to provide access to a diverse range of transportation modes, such as roads, railways, sea routes, inland waterways, and air transportation or promote intermodal transport. Intermodal transport refers to a transportation system that involves the use of two or more distinct modes of transportation. (Erkayman et al. 2011). Therefore, a potential location for a logistics center should be accessible to different mode of transports, at least two types including road transport as the most common transport mode.

For logistics centers serving the B2C industry, the initial step is to identify the market or key customer centers that the logistics center will serve, as well as the market size and volume of logistics centers required to meet the demand. The size of a logistics center can vary widely, with some centers spanning up to 500 hectares and including facilities such as distribution center, parking areas, and office buildings. As a result, it is crucial to ensure that the plot of land selected for implementing a logistics center is large enough to accommodate the estimated area requirements. To this end, it is recommended that preselected municipalities have plots of land that meet the expected area requirements of the logistics center. This can ensure that the logistics center operates at optimal capacity and meets the demands of the identified market.

Additionally, the market distribution should be considered in the preselection process, as the closer the logistics center is to the market, the lower the transportation cost and travel time. Based on the identified market that the logistics center will serve and the market distribution, potential area for implementing a logistics center can be identified. To maximize efficiency, it is important to locate a logistics center close to urban areas and cities, especially given the ongoing global trend towards urbanization. According to the United Nations (2018), more than 55 percent of the global population currently resides in urban areas, and this proportion is projected to rise to 68 percent by 2050. Moreover, more than 70 percent of the world's population resides in cities (Shchegol'kova, Rybka and Kozlova, 2023). Therefore, a logistics center that is located in proximity to large cities and urban areas can ensure that ecommerce orders are delivered to customers in a timely and cost-effective manner.

Despite the closeness to customers or commercial market, logistics centers should not be located in major cities due to the increasing trend of logistics sprawl in various countries. Logistics sprawl refers to the spatial dispersal of logistics facilities and distribution centers, which have been moving outward from inner urban areas to suburban and exurban regions. Land cost is the the primary factor influencing the location of logistics facilities (Allen, Browne and Cherrett, 2012), followed by accessibility to transportation. Logistics facilities are typically situated in proximity to highways and other transport infrastructure, in comparison to other sectors. Due to traffic congestion in inner urban areas, logistics facilities are increasingly being being established in suburban regions, offering more affordable industrial landand and easier access to road, rail, and air transport. The movement of logistics facilities away from urban centers has been confirmed by numerous studies on logistics sprawl, including those in Gothenburg, Atlanta, Zurich, Los Angeles, and Tokyo. (He et al., 2018)

In addition to reducing costs for businesses, the location of new logistics centers in suburban and exurban areas can have positive environmental implications and minimize the impact of these centers on urban populations. The continued migration of people to urban areas results in higher population density, which reduces the availability of land for residential buildings and can exacerbate existing environmental challenges. Therefore, the construction of a new logistics center in such an area can further damage the already-suffering environment. Until the impact of a new logistics center exceeds the environment's ability to recover, it will require considerable time, money, and effort to restore the environment to a functional state. Furthermore, high population density in urban areas means that the harmful impacts of logistics centers, such as air pollution and noise, can affect a larger number of people than in suburban and exurban areas with lower population density. As the pollution situation worsens over time, the health of nearby residents can be significantly impacted, leading to many costly legal implications such as the ability to be sued for health damages. Additionally, the increase in traffic congestion resulting from the operation of a logistics center in urban areas can negatively impact the logistics business itself. Congestion can increase the waiting time for drivers, resulting in delayed deliveries and longer lead times. These delays can reduce customer satisfaction and damage the reputation of the logistics company. In contrast, locating a logistics center in suburban or exurban areas can reduce traffic congestion, improve air quality in urban area, and minimize noise pollution. This can result in a more positive perception of the logistics center by the local community and increase the likelihood of successful business operations.

As the logistics industry is a labor-intensive industry, another crucial factor that should be take into consideration for a logistics center location is the accessibility to labor force. This indicates that a municipality that is feasible to place a logistic center should be able to supply adequate human resource for the operation of the center. The capacity of a municipality to provide a workforce for a logistics center can be assessed based on the population or, more specifically, the number of individuals within the labor force. This means that a municipality with a small number of labor force or a small population should not be selected as a viable alternative for the decision-making process. Although labor can potentially move from other municipalities to the one where the logistics center is located, this movement will inevitably increase the cost that businesses need to pay, such as employee relocation support or travel allowance. These costs are expected to be considerably higher for municipalities where the labor force is small in size. In this case, the criterion of the number of labor force may be sufficient to consider, without explicitly requiring a specialized workforce. This is due to the scarcity of labor force in the logistics sector, where the requirement for highly specialized skills could pose challenges for firms in identifying suitable locations for logistics centers. Furthermore, it is worth noting that a significant proportion of the labor force in logistics centers consists of individuals engaged in physical work or driving roles, which do not necessarily demand extensive technical skills or advanced education degrees like those required in engineering, medicine, or law. These individuals can be trained by the company to perform their roles effectively. Thus, considering the number of labor force may be a more appropriate criterion in this context.

Based on the four key factors, the preselected municipalities are selected and presented in section 5.2.

4.2 Criteria determination

The criteria used in evaluation process of potential logistics center locations are derive from the literature review. These criteria should be suitable for macro-level analysis. For example, while the criterion of "Impact to nearby residents" may be used in selecting a specific plot for a logistics center, it may not be applicable at the municipality level.

There are 9 selected criteria, namely Proximity to key customer centers, Accessibility to intermodal transportation, Land price, Accessibility to labor force, Labor cost, Government policy, Environment situation, Traffic congestion, and Unemployment. It is important to emphasize that these criteria serve as general guidelines for the framework. The specific criteria for each case study can be defined based on the guiding criteria, location’s characteristics and the availability of relevant data, ensuring that the specific criteria can reflect and illustrate the corresponding guiding criteria given the available data at the time of the study. The selection of specific criteria utilized in this study and their scales are presented in section 5.3.

The inclusion of these guiding criteria ensures a coverage of multiple considerations of involved stakeholders, addressing various dimensions of sustainability. The inclusion of environment situation as a criterion is crucial as it represents the environmental conditions of an alternative location, providing insights into its sustainability. While traffic congestion and unemployment may not rank among the most widely recognized criteria, they still hold significance and are chosen by the author for the evaluation process. Traffic congestion stands out as a prominent issue stemming from logistics activities, attracting considerable attention from communities and firms due to its environmental and financial implications. Unemployment, on the other hand, carries social implications relevant to communities.

Labor cost and land price represent cost-related criteria, which are highlighted as crucial factors in the literature review. Land price represents a substantial fixed cost in logistics center investments, while labor cost plays an important role in the overall operational expenses of labor-intensive logistics centers. Likewise, the criterion of Proximity to key customer centers is selected as considering the proximity to customers/markets as an essential criterion aligns with the literature review, especially in the context of a logistics center intended to serve the business-to-customer industry. In this context, it reflects the municipality's closeness to the key customer centers the logistics center aims to serve.

Although not commonly utilized in the literature review, the author suggests and selects two additional criteria: Accessibility to labor force and Government policy. The labor-intensive nature of the logistics industry underscores the importance of high accessibility to labor force, which can reduce operational costs and mitigate potential challenges associated with labor shortages. The inclusion of the Government policy criterion stems from the recognition that government initiatives, such as promotional tax policies or other incentives, can significantly alleviate costs and provide support for logistics firms operating in the municipality.

The identified criteria are categorized into three group, namely, (business) profitability, social - environmental, and sustainability. The profitability group includes criteria that aim to minimize costs and maximize profits of the businesses. The social - environmental group comprises criteria of a location that can have impacts on the environment and criteria that represent environmental and social conditions of the location. The sustainability group encompasses criteria from the first two groups, which cover all dimensions of sustainability.

The selected criteria and their groups are presented in Figure 6.

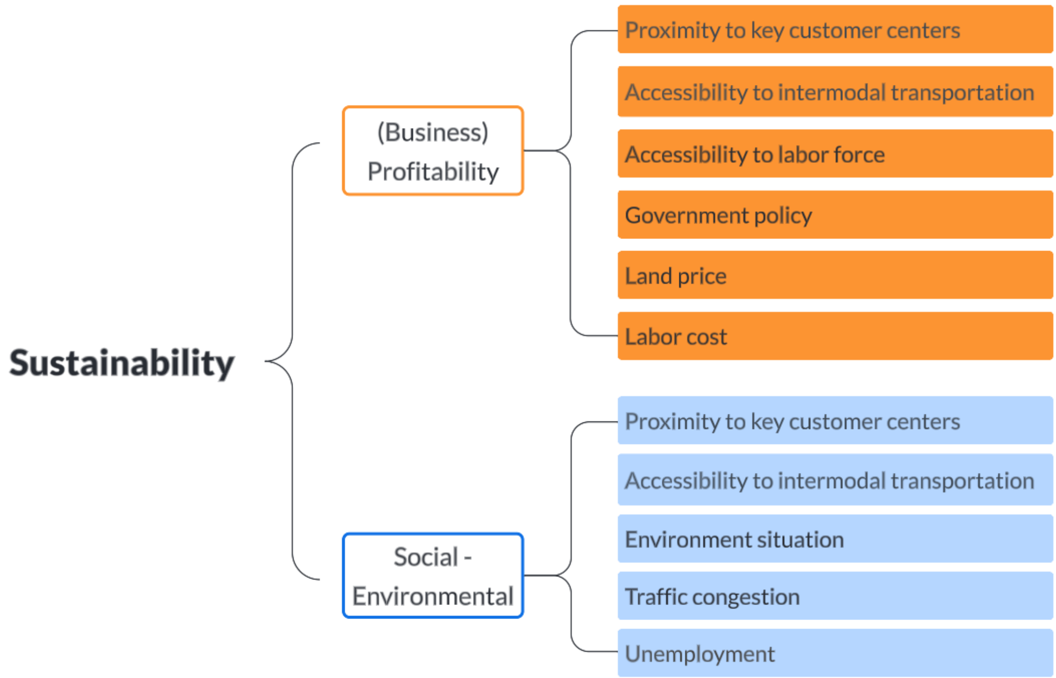

Figure 6. Criteria and their categorized groups

a. Profitability

- Proximity to key customer centers: A logistics center located closer to the key customer centers will result in less travel distance and energy consumption, hence reducing the costs for the business.
- Accessibility to intermodal transportation: The proximity and ease of access to various modes of transportation are crucial for optimizing logistics operations and minimizing costs. By having convenient access to intermodal transportation, the logistics center can efficiently connect with different transportation networks and facilitate the movement of goods.
- Accessibility to labor force and Labor cost: As logistics is a labor-intensive industry, the labor force accessibility and labor cost of the location is necessary to take into consideration to ensure the probably operation of the logistics and to reduce operation costs.
- Government policy: The introduction of preferential tax policies or other incentives by the local government may serve as a means to encourage investment and stimulate

the growth of the local economy. Such measures can significantly decrease the expenses related to constructing and operating the logistics center.

- Land price: The smooth operation of a logistics center often depends on having sufficient surrounding space, and thus the cost of land is a significant factor in site selection. A higher land price can result in increased investment costs for establishing a logistics center, which can limit the scale of construction and the financial capacity of the company.

b. Social – Environmental

- Proximity to key customer centers: A logistics center located closer to these key areas will result in less energy consumption and emissions, hence reducing the impact on the environment.
- Accessibility to intermodal transportation: The proximity and accessibility to diverse transportation modes enable the center to harness the intermodal advantage and mitigate the environmental impacts associated with transportation activities. Leveraging intermodal transportation options allows for the seamless movement of goods, reducing the reliance on a single mode of transport and promoting modal shift strategies that can contribute to sustainable and eco-friendly transportation practices.
- Traffic congestion: The optimal location is one where transportation activities associated with the logistics center do not significantly contribute to traffic congestion. Choosing a location with lower traffic flow can mitigate the negative impact of transportation activities on traffic congestion. A lower traffic flow can also lead to reduced transportation costs, as there are fewer delays and less time spent waiting in traffic.
- Unemployment: The placement of a logistics center in a municipality is expected to have a significant impact on employment rates, as it is likely to create job opportunities and contribute to the reduction of unemployment rates. The extent of this impact will depend on the level of unemployment in the municipality, with higher rates of unemployment likely to result in a larger contribution from the logistics center towards job creation.
- Environment situation: Environmental factors such as weather conditions, pollution indexes, and CO2 consumption should be carefully considered in order to understand how the logistics center will be impacted or how it may impact the environment. For instance, the logistics center's construction in an area with high rainfall levels may increase construction costs due to longer construction duration. On the other hand,

> the logistics center should ideally be situated in a municipality where its current impacts on the environment per person and per area unit are minimal, as this would indicate lower future impacts of the logistics center on population and land area scales.

When considering the environmental situation of potential municipalities for locating a new logistics center, it is important to recognize that areas that have already been heavily impacted by industrial activity, transportation, and other sources of environmental degradation are likely to be particularly vulnerable to additional damage. Hence, locating a new logistics center in these areas might exacerbate the environment. While some may argue that locating a logistics center within such areas, for example existing industrial agglomerations can help mitigate environmental impacts by concentrating the effects in a single area, this approach may ultimately be counterproductive over the long-term.

The clustering of industrial facilities in a single location can reduce the impact on the environment in the short or medium term, as much of the environmental degradation is concentrated in a specific area. However, as more facilities are added to the agglomeration, the overall impact on the region becomes increasingly severe. In addition, the presence of these facilities may attract more people to the area, potentially exacerbating environmental impacts by increasing the need for additional land, resources, and infrastructure.

Moreover, the accelerated impacts on the environment, while the area of land remains constant, may exceed the environment's recovery ability. Thus, it may require significant investment in terms of money, time, and effort to recover the environment from the impact. In cases where a logistics center is preferable to be located in a region that has already located many industrial facilities, an environmental assessment of the region and an estimation of the total impact of the logistics center on the region in the future are necessary to evaluate whether the placement of the logistics center is within the tolerance limits and recovery ability of the region's environment. Undertaking an environmental assessment to evaluate the total impact of a logistics center on region scale and its surrounding environment is a complex and expensive process that may not be feasible for businesses to undertake alone.

Therefore, it may be more optimal for businesses to consider selecting a location where the current impacts on the environment per person and per area unit are smaller to identify the region in which the new logistics center has minimal impact on the environment.

4.3 Rank-order centroid weight method

The rank-order centroid (ROC) weight approach is a simple yet effective method for assigning weights to criteria. The ROC weight method is so named because the weights are estimated by calculating the centroid, or center of mass, of the simplex that is defined by the ranking of the criteria. This approach is simple when we only have knowledge of the rank order of the criteria's true weights but lack additional quantitative information about them. As the number of criteria increases, the error associated with the ranked criteria decreases. Compared with AHP, which is one of the popular weight determination methods, the straightforwardness and user-friendliness of centroid weights make it a feasible approach for establishing criterion weights. (Roszkowska, 2013)

This method involves ranking the criteria from the most to the least important, and then determining the centroid of all possible weights that maintain the rank order of objective importance. By doing so, an estimate of the weights is produced that minimizes the maximum error of each weight. If the rank order of the true weight is known, but there is no other quantitative information available, it may be assumed that the weights are uniformly distributed on the simplex of rank order weight $w_{r_1} \geq w_{r_2} \geq \cdots \geq w_{r_n}$, where $w_{r_1} + w_{r_2} + \cdots + w_{r_n} = 1$ and r_i is a rank position of w_{r_i} . For $n > 2$, the formula for rank sum determination can be expressed as following (Roszkowska, 2013):

$$w_j(ROC) = \frac{1}{n}\sum_{k=j}^{n}\frac{1}{r_k} \tag{1}$$

4.4 Similarity-based TOPSIS with linguistic-quantifier based aggregation utilizing OWA operators

In this study, the Similarity-based TOPSIS method with linguistic-quantifier based aggregation using ordered weighted aggregation (OWA) has been selected for the location selection process. This decision was made based on its ability to handle large amounts of objective and quantitative data, as well as its ability to reflect the decision-makers' personal preferences. The OWA operator, with its linguistic requirements such as 'at least most,' 'at least many,' or 'at least few,' can reflect the decision-makers' preferences on how alternatives similar to PIS or NIS should be considered. For instance, a decision maker might require 'at least many' of values of criteria to be highly similar to PIS and 'at least few' of criteria values to be similar to NIS to consider an alternative is a good option. This example is one of many possible combinations of the method. The flexibility of the method allows decision makers and practitioners to tailor their analysis to specific location problems and consider multiple perspectives. This can lead to a more comprehensive understanding of the trade-offs and opportunities associated with various potential locations for a logistics center, which can result in more informed and effective decision-making.

The Similarity-based TOPSIS method with OWA operators is proposed by Luukka and Stoklasa (2021). The authors normalized the values of the alternatives to the unit interval to simplify the definition of the positive ideal solution (PIS) and negative ideal solution (NIS), making them independent of the actual performance of the alternatives. They also used a similarity measure, instead of a distance measure, to compute the similarity between the alternatives and the ideal vectors. The similarity vectors, which represent the criteria-wise similarities to PIS and NIS, were aggregated using two different OWA operators that allowed for varying linguistic quantifications of similarity. Finally, the authors adjusted the relative closeness computation by using similarity measures, rather than the distance measure used in the original TOPSIS method.

The following outlines the procedure for applying Similarity based TOPSIS using OWA operators:

Step 1: Normalize the decision matrix of a given set of *m* alternatives and *n* criteria into a unit interval by Min-max normalization method

$$z_{ij} = \frac{x_{ij} - min_i(x_{ij})}{max_i(x_{ij}) - min_i(x_{ij})} \ , i = 1, \dots, m, j = 1, \dots, n \tag{2}$$

where m is the number of alternatives, n is the number of criteria, x_{ij} is the performance measure of the alternative i with respect to the criterion j.

Step 2: Calculate the weighted normalized decision matrix $Y = [y_{ij}]$

$$y_{ij} = z_{ij} * w_j \ , i = 1, \dots, m, j = 1, \dots, n \tag{3}$$

where w_j is the weight value of criterion j.

In this study, the weight w_j is the $w_j(ROC)$, which is calculated by equation (1).

Step 3: Calculate weights of OWA operator depending on selected linguistic requirements ('at least one', 'at least few', 'at least some', 'at least many', 'at least most' and 'at least all') with the respective α value in Table 4. The used quantifier is $Q(x) = x^{\alpha}$, where $\alpha \geq 0$. The weights are computed as follows

$$w_j^+ = Q_1\left(\frac{j}{n}\right) - Q_1\left(\frac{j-1}{n}\right), j = 1, \dots, n \quad (4)$$

$$w_j^- = Q_2\left(\frac{j}{n}\right) - Q_2\left(\frac{j-1}{n}\right), j = 1, \dots, n \quad (5)$$

where Q_1 and Q_2 denote Regular Increasing Monotone (RIM) functions for selected linguistic requirements.

Table 4. Different linguistic quantifiers and their alpha values

Weight	At least one	At least few	At least some	At least many	At least most	At least all
α	$\alpha \to 0$	0.1	0.5	2	10	$\alpha \to \infty$

It is important to note that there are two sets of weights with different linguistic requirements for PIS and NIS.

Step 4: Define the positive and negative ideal solutions (PIS and NIS)

$$Y^+ = [y_1^+, \dots, y_m^+] \text{ such that } y_j^+ = \begin{cases} \max_i(y_{ij}) \text{ if } j \text{ is benefit} - \text{type criteria} \\ \min_i(y_{ij}) \text{ if } j \text{ is cost} - \text{type criteria} \end{cases} \quad (6)$$

$$Y^- = [y_1^-, \dots, y_m^-] \text{ such that } y_j^- = \begin{cases} \min_i(y_{ij}) \text{ if } j \text{ is benefit} - \text{type criteria} \\ \max_i(y_{ij}) \text{ if } j \text{ is cost} - \text{type criteria} \end{cases} \quad (7)$$

Step 5: Calculate similarity vector for each alternative

- with regard to PIS

$$s_{ij}^+ = \sqrt{w_j - |y_{ij} - y_j^+|}, , i = 1, \dots, m, j = 1, \dots, n \quad (8)$$

- with regard to NIS

$$s_{ij}^{-} = \sqrt{w_j - \left|y_{ij} - y_j^{-}\right|}\,,, i = 1, \dots, m, j = 1, \dots, n \tag{9}$$

Step 6: Calculate the similarity of each alternative regarding PIS and NIS by using OWA operator

$$s_i^{+} = \sum_{j=1}^{n} w_j^{+} o_j^{+} \tag{10}$$

where o_j^{+} is the j^{th} largest element of similarity vector of alternative i with respect to PIS.

$$s_i^{-} = \sum_{j=1}^{n} w_j^{-} o_j^{-} \tag{11}$$

where o_j^{+} is the j^{th} largest element of similarity vector of alternative i with respect to NIS.

Step 7: Calculate the relative closeness of each alternative to PIS:

$$RC_i = \frac{s_i^{+}}{s_i^{+} + s_i^{-}}\,, i = 1, \dots, n \tag{12}$$

Step 8: Rank alternatives based on the RC_i values. The higher value of RC_i, the better alternative.

5. Illustration case study

In the context of this study, a specific case study is conducted to illustrate the process of selecting a suitable location for a logistics center in Finland using sustainability criteria. The purpose of this case study is to demonstrate the effectiveness and practical implementation of the proposed method. The scenario involves a firm that is seeking an optimal location to construct a new logistics center in Finland. The intended logistics center is expected to efficiently serve the entire business-to-customer market in Finland and possess adequate capacity to accommodate future market growth. It is assumed that each municipality in Finland has at least one available land plot that meets or exceeds the minimum required area for constructing the logistics center. Furthermore, it is presumed that the financial resources of the company are sufficient to cover all anticipated costs associated with the construction and operation of the new logistics center, ensuring that the company does not face bankruptcy. This assumption is crucial to ensure that the firm is capable of assuming responsibility for assessing and mitigating current and future environmental and social impacts.

5.1 About Finland and problem statement

Finland has a total population of around 5.5 million and covers an area of 338 thousand square kilometers with an average population density of 18 inhabitants per square kilometer. However, this figure varies significantly across the country, ranging from as low as 0.2 in some northern regions to nearly 3,000 in Helsinki, the capital city. Most of the population is concentrated in the southern part of the country, with the Helsinki metropolitan area accounting for approximately 27 percent of the total population, equivalent to about 1.5 million people. (European Commission, 2022)

Finland comprises 309 municipalities, with a majority of them being small, having less than 6,000 residents. Nine cities in the country have a population exceeding 100,000. The largest city is the capital Helsinki, with a population of approximately 656,000 as of 2020, followed by Espoo, Tampere, Vantaa, Oulu, Turku, Jyväskylä, Lahti, and Kuopio. Although these cities cover only one percent of Finland's area, they account for thirty percent of the country's population. Additionally, Finland has 19 regions, out of which 18 are located on the mainland, and the autonomous province of Åland Islands is situated off the country's southwest coast. (Association of Finnish Municipalities, 2021)

The population ranking by region depicted in Figure 7 illustrates that Uusimaa, Pirkanmaa, Southwest Finland, North Ostrobothnia, Central Finland, North Savo, Satakunta, and Päijät-Häme are the top eight regions in terms of population. It is worth noting that these regions collectively represent over 70 percent of the entire population of Finland. The major cities of these regions are Helsinki, Tampere, Turku, Oulu, Jyväskylä, Kuopio, Pori, Lahti in respective. Given the concentration of population, it is logical to consider locating a logistic center that can effectively serve the entire country in close proximity to these areas.

The road network of Finland is organized into four distinct categories, with the main roads consisting of two types known as Highway Class I and Highway Class II, which is presented in Figure 8. The Highway Class I roads serve national and interprovincial long-distance traffic (Väylävirasto, 2023a) and are considered the backbone of the network to connect major Finnish cities such as Helsinki, Tampere, and Turku. These cities represent the largest urban centers in Finland. The Highway Class II roads, on the other hand, act as secondary connections to the main network and provide access to minor cities and state border crossings. It is important to note that the term "major city" in this context does not necessarily refer to the size of the city, but rather to its status as a development center for Finnish regions. In other words, a Finnish major city may or may not be a large city. The concept of a major city in Finland is closely linked to the country's regional development policies. According to these policies, major cities are identified as centers of economic growth for their respective regions. They are expected to promote businesses, develop infrastructure and service, and drive economic development. As such, major cities in Finland typically have higher population than other minor municipalities.

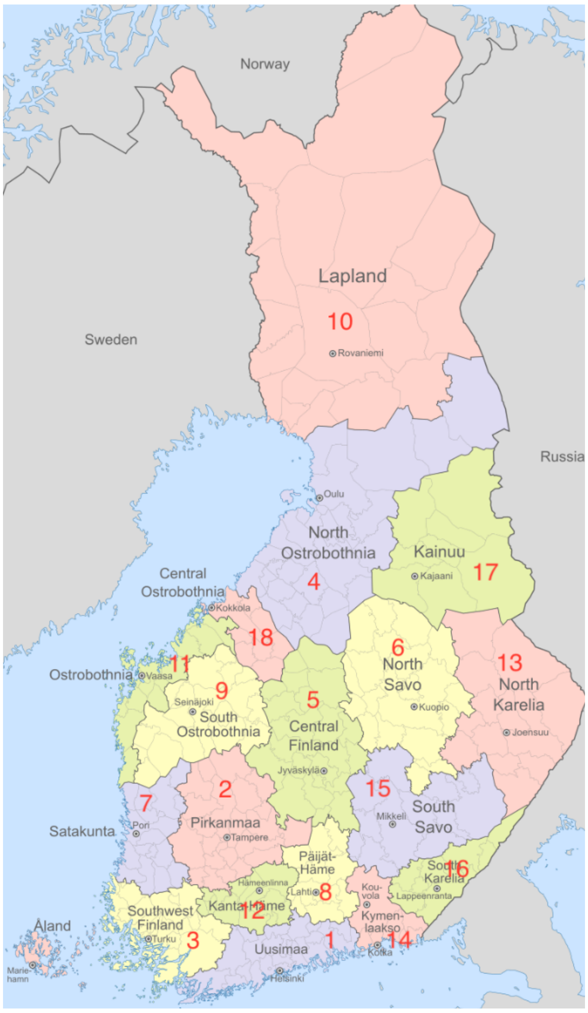

Figure 7. Finnish regions and their population ranking from the highest (National Land Survey of Finland, 2017)

Figure 8. The main road network in Finland (Väylävirasto, 2023b)

5.2 Preselected alternative

As discussed in section 4.1, the four essential factors for selecting the appropriate location for a logistics center in Finland include accessibility to the road and railway networks, proximity to key customer centers, availability of sufficient labor force, and avoiding large cities. Drawing upon these fundamental criteria, the author of this research has further established specific criteria tailored to the Finnish context. By applying these specific criteria, the study has identified 14 municipalities including Akaa (A1), Hämeenlinna (A2), Hyvinkää (A3), Jämsä (A4), Janakkala (A5), Kouvola (A6), Lohja (A7), Mäntsälä (A8), Mikkeli (A9), Riihimäki (A10), Salo (A11), Valkeakoski (A12), Varkaus (A13) and Vihti (A14), which are shown in Figure 9.

Figure 9. Preselected municipalities (Own work with municipality’s edge from National Land Survey of Finland, 2017)

To ensure the accessibility of the selected municipalities to both road and railway networks, the criteria for selection are based on the presence of transportation infrastructure, including highway intersections and access to the railway network. More precisely, these municipalities have been selected based on the presence of at least one intersection of Highways Class I and Class II, or two Highways Class I, which makes them easily accessible through the road network. In cases where the highway intersection is located on or near the municipality borders, all related municipalities have been included in the selection process. Regarding accessibility to the railway network, each of selected municipalities is traversed by a railway line, and they all have at least one station in the municipality, ensuring connectivity to the railway network. The main highway network and railway network have been presented in Figure 8 and Figure 10, respectively.

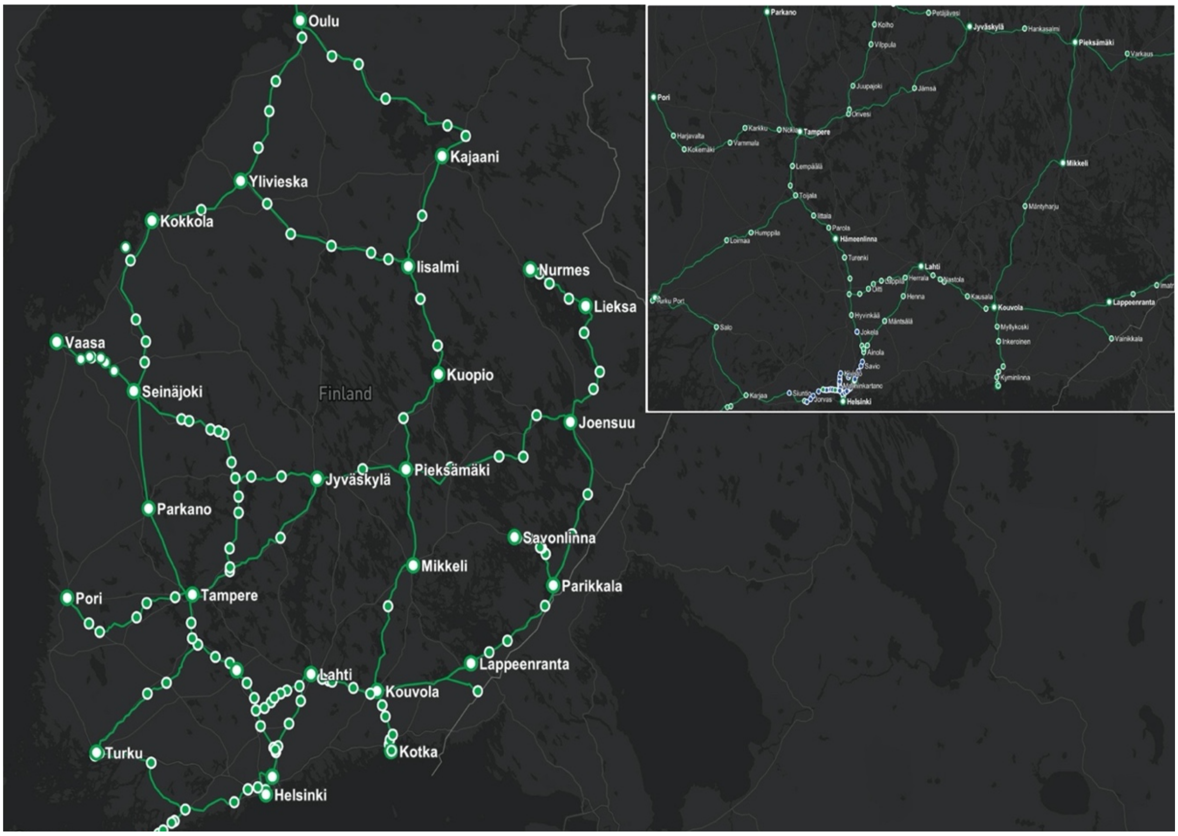

Figure 10. Railway network and stations (VR, 2023)

In terms of proximity to key customer centers, specific criteria have been established to determine suitable and unsuitable alternatives. The selected municipalities are those situated along the main highway network that connects Helsinki with the seven major cities of the highest population regions in Finland. These major cities, along with Helsinki, are recognized as key customer centers of the retail industry in Finland. They are considered representative of the eight most populated provinces in the country, accounting for around 75 percent of the total population. Furthermore, municipalities located far away from Helsinki and the major cities in the southern region of Finland, such as Äänekoski and Pyhäjärvi, are also excluded despite their access to the main highway and railway network, as well as their position along the main highway connecting Helsinki with specific major cities. Placing the logistics center in these remote municipalities would incur considerably higher transport costs due to the increased travel distance and frequency required to reach Helsinki and other key customer centers in the southern part of Finland.

To avoid large cities, municipalities included in the eight largest cities in Finland have been excluded from the selection process. Furthermore, to ensure the availability of a sufficient labor force, small municipalities with inadequate labor forces have also been excluded. For example, the municipality of Humppila, despite having a main road intersection and railway station and being near many key customer centers, is not selected due to its small population and insufficient labor force. The population of Humppila is only approximately 2000, with a labor force of 915 individuals (Statistics Finland, 2022d), which is considered inadequate for the operation of the logistics center. It is important to emphasize that the selection of excluding the eight largest cities and defining small municipalities with inadequate labor forces is based on the perspective of the author conducting this study. Different studies or researchers may adopt alternative considerations when evaluating potential locations for a logistics center.

The case of Kouvola presents a unique opportunity for logistics center location in Finland due to its strategic location. Unlike the 13 other municipalities that are located on the main highway network connecting Helsinki with the seven major cities in the region with the highest population, Kouvola is situated on the main highway network connecting Helsinki to two smaller major cities, Lappeenranta and Joensuu, which are the 13th and 14th highest population municipalities in Finland. Despite this difference, Kouvola is still an attractive location for logistics facilities as it is close to the capital region and has already been chosen as the location for around 300 logistics companies. This makes Kouvola a viable option for consideration as a logistics center location in Finland in this thesis.

5.3 Criterion selection

As discussed in section 4.2, nine general criteria have been identified, which are Proximity to key customer centers, Accessibility to intermodal transportation, Land price, Accessibility to labor force, Labor cost, Government policy, Environment situation, Traffic congestion, and Unemployment. Based on these criteria and availability of Finnish logistics data, in total 11 specific criteria are finally chosen to determine the best location for implementing logistics center with sustainability criteria in Finland. Three groups with these criteria are formed to support three models including business profitability model, social-environmental model, and sustainability criteria integrated model that integrates all criteria in profitability and social-environmental models.

It is important to emphasize that, regarding the criterion of Accessibility to intermodal transportation, only two specific criteria have been selected for the decision-making models: Proximity to airport and Proximity to harbor. This selection is justified by the consideration of the municipalities' accessibility to road and railway transport during the initial determination of preselected municipalities. As a result, the accessibility to road and railway transport is not included in the selection of specific criteria. However, it should be noted that in applied studies, practitioners have the flexibility to modify this setting. For instance, they can choose to include proximity to the railway network and proximity to the road network as specific criteria in the decision-making models, depending on the study's characteristics and the researchers' preferences.

Most of the criteria used for evaluating logistics center locations are expressed in numerical values. Some criteria are obtained as raw primary data from data sources, while others are aggregated by the author, based on the collected data, to provide a more accurate representation of the criteria. However, one criterion that stands out as an exception is Land price, which is evaluated based on qualitative values such as Low, Medium, and High. The Land price criterion is crucial in the assessment of logistics center location, but at the macro level, it is challenging to express land prices in specific numerical values, as prices may vary depending on the location and specific characteristics of the land. Moreover, some land prices may not be publicly available, or they may differ from the prices that are ultimately agreed upon during negotiations with government or landowners. Therefore, it is justifiable to convert the numerical values of land price into the qualitative scale of Low, Medium, and High to facilitate a comparative analysis of alternative locations.

These criteria, their measure unit and the explanation are shown in Table 5. The sources of data and the methods used to aggregate specific criteria are detailed in the subsequent section.

Table 5. Criteria and their type

Criterion (unit)	Explanation	Criteria type
Proximity to key customer centers (C1) (no unit)	The score of closeness to key customer centers with a scale of 0-1. The higher score, the closer location to the customer centers.	Benefit
Proximity to airport (C2) (km)	The aggregated distance to reflect the proximity to airport transportation. The shorter distance, the better location.	Cost
Proximity to harbor (C3) (km)	The distance to the nearest international seaport. The shorter distance, the better location.	Cost
GHGs emission score (C4) (no unit)	The aggregated score with a scale of 0-1 reflecting the CO2 consumption of the alternative per person and per km^2 of land area. The higher score, the more CO2 consumption.	Cost
Traffic situation (C5) (vehicles/km/day)	The daily average number of vehicles per km of total length of main road.	Cost
Number of labor force (C6) (persons)	The number of labor force in each alternative municipality.	Benefit
Labour cost (C7) (Euro)	The monthly full-time salary and wage.	Cost
Unemployment rate (C8) (%)	The unemployment rate of each alternative municipality.	Benefit
Tax rate (C9) (%)	The general real estate tax rate for industrial building.	Cost
Skilled labor percent (C10) (%)	The percentage of skilled labor.	Benefit
Land price (C11) (Low, Medium, and High)	Based on unit price per m^2 of business plots.	

5.4 Data collection and preparation

The numerical performance measure of each alternative on each criterion is collected from various data source and some of them are aggregated before applying in the models. The source and methodology for collecting the data used in this study are presented in Figure 11. The dashed lines represent the aggregation process used to obtain the final data, while the solid lines indicate the use of primary data without any further processing.

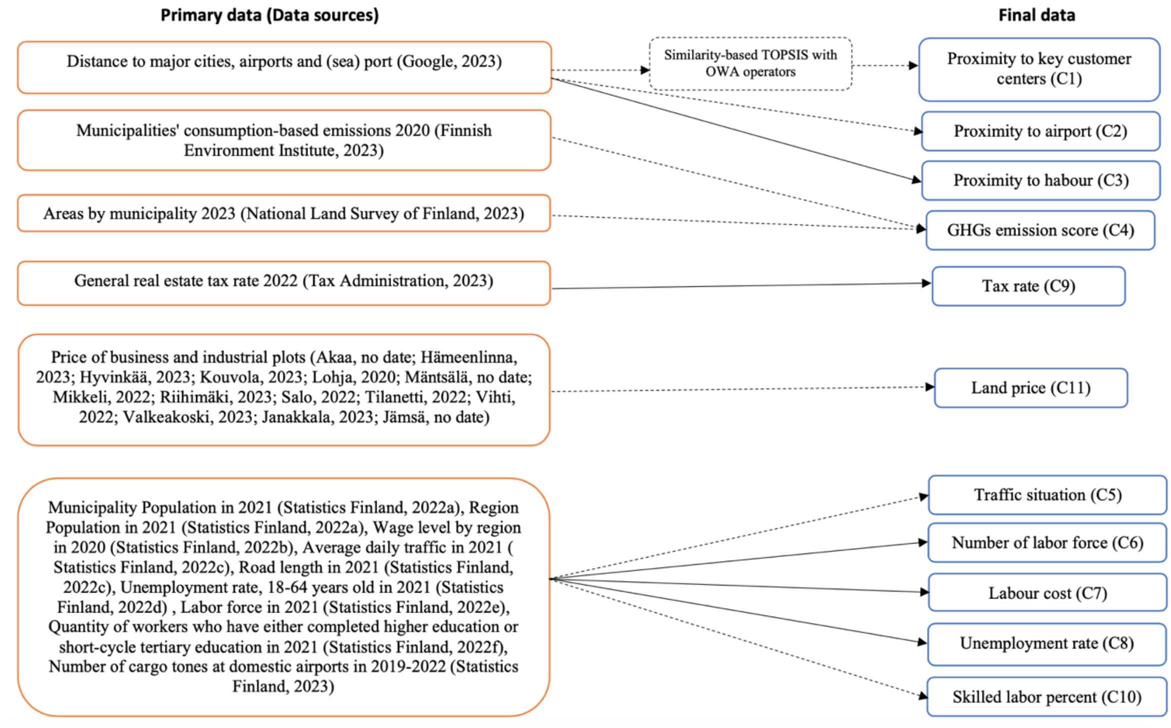

Figure 11. Data sources and collection process

**Note: Statistics Finland is the national statistical agency in Finland that produces unbiased statistics on Finnish society. Finnish Tax Administration is a government agency steered by the Ministry of Finance of Finland.*

The aggregation process of the data would be described in detail as follow.

a. Proximity to key customer centers

The Proximity to key customer centers score is identified as the most complex, requiring a separate multi-criteria decision-making approach to calculate the final index. Distance from each municipality to key customer centers is calculated using Google Maps, with the latitude and longitude of the highway intersection in each municipality and selected major cities being obtained. The highway intersection is utilized as the reference point for distance calculation since transportation is assumed to occur primarily via highways, thus making it an indispensable part of the transport journey. Following the identification of the highway intersection, the travel distance by highway road connecting each pair of municipality and major city is computed. This results in a matrix of distance for 14 municipalities and 8 major cities, which serves as input data for the proximity to key customer model.

In this model, the distances to the 8 major cities are considered as 8 criteria with the 14 municipalities. The weight of each criterion is determined by calculating the rate of population in each key region and the total population of the 8 regions. The Similarity-based TOPSIS with OWA operators is applied to calculate the proximity to key customer centers score, with the "at least most" linguistics requirement for the alternative to be similar to PIS and "at least few" values of the criteria to be highly similar to NIS. By adopting such an approach, the decision-making process embraces a risk-averse perspective, aligning with the author's preference. The proposed linguistics requirements for risk-averse decision makers' preferences are introduced by Luukka and Stoklasa (2021) in their article that presents the Similarity-based TOPSIS with OWA operators method. In this context, an alternative is deemed good (similar to PIS) if "at least most" of the criteria values (i.e., the weighted normalized distance values) are similar to the PIS. On the other hand, an alternative is considered bad (similar to NIS), if "at least few criteria" the criteria values are similar to those of NIS. The value of relative closeness of each of the 14 alternatives to the PIS is then obtained to represent the proximity to key customer centers score.

The specific linguistic requirements for calculating the proximity to key customer centers score can vary among different studies, as researchers are free to select different pairs of linguistic requirements. Furthermore, other researchers may employ alternative methods to calculate the proximity to key customer centers. However, the author of this study recommends the utilization of The Similarity-based TOPSIS with OWA operators method. This method not only incorporates the preferences of decision makers through the selection of linguistic requirements but also considers the varying importance of distances to different centers in the proximity score. For instance, in this study, the distance to Helsinki is considered more important than the distance to Tampere. Therefore, the distance to Helsinki is assigned a higher weight than the distance to Tampere in the calculation of the proximity to key customer centers score.

b. Proximity to Airport

The Proximity to Airport criterion is determined based on two main components, namely the distance from each municipality to Helsinki-Vantaa airport and Turku airport. The selection of these two airports is based on the amount of cargo transported through Finnish airports. The decision to include these airports among more than 20 domestic airports in Finland is supported by data obtained from Statistics Finland (2023), which reveals that the average amount of cargo tonnes transported at Helsinki-Vantaa airport and Turku airport during the period from 2019 to 2022 constitutes approximately 98 percent and 1.6 percent of the total cargo transported by air in Finland, respectively. This indicates that a vast majority of goods are transported through Helsinki-Vantaa airport, making it a crucial hub for cargo transportation in Finland. However, despite the relatively smaller cargo volume, Turku airport is still taken into consideration in order to avoid disregarding the potential advantages associated with municipalities in close proximity to Turku airport. The inclusion of both Helsinki-Vantaa airport and Turku airport in the evaluation of the Proximity to Airport criterion ensures that the assessment captures the geographical advantages provided by being situated near these airports. Although Helsinki-Vantaa airport holds the majority share of cargo transportation, the presence of Turku airport acknowledges the potential benefits that municipalities in its vicinity may offer.

The computation of this distance is conducted through the use of Google Maps, whereby the latitude and longitude of the highway intersection in each municipality and the airports are obtained. In addition, an additional criterion is incorporated, which is the existence of an airport within the municipality area, excluding Helsinki-Vantaa and Turku airport. The presence of an airport within a municipality is considered an advantage as it facilitates easier access to either Helsinki-Vantaa airport or Turku airport. The "cost" value for the municipality for not having an airport with its territory is calculated as follow:

$$a_i = \begin{cases} 0 \text{ if there is an airport within the municipality's territory} \\ \min(d_{1i}, d_{2i}) \text{ if there is not any airport within the municipality's territory} \end{cases} \quad (13)$$

where i = 1, ..., n, is the index of the selected municipalities, d_{1i} is the distance from the highway intersection within the municipality i to Helsinki-Vantaa airport, d_{2i} is the distance from the highway intersection within the municipality i to Turku airport.

After computing the cost value for the municipalities with or without an airport, the weight for each component is determined based on the amount of freight and mail transported by the airports. The data obtained from Statistics Finland for the period 2019-2022 reveals that on average, Helsinki-Vantaa airport accounts for 97.8 percent of the freight transported, while Turku airport accounts for only 1.6 percent. As such, the Proximity to airport criterion is aggregated by the following equation.

$$\text{Proximity to airport} = d_{1i} * 0.978 + d_{2i} * 0.016 + a_i * 0.006, \ i = 1, \ldots, n$$

where a_i is the "cost" value of the municipality i, d_{1i} is the distance from the highway intersection within the municipality i to Helsinki-Vantaa airport, d_{2i} is the distance from the highway intersection within the municipality i to Turku airport.

Based on the formulation of the Proximity to Airport criterion, it is evident that one of the distances to Helsinki-Vantaa airport and Turku airport is considered twice for the cost value of municipalities where an airport does not exist. However, this duplication has only a minor impact on the Proximity to Airport score. In fact, it contributes to a slightly higher cost for municipalities where an airport is absent, representing a weight of only 0.6 percent in the overall calculation. Consequently, municipalities that do have an airport have a slightly more favorable evaluation compared to those without one. Meanwhile, the distance to Helsinki-Vantaa airport plays a dominant role in determining the overall score since it constitutes approximately 98 percent of the Proximity to Airport.

c. GHGs emission score

The GHGs emission score is derived by aggregating the annual greenhouse gas emissions per person and per km2 of each municipality. The calculation of annual GHGs emissions in Finnish municipalities is conducted by the Finnish Environment Institute (SYKE) through the use of the ALas model (Alueellinen Laskenta or regional calculation). This model incorporates carbon dioxide, methane and nitrous oxide emissions, as well as F-gases, which are computed and presented as carbon dioxide equivalents (Finnish Environment Institute, 2021). The annual greenhouse gas emissions per person and per km2 are initially normalized to a unit interval by utilizing the Min-Max normalization method. Subsequently, they are aggregated using a 50/50 weight contribution, indicating that the social and environmental effects of GHG emissions are accorded equal importance.

d. Traffic situation

The Traffic situation criterion is defined by the average number of vehicles per one kilometer of road per day within a municipality. This is calculated by taking into account the average daily traffic count (in terms of vehicles per day) and the road length (in kilometers) of the municipality.

e. Skilled labor percentage

The Skilled labor percentage is the proportion of the population aged 15 or over who have completed higher education, including Bachelor's or equivalent level, Master's or equivalent level, Doctoral or equivalent level, or Short-cycle tertiary education, relative to the total population aged 15 or over.

f. Land price

The Land price criterion with three values of low, average and high, is computed based on the price of all available and public vacant plots that is collected from the website of 14 municipalities. Only business and industrial vacant plots are considered. On municipality website, the business and industrial plots are available with sale price in euro per km2 or in wholesale price. The wholesale price then is transformed to unit price in euro per km2. Next, the average price is calculated for each municipality, in which the plots whose price is not available are not included in the calculation. The municipality is categorized as low land price if the mean unit price is lower than 10, while if the mean unit price exceeds 30, the municipality is classified as high land price. In all other cases, the municipality is labelled as having an average land price.

It is important to highlight that the assessment and transformation of the land price, as well as the specific categorization thresholds, are based on the author's opinion in this particular study. Other studies may adopt different assessment methodologies and transformation techniques based on their research preferences.

6. Decision making models for illustrative case study

The original data of 11 criteria with 13 alternatives can be found in Table 6. These criteria are Proximity to key customer centers (C1), Proximity to airport (C2), Proximity to harbor (C3), GHGs emission score (C4), Traffic situation (C5), Number of labor force (C6), Labor cost (C7), Unemployment rate (C8), Tax rate (C9), Skilled labor percent (C10), Land price (C11). It is important to note that the criterion C11, representing land price, was not included in the calculation process. Instead, it was solely used for the evaluation process in the final step. This criterion is categorized into three levels: Low, Medium, and High, indicating the relative land price categories. Since it is not a numerical value, it cannot be directly incorporated into the calculation process alongside the other numerical criteria.

Table 6. Original data of 11 criteria

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
A1	0.294	136.8	145	0.174	16.2	7484	3604	8.8	1.1	0.2587	Low
A2	0.348	94.0	102	0.133	2.6	30906	3308	11.4	1.35	0.3294	Medium
A3	0.325	42.3	49.5	0.256	27.2	22725	4208	10	1.3	0.3173	Medium
A4	0.282	215.5	224	0.549	1.6	8157	3476	14.3	1	0.2379	Low
A5	0.345	64.3	71.7	0.281	11.4	7541	3308	9.3	1.1	0.2645	Medium
A6	0.280	141.3	56.1	0.296	1.4	35122	3457	12	1.45	0.2664	Medium
A7	0.149	57.2	54.7	0.333	4.6	21075	4208	9.3	1.03	0.2791	Medium
A8	0.361	48.9	55.9	0.170	11.8	10071	4208	7.1	1.4	0.2645	High
A9	0.117	223.7	158	0.042	1.2	23097	3168	10.7	1.37	0.3160	Low
A10	0.345	64.3	71.7	0.515	92.5	13298	3308	9.4	1.45	0.2920	Medium
A11	0.003	118.6	96.9	0.163	2.0	22866	3458	10.6	0.93	0.2675	Medium
A12	0.294	136.8	145	0.451	19.4	8892	3604	9.8	1.4	0.2806	Low
A13	0.000	309.1	242	0.362	11.8	8124	3364	14	1.45	0.2575	Medium
A14	0.236	49.7	58	0.104	10.1	14342	4208	7.6	0.95	0.3129	High

The Similarity-based TOPSIS with OWA operator method can produce multiple ranking sets of alternatives based on different pairs of OWA weights for calculating similarities to PIS and NIS. These relative closeness values and respective ranking sets may represent the preferences of different types of decision-makers. The selection of the preferred pair of OWA weights is at the discretion of the decision-maker.

This section aims to present a pair of linguistic requirements that are commonly considered by decision-makers to provide more insights on how to analyze, evaluate, and identify the optimal location for a logistics center. These linguistic requirements, "at least many" for PIS and "at least few" for NIS, are applied consistently across three models: the Profitability model, Social-Environmental model, and Sustainability criteria integrated model. This specific pair of linguistic requirements reflects the preferences of a risk-averse decision-maker.

The risk-averse decision-maker exhibits a tendency to avoid risk and, therefore, considers a municipality a good alternative if "at least many" criteria of that municipality are similar to the PIS. Conversely, a municipality is deemed bad if "at least few" of its criteria are similar to the NIS.

The following outlines the procedure for applying Similarity based TOPSIS with OWA operator in selection of logistics center location in Finland with the risk-avoidance decision maker's preference. The models are computed differently with distinct set of criteria, ROC weights and linguistic requirements.

a. Profitability model

Step 1: The decision matrix of Profitability model, which consists of 13 alternatives and 7 criteria, which are Proximity to key customer centers (C1), Proximity to airport (C2), and Proximity to harbour (C3), Number of labor force (C6) and Labour cost (C7), Tax rate (C9) and Skilled labor percent (C10). The criteria are normalized into a unit interval using the Min-max normalization method to ensure that the decision matrix is comparable across criteria. Equation (2) was used for this normalization process. The resulting normalized matrix is presented in Table 7.

Table 7. Normalized decision matrix of 7 numerical criteria

	C1	C2	C3	C6	C7	C9	C10
A1	0.815	0.354	0.496	0	0.419	0.327	0.227
A2	0.965	0.194	0.273	0.847	0.135	0.808	1
A3	0.900	0	0	0.551	1	0.712	0.868
A4	0.777	0.649	0.906	0.024	0.296	0.135	0
A5	0.414	0.082	0.115	0.002	0.135	0.327	0.290
A6	1.000	0.371	0.034	1	0.278	1	0.311
A7	0.323	0.056	0.027	0.492	1	0.192	0.450
A8	0.956	0.024	0.033	0.094	1	0.904	0.290
A9	0.007	0.680	0.564	0.565	0	0.846	0.853
A10	0	0.082	0.115	0.210	0.135	1	0.591
A11	0.654	0.286	0.246	0.557	0.279	0	0.324
A12	0.815	0.354	0.496	0.051	0.419	0.904	0.466
A13	0.956	1	1	0.023	0.188	1.000	0.214
A14	0.783	0.027	0.044	0.248	1	0.038	0.820

Step 2: Before calculating the weighted normalized decision matrix from the normalized decision matrix obtained in Step 1, the weight is calculated based on the criteria rank order

in each model. The rank orders of criteria in each model are different. In order to calculate the weighted normalized decision matrix, the weight for each criterion in the different models are determined based on their rank orders using Rank-order centroid weight method. The rank orders of the criteria differ depending on the model being used. The rank orders of criteria and the respective weights for the Profitability model are presented in Table 8.

In the Profitability model, the criteria that rank highest in importance are Proximity to key customer centers (C1), Proximity to airport (C2), and Proximity to harbour (C3). This is because transportation costs are a significant factor in logistics, and the less travel distance required to reach customer centers, airport, or harbour, the less expensive the transportation costs. The proximity to airports is considered more important than the proximity to harbour because air transportation is used more frequently in the retail industry than water transportation due to the importance of delivery time. The Number of labor force (C6) and Labour cost (C7) are the next most important criteria as they are directly related to the cost of operating the logistics center. Tax rate (C9) and Skilled labour percent (C10) are considered the least important since they are supportive factors that help to minimize costs but do not have a significant impact on the overall profitability.

Based on the criteria weights, the weighted normalized decision matrix for Profitability model is conducted by using equation (3) and is shown in Table 10.

Table 8. ROC weights for Profitability model

	Rank order	ROC Weight
C1	1	0.370
C2	2	0.228
C3	3	0.156
C6	4	0.109
C7	5	0.073
C9	6	0.044
C10	7	0.020

Table 9. OWA weights for different linguistic quantifiers for Profitability model

OWA weight	Few	Some	Many	Most	All
W1	0.823	0.378	0.020	0.000	0.000
W2	0.059	0.157	0.061	0.000	0.000
W3	0.037	0.120	0.102	0.000	0.000
W4	0.027	0.101	0.143	0.004	0.000
W5	0.021	0.089	0.184	0.031	0.000
W6	0.018	0.081	0.224	0.179	0.000
W7	0.015	0.074	0.265	0.786	1.000

Table 10. Weighted normalized decision matrix for Profitability model

	C1	C2	C3	C6	C7	C9	C10
A1	0.302	0.081	0.077	0.000	0.031	0.014	0.005
A2	0.358	0.044	0.043	0.092	0.010	0.036	0.020
A3	0.333	0	0	0.060	0.073	0.031	0.018
A4	0.288	0.148	0.142	0.003	0.022	0.006	0
A5	0.153	0.019	0.018	0	0.010	0.014	0.006
A6	0.370	0.084	0.005	0.109	0.020	0.044	0.006
A7	0.120	0.013	0.004	0.053	0.073	0.009	0.009
A8	0.354	0.006	0.005	0.010	0.073	0.040	0.006
A9	0.003	0.155	0.088	0.061	0	0.037	0.017
A10	0	0.019	0.018	0.023	0.010	0.044	0.012
A11	0.242	0.065	0.038	0.060	0.020	0	0.007
A12	0.302	0.081	0.077	0.006	0.031	0.040	0.010
A13	0.354	0.228	0.156	0.003	0.014	0.044	0.004
A14	0.290	0.006	0.007	0.027	0.073	0.002	0.017

Step 3: Weights of OWA operators are calculated, depending on selected linguistic requirements with the respective α value in Table 4. The quantifier used in this study is $Q(x) = x^{\alpha}$ where α is the corresponding α value for the selected linguistic requirement. The selected linguistic requirements for this study are (at least) few, (at least) some, (at least) many, (at least) most and (at least) all.

It is important to note that the ROC weights and OWA weight sets are different for each model due to the varying number of criteria in each model. The OWA weight sets for each linguistic requirement in Profitability model are shown in Table 9.

Step 4: The positive and negative ideal solutions (PIS and NIS) are then defined based on equation (6) and (7). For Profitability model, the PIS and NIS are $Y^{+} = [0.370, 0, 0, 0.109, 0, 0, 0.020]$ and $Y^{-} = [0, 0.228, 0.156, 0, 0.073, 0.044, 0]$, respectively.

Step 5: Similarity vector for each alternative with regard to PIS and NIS are computed by using equation (8) for similarity-to-PIS vector and equation (9) for similarity-to-NIS vector. The similarity vectors of the given alternatives to PIS and NIS are presented in Table 11 and 12.

Table 11. Similarity-to-PIS vectors for Profitability model

	C1	C2	C3	C6	C7	C9	C10
A1	0.549	0.383	0.280	0.000	0.206	0.173	0.068
A2	0.598	0.428	0.337	0.303	0.251	0.092	0.143
A3	0.577	0.477	0.395	0.245	0.000	0.113	0.133
A4	0.536	0.283	0.121	0.051	0.226	0.196	0.000
A5	0.392	0.457	0.372	0.015	0.251	0.173	0.077
A6	0.609	0.378	0.388	0.329	0.229	0.000	0.080
A7	0.346	0.464	0.390	0.231	0.000	0.189	0.096
A8	0.595	0.471	0.388	0.101	0.000	0.065	0.077
A9	0.052	0.270	0.261	0.248	0.270	0.082	0.132
A10	0.000	0.457	0.372	0.151	0.251	0.000	0.110
A11	0.492	0.403	0.343	0.246	0.229	0.210	0.081
A12	0.549	0.383	0.280	0.074	0.206	0.065	0.098
A13	0.595	0.000	0.000	0.050	0.243	0.000	0.066
A14	0.538	0.470	0.386	0.164	0.000	0.206	0.129

Table 12. Similarity-to-NIS vectors for Profitability model

	C1	C2	C3	C6	C7	C9	C10
A1	0.262	0.284	0.278	0.329	0.175	0.120	0.126
A2	0.113	0.210	0.206	0.129	0.099	0.189	0.000
A3	0.192	0.000	0.000	0.221	0.270	0.177	0.052
A4	0.287	0.384	0.376	0.325	0.147	0.077	0.143
A5	0.466	0.137	0.134	0.329	0.099	0.120	0.120
A6	0.000	0.291	0.073	0.000	0.142	0.210	0.119
A7	0.501	0.112	0.065	0.235	0.270	0.092	0.106
A8	0.128	0.075	0.072	0.314	0.270	0.200	0.120
A9	0.606	0.393	0.297	0.217	0.000	0.193	0.055
A10	0.609	0.137	0.134	0.293	0.099	0.210	0.091
A11	0.358	0.255	0.196	0.219	0.142	0.000	0.117
A12	0.262	0.284	0.278	0.321	0.175	0.200	0.104
A13	0.128	0.477	0.395	0.326	0.117	0.210	0.127
A14	0.284	0.079	0.083	0.286	0.270	0.041	0.061

Step 6: The similarity of each alternative regarding PIS and NIS by using OWA operators is calculated by using equation (10) and (11) with the OWA weights of the linguistics requirements of (at least) many and (at least) few in Table 9.

Step 7: The relative closeness of each alternative to PIS is computed by using equation (12).

The relative closeness values of alternatives to PIS for Profitability model are presented and evaluated in section 7.

b. Social – Environmental model

Step 1: The decision matrix of Social – Environmental model, which consists of 13 alternatives and 6 criteria, which are Proximity to key customer centers (C1), Proximity to airport (C2), and Proximity to harbour (C3), GHGs emission score (C4), Traffic situation (C5) and Unemployment rate (C8). The criteria are normalized into a unit interval using the Min-max normalization method to ensure that the decision matrix is comparable across criteria. Equation (2) was used for this normalization process. The resulting normalized matrix is presented in Table 13.

Table 13. Normalized decision matrix of 6 numerical criteria

	C1	C2	C3	C4	C5	C8
A1	0.815	0.354	0.496	0.260	0.165	0.236
A2	0.965	0.194	0.273	0.179	0.015	0.597
A3	0.900	0	0	0.422	0.285	0.403
A4	0.777	0.649	0.906	1	0.005	1
A5	0.414	0.082	0.115	0.471	0.111	0.306
A6	1.000	0.371	0.034	0.501	0.003	0.681
A7	0.323	0.056	0.027	0.574	0.038	0.306
A8	0.956	0.024	0.033	0.252	0.116	0
A9	0.007	0.680	0.564	0	0	0.500
A10	0	0.082	0.115	0.934	1	0.319
A11	0.654	0.286	0.246	0.238	0.009	0.486
A12	0.815	0.354	0.496	0.807	0.199	0.375
A13	0.956	1	1	0.630	0.116	0.958
A14	0.783	0.027	0.044	0.123	0.098	0.069

Step 2: The rank orders of criteria and the respective ROC weights for the Social – Environmental model are presented in Table 14.

In the Social-Environmental model, the criteria of proximity to key customer centers (C1), proximity to airport (C2), and proximity to harbour (C3) are again the most important criteria. This is because minimizing the travel distance can reduce emissions, pollution, and energy consumption, which are essential for sustainable development. GHGs emission score (C4) and Traffic situation (C5) are the next most important criteria as they represent the current environmental conditions and traffic congestion in the given municipalities. Unemployment rate (C8) is the final criterion and contributes to social concerns if the logistics center is located in the given municipality. The criteria of GHGs emission score and traffic situation are related directly to the global effect of air pollution, which impacts on a global scale, thus prioritizing them over local social concerns.

Table 14. ROC weights for Social – Environmental model

	Rank order	ROC Weight
C1	1	0.408
C2	2	0.242
C3	3	0.158
C4	4	0.103
C5	5	0.061
C8	6	0.028

Table 15. OWA weights for different linguistic quantifiers for Social – Environmental model

OWA weight	Few	Some	Many	Most	All
W1	0.836	0.408	0.028	0.000	0.000
W2	0.060	0.169	0.083	0.000	0.000
W3	0.037	0.130	0.139	0.001	0.000
W4	0.027	0.109	0.194	0.016	0.000
W5	0.022	0.096	0.250	0.144	0.000
W6	0.018	0.087	0.306	0.838	1.000

Based on the criteria weights, the weighted normalized decision matrix for Social – Environmental model is conducted and is shown in Table 16.

Step 3: Weights of OWA operators are calculated similar to Profitability model. The OWA weight sets for each linguistic requirement in Social – Environmental model are shown in Table 15.

Step 4: For Social – Environmental model, the PIS and NIS are also defined based on equation (6) and (7). The PIS and NIS are $Y^+ = [0.408, 0, 0, 0, 0, 0.028]$ and $Y^- = [0, 0.242, 0.158, 0.103, 0.061, 0]$, respectively.

Table 16. Weighted normalized decision matrix for Social – Environmental model

	C1	C2	C3	C4	C5	C8
A1	0.333	0.086	0.079	0.027	0.010	0.007
A2	0.394	0.047	0.043	0.018	0.001	0.017
A3	0.368	0	0	0.043	0.017	0.011
A4	0.317	0.157	0.144	0.103	0.000	0.028
A5	0.169	0.020	0.018	0.048	0.007	0.008
A6	0.408	0.090	0.005	0.052	0.000	0.019
A7	0.132	0.013	0.004	0.059	0.002	0.008
A8	0.390	0.006	0.005	0.026	0.007	0
A9	0.003	0.164	0.089	0	0	0.014
A10	0	0.020	0.018	0.096	0.061	0.009
A11	0.267	0.069	0.039	0.024	0.001	0.014
A12	0.333	0.086	0.079	0.083	0.012	0.010
A13	0.390	0.242	0.158	0.065	0.007	0.027
A14	0.320	0.007	0.007	0.013	0.006	0.002

Step 5: Similarity vector for each alternative with regard to PIS and NIS are computed by using equation (8) for similarity-to-PIS vector and equation (9) for similarity-to-NIS vector. The similarity vectors of the given alternatives to PIS and NIS are presented in Table 17 and 18, respectively.

Step 6: The similarity of each alternative regarding PIS and NIS by using OWA operators is calculated by using equation (10) and (11) with the OWA weights of the linguistics requirements of (at least) many and (at least) few in Table 15.

Step 7: The relative closeness of each alternative to PIS is computed by using equation (12).

The relative closeness values of alternatives to PIS for Social-Environmental model are presented and evaluated in section 7.

Table 17. Similarity-to-PIS vectors for Social – Environmental model

	C1	C2	C3	C4	C5	C8
A1	0.577	0.395	0.282	0.276	0.226	0.081
A2	0.628	0.441	0.339	0.291	0.245	0.129
A3	0.606	0.492	0.398	0.244	0.209	0.106
A4	0.563	0.291	0.122	0.000	0.247	0.167
A5	0.411	0.471	0.374	0.233	0.233	0.092
A6	0.639	0.390	0.391	0.226	0.247	0.137
A7	0.363	0.478	0.393	0.209	0.243	0.092
A8	0.625	0.486	0.391	0.277	0.232	0
A9	0.055	0.278	0.263	0.321	0.247	0.118
A10	0	0.471	0.374	0.083	0.000	0.094
A11	0.517	0.415	0.345	0.280	0.246	0.116
A12	0.577	0.395	0.282	0.141	0.221	0.102
A13	0.625	0.000	0.000	0.195	0.232	0.163
A14	0.565	0.485	0.389	0.300	0.235	0.044

Table 18. Similarity-to-NIS vectors for Social – Environmental model

	C1	C2	C3	C4	C5	C8
A1	0.275	0.293	0.280	0.163	0.100	0.146
A2	0.119	0.216	0.208	0.136	0.031	0.106
A3	0.202	0.000	0.000	0.208	0.132	0.129
A4	0.302	0.396	0.379	0.321	0.017	0.000
A5	0.489	0.141	0.135	0.220	0.083	0.139
A6	0.000	0.299	0.074	0.227	0.013	0.094
A7	0.526	0.116	0.065	0.243	0.048	0.139
A8	0.134	0.077	0.073	0.161	0.084	0.167
A9	0.637	0.405	0.299	0.000	0.000	0.118
A10	0.639	0.141	0.135	0.310	0.247	0.137
A11	0.376	0.263	0.197	0.156	0.024	0.119
A12	0.275	0.293	0.280	0.288	0.110	0.132
A13	0.134	0.492	0.398	0.254	0.084	0.034
A14	0.298	0.081	0.084	0.112	0.077	0.161

c. Sustainability criteria integrated model

Step 1: The decision matrix of Sustainability criteria integrated model, which consists of 13 alternatives and 10 criteria, which are Proximity to key customer centers (C1), Proximity to airport (C2), Proximity to harbor (C3), GHGs emission score (C4), Traffic situation (C5), Number of labor force (C6), Labor cost (C7), Unemployment rate (C8), Tax rate (C9), Skilled labor percent (C10). The criteria are normalized into a unit interval using the Min-max normalization method to ensure that the decision matrix is comparable across criteria. Equation (2) was used for this normalization process. The resulting normalized matrix is presented in Table 19.

Table 19. Normalized decision matrix of 10 numerical criteria

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	0.815	0.354	0.496	0.260	0.165	0	0.419	0.236	0.327	0.227
A2	0.965	0.194	0.273	0.179	0.015	0.847	0.135	0.597	0.808	1
A3	0.900	0	0	0.422	0.285	0.551	1	0.403	0.712	0.868
A4	0.777	0.649	0.906	1	0.005	0.024	0.296	1	0.135	0
A5	0.414	0.082	0.115	0.471	0.111	0.002	0.135	0.306	0.327	0.290
A6	1.000	0.371	0.034	0.501	0.003	1	0.278	0.681	1	0.311
A7	0.323	0.056	0.027	0.574	0.038	0.492	1	0.306	0.192	0.450
A8	0.956	0.024	0.033	0.252	0.116	0.094	1	0	0.904	0.290
A9	0.007	0.680	0.564	0	0	0.565	0	0.500	0.846	0.853
A10	0	0.082	0.115	0.934	1	0.210	0.135	0.319	1	0.591
A11	0.654	0.286	0.246	0.238	0.009	0.557	0.279	0.486	0	0.324
A12	0.815	0.354	0.496	0.807	0.199	0.051	0.419	0.375	0.904	0.466
A13	0.956	1	1	0.630	0.116	0.023	0.188	0.958	1.000	0.214
A14	0.783	0.027	0.044	0.123	0.098	0.248	1	0.069	0.038	0.820

Step 2: The rank orders of criteria and the respective ROC weights for Sustainability criteria integrated model are presented in Table 20. In the integrated model, the top three most important criteria are again proximity to key customer centers (C1), proximity to airport (C2), and proximity to harbor (C3), as they contribute to both profitability and social-

environmental concerns. Following these, GHGs emission score (C4) and traffic situation (C5) are essential criteria for ensuring the sustainability of the local environment.

Based on the criteria weights, the weighted normalized decision matrix for Sustainability criteria integrated model is conducted and is shown in Table 22.

Table 20. ROC weights for Sustainability criteria integrated model

	Rank order	ROC Weight
C1	1	0.2929
C2	2	0.1929
C3	3	0.1429
C4	4	0.1096
C5	5	0.0846
C6	6	0.0646
C7	7	0.0479
C8	8	0.0336
C9	9	0.0211
C10	10	0.0100

Table 21. OWA weights for different linguistic quantifiers for Sustainability criteria integrated model

OWA weight	Few	Some	Many	Most	All
W1	0.794	0.316	0.010	0.000	0.000
W2	0.057	0.131	0.030	0.000	0.000
W3	0.035	0.101	0.050	0.000	0.000
W4	0.026	0.085	0.070	0.000	0.000
W5	0.021	0.075	0.090	0.001	0.000
W6	0.017	0.067	0.110	0.005	0.000
W7	0.015	0.062	0.130	0.022	0.000
W8	0.013	0.058	0.150	0.079	0.000
W9	0.012	0.054	0.170	0.241	0.000
W10	0.010	0.051	0.190	0.651	1.000

Table 22. Weighted normalized decision matrix for Sustainability criteria integrated model

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	0.239	0.068	0.071	0.028	0.014	0.000	0.020	0.008	0.007	0.002
A2	0.283	0.037	0.039	0.020	0.001	0.055	0.006	0.020	0.017	0.010
A3	0.264	0.000	0.000	0.046	0.024	0.036	0.048	0.014	0.015	0.009
A4	0.228	0.125	0.130	0.110	0.000	0.002	0.014	0.034	0.003	0.000
A5	0.121	0.016	0.016	0.052	0.009	0.000	0.006	0.010	0.007	0.003
A6	0.293	0.072	0.005	0.055	0.000	0.065	0.013	0.023	0.021	0.003
A7	0.095	0.011	0.004	0.063	0.003	0.032	0.048	0.010	0.004	0.005
A8	0.280	0.005	0.005	0.028	0.010	0.006	0.048	0.000	0.019	0.003
A9	0.002	0.131	0.081	0.000	0.000	0.036	0.000	0.017	0.018	0.009
A10	0.000	0.016	0.016	0.102	0.085	0.014	0.006	0.011	0.021	0.006
A11	0.191	0.055	0.035	0.026	0.001	0.036	0.013	0.016	0.000	0.003
A12	0.239	0.068	0.071	0.088	0.017	0.003	0.020	0.013	0.019	0.005
A13	0.280	0.193	0.143	0.069	0.010	0.001	0.009	0.032	0.021	0.002
A14	0.229	0.005	0.006	0.013	0.008	0.016	0.048	0.002	0.001	0.008

Step 3: Weights of OWA operators are calculated similar to Profitability model. The OWA weight sets for each linguistic requirement in Sustainability criteria integrated model are shown in Table 21.

Step 4: For Sustainability criteria integrated model, the PIS and NIS are also defined based on equation (3) and (4). The PIS and NIS are $Y^+ = [0.293, 0, 0, 0, 0, 0.065, 0, 0.034, 0, 0.010]$ and $Y^- = [0, 0.193, 0.143, 0.110, 0.085, 0, 0.048, 0, 0.021, 0]$, in respective.

Step 5 Similarity vector for each alternative with regard to PIS and NIS are computed by using equation (8) for similarity-to-PIS vector and equation (9) for similarity-to-NIS vector. The similarity vectors of the given alternatives to PIS and NIS are presented in Table 23 and 24.

Table 23. Similarity-to-PIS vectors for Sustainability criteria integrated model

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	0.488	0.353	0.268	0.285	0.266	0.000	0.167	0.089	0.119	0.048
A2	0.532	0.394	0.322	0.300	0.289	0.234	0.204	0.142	0.064	0.100
A3	0.513	0.439	0.378	0.252	0.246	0.189	0.000	0.116	0.078	0.093
A4	0.477	0.260	0.116	0.000	0.290	0.040	0.184	0.183	0.135	0.000
A5	0.348	0.421	0.356	0.241	0.274	0.012	0.204	0.101	0.119	0.054
A6	0.541	0.348	0.371	0.234	0.290	0.254	0.186	0.151	0.000	0.056
A7	0.308	0.427	0.373	0.216	0.285	0.178	0.000	0.101	0.131	0.067
A8	0.529	0.434	0.372	0.286	0.273	0.078	0.000	0.000	0.045	0.054
A9	0.046	0.249	0.250	0.331	0.291	0.191	0.219	0.130	0.057	0.092
A10	0.000	0.421	0.356	0.085	0.000	0.117	0.204	0.104	0.000	0.077
A11	0.438	0.371	0.328	0.289	0.289	0.190	0.186	0.128	0.145	0.057
A12	0.488	0.353	0.268	0.145	0.260	0.057	0.167	0.112	0.045	0.068
A13	0.529	0.000	0.000	0.201	0.273	0.039	0.197	0.179	0.000	0.046
A14	0.479	0.433	0.370	0.310	0.276	0.127	0.000	0.048	0.142	0.091

Step 6: The similarity of each alternative regarding PIS and NIS by using OWA operators is calculated by using equation (10) and (11) with the OWA weights of the linguistics requirements of (at least) many and (at least) few in Table 21.

Step 7: The relative closeness of each alternative to PIS is computed by using equation (12).

The values of relative closeness of alternatives to PIS for Sustainability criteria integrated model are presented and evaluated in section 7.

Table 24. Similarity-to-NIS vectors for Sustainability criteria integrated model

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	0.233	0.261	0.266	0.169	0.118	0.254	0.142	0.160	0.083	0.088
A2	0.101	0.193	0.197	0.140	0.036	0.099	0.080	0.116	0.131	0.000
A3	0.171	0.000	0.000	0.215	0.155	0.170	0.219	0.142	0.123	0.036
A4	0.256	0.354	0.360	0.331	0.020	0.251	0.119	0.000	0.053	0.100
A5	0.414	0.126	0.128	0.227	0.097	0.254	0.080	0.153	0.083	0.084
A6	0.000	0.268	0.070	0.234	0.015	0.000	0.115	0.104	0.145	0.083
A7	0.445	0.103	0.062	0.251	0.056	0.181	0.219	0.153	0.064	0.074
A8	0.113	0.069	0.069	0.166	0.099	0.242	0.219	0.183	0.138	0.084
A9	0.539	0.362	0.284	0.000	0.000	0.168	0.000	0.130	0.134	0.038
A10	0.541	0.126	0.128	0.320	0.291	0.226	0.080	0.151	0.145	0.064
A11	0.318	0.235	0.188	0.161	0.028	0.169	0.116	0.131	0.000	0.082
A12	0.233	0.261	0.266	0.297	0.130	0.248	0.142	0.145	0.138	0.073
A13	0.113	0.439	0.378	0.263	0.099	0.251	0.095	0.037	0.145	0.089
A14	0.252	0.073	0.079	0.116	0.091	0.220	0.219	0.177	0.028	0.042

7. Result summary and discussion

Following the calculation of the overall similarities to PIS and NIS, as well as the closeness relative to PIS, for each model using the references provided by a risk-avoidance decision maker, this section aims to identify the optimal location for a logistics center based on the evaluation of the values of closeness relative. It is important to note that the evaluation is carried out in accordance with the references provided by a risk-avoidance decision maker. In accordance with the references of the risk-avoidance decision maker, the linguistic requirement for similarity towards PIS is set as "at least many," and towards NIS is set as "at least few."

For evaluation, both ranking order and relative comparison of relative closeness values are used to evaluate the alternative. The determination of the optimal location is typically based on the ranking orders derived from the relative closeness values, as demonstrated in Table 25, 26, and 27. However, the absolute rank order may not provide sufficient information about the alternatives, and thus, consideration of the relative closeness values is more appropriate in such cases. For instance, small differences in the relative closeness values of certain alternatives can result in significant changes in their ranking orders.

To facilitate the comparison of relative closeness values, the minimum relative closeness values of each model are computed, and the rate of the relative closeness values and their respective minimum values are determined for each alternative in each model. These values are presented in the "RC/RCmin" column of the tables. The value of RC/RCmin is employed as a measure to signify the relative magnitude of relative closeness values in relation to the minimum value. When there are substantial disparities or notable size differences among the relative closeness values, the larger relative closeness value is regarded as significantly superior to the smaller values. In contrast, when the discrepancies between relative closeness values are minimal or the values are relatively small in magnitude, they are deemed relatively close or comparable to one another. The relative magnitude of relative closeness values in relation to the minimum value is used to evaluate the relative overall performance of the alternatives.

In the Profitability model with seven criteria, the decision maker is highly cautious when it comes to considering the profitability aspect of the logistics center's location, as it can significantly impact the financial ability of the business in the long term. In addition, it is difficult to relocate the logistics center once it is constructed, and any tradeoff for re-selection and re-construction in the event of an inappropriate location will pose significant problems Therefore, he/she requires many criteria of the alternative to be highly similar to PIS in order to be deemed profitable for the firm, while just a few criteria with similarities to NIS is enough to consider it unfavorable. It is important to note that the specific criteria for which the similarity is required are not specified. As such, the OWA weights used for calculating the overall similarity to PIS have been set to w^{+} = [0.020, 0.061, 0.102, 0.143, 0.184, 0.224, 0.265], representing a preference for "many" criteria. On the other hand, the OWA weights for calculating the overall similarity to NIS, which is represented by the linguistic requirement value of "few," have been set to w^{-} = [0.823, 0.059, 0.037, 0.027, 0.021, 0.018, 0.015].

Table 25 presents the similarities of the municipalities to PIS and NIS, as well as the relative closeness values of the municipalities to PIS when considering the profitability aspect.

Table 25. Similarities of the municipalities to PIS and NIS and relative closeness values of the municipalities to PIS in Profitability model with the pair of "many" – "few" linguistics requirements

	S+	S-	RC	Rank	RC/RCmin	Land price
A1	0.140	0.313	0.309	7	3.628	Low
A2	**0.219**	**0.200**	**0.523**	**1**	**6.151**	**Medium**
A3	**0.166**	**0.248**	**0.401**	**3**	**4.716**	**Medium**
A4	0.113	0.365	0.236	11	2.780	Low
A5	0.160	0.418	0.277	9	3.256	Medium
A6	**0.182**	**0.262**	**0.410**	**2**	**4.823**	**Medium**
A7	0.158	0.444	0.262	10	3.082	Medium
A8	0.124	0.290	0.299	8	3.520	High
A9	0.141	0.544	0.205	12	2.415	Low
A10	0.099	0.536	0.157	13	1.841	Medium
A11	0.216	0.328	0.397	4	4.663	Medium
A12	0.145	0.307	0.320	6	3.764	Low
A13	0.041	0.440	0.085	14	1.000	Medium
A14	0.168	0.267	0.386	5	4.535	High

**Note: In the table, the best alternative and its values is highlighted using red bold text, while the second and third best alternatives and their values is highlighted with bold text.*

Based on the results presented in Table 25, it can be seen that the suggested ranking order of the municipalities in this case would be A2 → A6 → A3 → A11 → A14 → A12 → A1 → A8 → A5 → A7 → A4 → A9 → A10 → A13. A2 is the most suitable municipality when considering profitability as the most important criterion. A2 has the highest relative closeness value to PIS among all the alternatives, and its value is significantly higher than the others. Specifically, the relative closeness value of A2 is approximately 6 times the minimum value, while the values for A6, A3, A11, and A14, which are ranked second to fifth, are approximately 4.5-4.8 times the minimum value. This suggests that A2 performs remarkably better than the other alternatives in terms of profitability, and the differences in relative closeness values among the alternatives ranked second to fifth are not significant enough to distinguish them from one another. The ranking of these alternatives can be affected by land price. Notably, the land price in the top 4 municipalities with the highest RC values is at medium range, which implies that the price of land may not significantly affect their importance ranking order.

In Social-Environmental model, which includes six selected criteria, the decision maker keeps adopting a cautious and risk-averse attitude during the decision-making process to avoid potential risks associated with social and environmental aspects. The decision maker does not specify any particular criteria that the similarity needs to be found. For an alternative to be considered similar to PIS, its performances should be similar to the given ideal in (at least) "many" criteria, while for an alternative to be considered similar to NIS, its performances should be similar to the given ideal in (at least) "few" criteria. To achieve this preference, the OWA weights used for calculating the overall similarity to PIS are set as w^{+} = [0.028, 0.083, 0.139, 0.194, 0.250, 0.306]. Conversely, the OWA weights for calculating the overall similarity to the NIS are set as w^{-}= [0.836, 0.060, 0.037, 0.027, 0.022, 0.018]. Table 26 presents the similarities of the municipalities to PIS and NIS and the RC values of the municipalities to PIS in the case of Social-Environmental consideration.

According to the results presented in Table 26, the ordering of the municipalities in this case is suggested as A8 → A2 → A3 → A6 → A14 → A1 → A11 → A12 → A5 → A7 → A4 → A9 → A13 → A10. With the highest value of relative closeness to PIS, A8 is the most favorable location for the implementation of a new logistics center from the social and environmental perspective. However, it is noteworthy that the difference in relative closeness values between the top three alternatives is relatively small. As seen from the rate of relative closeness values and the minimum value of relative closeness, the outstanding performance of A8 is not significantly higher than the other top alternatives. Therefore, it can be concluded that although A8 is suggested as the optimal location, it is closely followed by other alternatives in the top 3 rankings, which means that other municipalities in the top 3 may also be viable options.

Table 26. Similarities of the municipalities to PIS and NIS and RC values of the municipalities to PIS in Social-Environmental model with the pair of “many” – “few” linguistics requirements

	S^+	S^+	RC	Rank	RC/RCmin
A1	0.223	0.281	0.442	6	3.885
A2	**0.259**	**0.204**	**0.558**	**2**	**4.904**
A3	**0.245**	**0.195**	**0.557**	**3**	**4.893**
A4	0.137	0.374	0.268	11	2.353
A5	0.231	0.436	0.347	9	3.044
A6	0.251	0.270	0.482	4	4.234
A7	0.224	0.465	0.325	10	2.857
A8	**0.224**	**0.159**	**0.585**	**1**	**5.135**
A9	0.163	0.571	0.222	12	1.949
A10	0.073	0.571	0.114	14	1.000
A11	0.248	0.345	0.419	7	3.678
A12	0.198	0.285	0.410	8	3.598
A13	0.096	0.450	0.175	13	1.537
A14	0.241	0.268	0.473	5	4.152

**Note: In the table, the best alternative and its values is highlighted using red bold text, while the second and third best alternatives and their values is highlighted with bold text.*

For Sustainability criteria integrated model, which incorporates all eleven sustainability criteria, the decision maker takes into accounts both the profitability of the firm as well as the social and environmental concerns of other stakeholders to be equally important. Similar to the previous models, the decision maker does not specify any particular criteria that should be highly similar to PIS or NIS. As the selection of location can have a significant impact on all of these stakeholders, the decision maker expects that at least "many" criteria of the given alternative are highly similar to PIS in order to ensure profitability while also minimizing impact on the social and environmental aspects. Conversely, if "few" criteria are highly similar to NIS, the alternative will be considered a poor choice. The OWA weight sets for the calculation of the overall similarity to PIS and NIS are w^+ = [0.010, 0.030, 0.050, 0.070, 0.090, 0.110, 0.130, 0.150, 0.170, 0.190] and w^- = [0.794, 0.057, 0.035, 0.026, 0.021, 0.017, 0.015, 0.013, 0.012, 0.010] in respective. The respective results are presented in Table 27.

The results in Table 27 suggests order of the municipalities as A2 → A3 → A6 → A11 → A14 → A1 → A8 → A12 → A5 → A7 → A9 → A4 → A13 → A10. In this case, A2 is the top-ranked alternative when all sustainability criteria are taken into account in a single model, with the highest value of relative closeness to PIS. A2's relative closeness value is significantly higher than the other alternatives in the top 5 highest relative closeness values. A3, A6, A11, and A14 are ranked second to fifth, respectively, with a relatively small difference between their relative closeness values. This indicates that these alternatives have comparable performance in terms of overall sustainability criteria. Moreover, the land price in the top four municipalities, including A2, A3, A6, and A11, is at the medium range, suggesting that the price of land might not significantly affect their importance ranking order.

Table 27. Similarities of the municipalities to PIS and NIS and relative closeness values of the municipalities to PIS in Sustainability criteria integrated model with the pair of “many” – “few” linguistics requirements

	S+	S-	RC	Rank	RC/RCmin	Land Price
A1	0.128	0.253	0.335	6	2.908	Low
A2	**0.183**	**0.183**	**0.499**	**1**	**4.331**	**Medium**
A3	**0.140**	**0.204**	**0.407**	**2**	**3.526**	**Medium**
A4	0.092	0.334	0.215	12	1.868	Low
A5	0.138	0.365	0.274	9	2.376	Medium
A6	**0.159**	**0.239**	**0.400**	**3**	**3.470**	**Medium**
A7	0.133	0.388	0.256	10	2.217	Medium
A8	0.104	0.224	0.316	7	2.745	High
A9	0.132	0.469	0.219	11	1.903	Low
A10	0.062	0.475	0.115	14	1.000	Medium
A11	0.178	0.286	0.383	4	3.321	Medium
A12	0.121	0.280	0.302	8	2.618	Low
A13	0.064	0.395	0.139	13	1.202	Medium
A14	0.137	0.232	0.371	5	3.215	High

**Note: In the table, the best alternative and its values is highlighted using red bold text, while the second and third best alternatives and their values is highlighted with bold text.*

To ensure sustainable development, the interests of all stakeholders should be taken into account when selecting a logistics center location. Two approaches are used: the integration of Profitability and Social-Environmental models and the integration of all sustainability criteria in one single model. By analyzing the results obtained from these approaches, the author suggests that location A2 (Hämeenlinna) emerges as the most suitable choice for establishing a new logistics center in Finland, with location A3 (Hyvinkää) ranking as the second most appropriate option.

Table 28 provides an overview of the optimal municipalities suggested by each model. According to Table 28, if the decision maker prioritizes profitability, A2 should be selected as the most optimal alternative as it has a significantly high value of relative closeness in the Profitability model. Conversely, if the decision maker's primary concern is the social and environmental impacts associated with the logistics center, A2 remains a favorable option. This conclusion is supported by A2's second highest relative closeness value in the Social-Environmental model, which closely approximates the highest relative closeness value. A3 can be considered as the second most appropriate option, as it has relatively high relative closeness values in both the Profitability and Social-Environmental models.

Table 28. Optimal municipalities suggestions by models for the risk-averse decision maker

Optimal municipalities	Profitability model		Social-Environmental model		Sustainability criteria integrated model	
	RC	Municipality	RC	Municipality	RC	Municipality
1st	0.523	A2	0.585	A8	0.499	A2
2nd	0.410	A6	0.558	A2	0.407	A3
3rd	0.401	A3	0.557	A3	0.400	A6

The third model, which integrates all sustainability criteria in one single model, confirms that A2 and A3 are the top options. A2 is the most appropriate alternative, followed by A3. However, a limitation of the model that integrates all sustainability criteria into one single model becomes apparent when comparing these three models. It is possible that some information might be overlooked from the results of the Sustainability criteria integrated model.

For instance, although A2 is the best municipality according to the Sustainability criteria integrated model, it is the second optimal choice in terms of the Social-Environmental model. If the decision maker solely relies on the results of the Sustainability criteria integrated model, he/she may overlook information related to social and environmental concerns, despite the fact that the criteria relevant to such concerns are considered in this integrated model.

In this case, it is important to note that although location A8 holds the highest relative closeness value in the Social-Environmental model, it is not deemed a suitable site for constructing a new logistics center. This decision is based on its low-ranking order in the Profitability model, as it is positioned in eighth place and has a high land price. Choosing A8 as the location for the logistics center may yield favorable social and environmental outcomes, but it carries inherent risks related to profitability concerns. Furthermore, a concern may arise regarding A6, which ranks second in the Profitability model, fourth in the Social-Environmental model, and third in the integrated Sustainability Criteria model. While A6 may appear to be a viable option from a profitability standpoint, following A2, it poses greater risks in terms of social and environmental considerations. Despite its fourth-place ranking in the Social-Environmental model, the relative closeness value of A6 significantly deviates from the top three alternatives. Consequently, selecting A6 as the location for a new logistics center carries a higher degree of risk in terms of social and environmental concerns.

For a risk-averse decision maker, who requires (at least) "many" criteria of the given alternatives that are similar to PIS to be considered "good" and (at least) "few" criteria of the given alternatives that are similar to NIS to be considered "bad," the suggestion of A2 (Hämeenlinna) and A3 (Hyvinkää) as potential locations for a logistics center demonstrates the effectiveness of the method for addressing multi-criteria problems in logistics center location selection. An evaluation of various factors indicates that A2 and A3 possess several advantages.

Starting with A2, it can be observed from Table 28 that this municipality has favorable advantages in terms of profitability, as well as social and environmental factors. A2 ranks second highest in terms of proximity to key customer centers, indicating its advantageous position for reducing travel distance, transportation costs as well as GHG emissions. Additionally, A2 boasts for the highest percentage of skill labor forces and the second largest labor force, along with having the second lowest labor cost, all of which essentially contribute to its profitability viability of the location. Furthermore, A2 ranks third lowest in terms of CO_2 emissions, reflecting its relatively positive environmental performance. Moreover, A2 has the fifth lowest level of average daily vehicle traffic within the municipality, which might indicate a relatively smooth traffic situation. Overall, all the criteria of A2 fall in the middle range or close to the best values, making it a highly suitable option from a sustainability perspective.

Turning to A3, this municipality exhibits many favorable criteria while having a few disadvantages. A3 excels in terms of proximity to the airport and harbor, which enhances its connectivity and logistical advantages. Furthermore, A3 possesses the second highest percentage of skilled labor force, which contributes to its profitability by ensuring a capable workforce. However, A3's profitability is hindered by its high labor cost, ranking fourth highest among the options. Additionally, A3's traffic situation is the second worst among the criteria considered, negatively impacting its social and environmental performance. Consequently, A3 is comparatively weaker than A2 in terms of both profitability and social and environmental considerations.

From the author's perspective, both A2 and A3 represent good choices for locating a logistics center due to their favorable geographical positions along the country's main routes and the multitude of advantages outlined above. The effectiveness of selecting A2 and A3 as logistics center locations is further supported by the fact that many companies such as Tammer Brands Oy, Kesko and Etra Oy have already chosen these municipalities for their own logistics centers (Tammer, no date; K Group, 2023; ETRA, no date).

In conclusion, through the integration of Profitability and Social-Environmental models, as well as the consideration of Sustainability criteria integrated model, location A2 (Hämeenlinna) has emerged as the most suitable choice for establishing a new logistics center in Finland, followed by A3 (Hyvinkää). The results of the case study that suggest A2 and A3 as potential locations for a logistics center also demonstrates the effectiveness of the method for addressing the problem of logistics center location selection with multi-criteria. However, it is important to note a drawback of solely relying on the Sustainability Criteria Integrated model. This limitation becomes apparent as it may provide less information compared to the integration of Profitability and Social-Environmental models. By solely considering the Sustainability Criteria Integrated model, important details and trade-offs among various sustainability criteria, including social and environmental concerns, could potentially be overlooked.

8. Sensitivity analysis

The utilization of The Similarity-based TOPSIS with OWA operators method provides a flexible approach to generate a ranking set of alternatives based on the varying preferences of decision makers. This approach incorporates different linguistic requirements of OWA weights for calculating similarities to the PIS and NIS. The flexibility provided by this method is of great significance, as decision makers may exhibit different attitudes towards various aspects, leading to varying preferences across different models, or they may display consistent preferences across all models. For instance, one decision maker may consistently adopt a risk-averse attitude when considering all aspects of profitability, social, and environmental concerns. Conversely, another decision maker may adopt a risk-averse attitude solely regarding profitability, while maintaining a risk-neutral attitude towards social and environmental concerns. In such cases, the proposed framework can adequately support the representation of these diverse preferences by assigning specific pairs of linguistic requirements, which correspond to the respective preferences, for each model.

With the different preferences, the rankings of alternatives can significantly vary depending on the linguistically quantified requirements employed in the evaluation process. This section aims to demonstrate the inherent flexibility of the proposed method in accommodating the selection of linguistic requirements. This flexibility empowers decision makers to align the evaluation process with their individual attitudes when selecting the most suitable location for logistics centers. By conducting a sensitivity analysis that involves modifying the preferred pair of OWA weights, this section seeks to illustrate the operation of the method.

For the sensitivity analysis, a total of 25 pairs of OWA weights are selected, representing combinations of five distinct linguistic requirements, namely (at least) few, (at least) some, (at least) many, (at least) most and (at least) all. The obtained results are presented in Table 29, 30 and 31, corresponding to the Profitability, Social-Environmental, and Sustainability criteria integrated models, respectively. Each table represents the rankings obtained for the

25 combinations of linguistic requirements, offering insights into the varying suggestions for optimal municipalities aligning with specifics preferences of decision makers. From the results of the tables, it is evident that the proposed method is able to accommodate a wide range of decision makers' preferences. If decision makers consider only the Sustainability criteria integrated model, where all sustainability criteria are integrated, the method can reflect 25 pairs of preferences. On the other hand, if decision makers prefer the integration of the Profitability and Social-Environmental models and have separate preferences for each model, there are 625 possible combinations of preferences that can be reflected by the method. This highlights the significant flexibility of the framework in accommodating diverse decision makers' preferences, allowing for specific preferences at the model level. Consequently, decision makers can adopt different preferences for each dimension of sustainability, reflecting the complex reality in which different concerns may elicit different preferences.

Following the presentation of the rankings for the three models encompassing the different combinations of linguistic requirements, further analysis is conducted to explore two additional well-known decision-maker attitudes: risk-seeking and risk-neutral. This analysis aims to provide a more detailed understanding of the changes in the suggested optimal locations relative to the optimal locations proposed based on the reference of a risk-avoidance decision maker, as discussed in the preceding section. It is important to note that the attitudes of decision makers can vary widely, and there are numerous other potential attitudes with specific linguistic quantifications. However, as this study represents one of the first attempts to utilize Luukka and Stoklasa's (2021) proposed method and the author aims to investigate their recommended considerations, the focus will be on risk-averse, risk-seeking and risk-neutral attitudes as their suggestions.

Finally, the examination of equal OWA weights is carried out to analyze the influence of OWA weights on the ranking orders of municipalities. This examination seeks to ascertain whether there are any variations in the ranking orders of municipalities when the decision maker's preferences are not considered. In this case, equal OWA weights are utilized, implying that the non-OWA weights serve as the sole determinants of the ranking order.

Table 29. Rank orders of alternatives in Profitability model with different pairs of linguistic requirements

PIS	All	All	All	All	All	Most	Most	Most	Most	Most	Many	Many	Many	Many	Many	Some	Some	Some	Some	Some	Few	Few	Few	Few	Few
NIS	All	Most	Many	Some	Few	All	Most	Many	Some	Few	All	Most	Many	Some	Few	All	Most	Many	Some	Few	All	Most	Many	Some	Few
A1	12	12	11	11	10	12	12	11	10	9	12	12	10	10	7	13	13	10	7	7	14	14	11	6	7
A2	**1**	**1**	**1**	**1**	**1**	**1**	3	**1**	**1**	**1**	**1**	3	3	**1**	**1**	**1**	3	3	**1**	**1**	**1**	3	3	**1**	**1**
A3	**1**	6	6	7	7	**1**	**1**	6	6	6	**1**	**1**	2	3	3	**1**	**1**	2	3	2	**1**	**1**	2	3	2
A4	11	11	12	12	12	11	11	12	12	12	10	10	13	12	11	9	9	12	11	9	9	9	12	9	9
A5	7	5	5	5	5	9	9	8	8	8	9	9	7	7	9	10	10	8	9	10	13	13	8	11	11
A6	**1**	7	8	8	8	**1**	2	4	7	7	**1**	2	**1**	2	2	**1**	2	**1**	2	3	**1**	2	**1**	2	3
A7	9	9	9	9	11	8	8	9	9	10	7	7	6	9	10	8	8	7	10	11	8	8	7	12	12
A8	10	10	10	10	9	10	10	10	11	11	8	8	8	6	8	7	7	5	5	5	7	7	5	4	5
A9	**1**	2	3	4	4	**1**	5	3	4	4	**1**	4	9	11	12	**1**	5	14	14	14	**1**	5	14	14	14
A10	13	13	13	13	13	13	13	13	13	13	13	13	12	13	13	12	11	9	12	13	11	10	9	13	13
A11	**1**	3	2	2	2	**1**	4	2	2	2	**1**	5	4	4	4	**1**	4	6	6	8	**1**	4	6	7	8
A12	6	4	4	3	3	7	7	5	3	3	11	11	11	8	6	11	12	11	8	6	10	12	13	8	6
A13	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	13	13	12	12	11	10	10	10
A14	8	8	7	6	6	6	6	7	5	5	6	6	5	5	5	6	6	4	4	4	6	6	4	5	4

**Note: In the table, the best alternative is highlighted using underlined bold text.*

Table 30. Rank orders of alternatives in Social – Environmental model with different pairs of linguistic requirements

PIS	All	All	All	All	All	Most	Most	Most	Most	Most	Many	Many	Many	Many	Many	Some	Some	Some	Some	Some	Few	Few	Few	Few	Few
NIS	All	Most	Many	Some	Few	All	Most	Many	Some	Few	All	Most	Many	Some	Few	All	Most	Many	Some	Few	All	Most	Many	Some	Few
A1	10	9	8	6	6	9	10	8	5	6	12	12	10	7	6	12	12	10	6	6	12	11	11	6	6
A2	6	4	3	**1**	**1**	6	4	3	**1**	**1**	6	6	3	3	2	6	5	4	3	3	6	5	4	3	3
A3	**1**	**1**	2	3	2	**1**	**1**	2	3	2	**1**	**1**	2	2	3	**1**	**1**	2	2	2	**1**	**1**	2	2	2
A4	4	11	12	12	12	**1**	6	12	12	12	1	4	12	11	11	**1**	4	11	11	9	**1**	4	9	10	9
A5	8	7	6	7	7	8	8	6	8	8	11	10	8	8	9	11	11	8	9	10	11	12	10	11	11
A6	**1**	2	**1**	2	3	**1**	2	**1**	2	3	1	2	**1**	4	4	1	2	**1**	4	4	**1**	2	**1**	4	4
A7	7	6	5	8	8	7	7	5	9	10	7	7	6	10	10	8	8	6	10	11	8	8	6	12	12
A8	12	12	11	11	11	12	12	11	10	9	9	9	5	**1**	**1**	9	9	3	**1**	**1**	9	9	3	**1**	**1**
A9	**1**	3	9	10	10	**1**	3	9	11	11	**1**	3	9	12	12	**1**	3	12	14	14	**1**	3	13	14	14
A10	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	13	13	14	14	14	13	13
A11	5	5	4	4	5	5	5	4	4	4	5	5	7	6	7	5	6	7	7	8	5	7	8	8	8
A12	9	8	7	5	4	10	11	10	6	5	13	13	11	9	8	13	13	13	8	7	13	13	12	7	7
A13	13	13	13	13	13	13	13	13	13	13	10	11	13	13	13	7	7	9	12	12	7	6	7	9	10
A14	11	10	10	9	9	11	9	7	7	7	8	8	4	5	5	10	10	5	5	5	10	10	5	5	5

**Note: In the table, the best alternative is highlighted using underlined bold text.*

Table 31. Rank orders of alternatives in Sustainability criteria integrated model with different pairs of linguistic requirements

PIS	All	All	All	All	All	Most	Most	Most	Most	Most	Many	Many	Many	Many	Many	Some	Some	Some	Some	Some	Few	Few	Few	Few	Few
NIS	All	Most	Many	Some	Few	All	Most	Many	Some	Few	All	Most	Many	Some	Few	All	Most	Many	Some	Few	All	Most	Many	Some	Few
A1	10	10	10	10	9	11	11	10	10	9	12	11	10	6	6	12	12	11	7	6	13	12	12	6	6
A2	**1**	2	**1**	**1**	**1**	**1**	4	**1**	**1**	**1**	**1**	5	2	**1**	**1**	**1**	5	2	**1**	**1**	**1**	5	2	**1**	**1**
A3	**1**	7	7	6	6	**1**	5	5	6	4	**1**	3	5	4	2	**1**	3	3	3	2	**1**	3	3	3	2
A4	11	11	12	12	12	**1**	8	11	12	12	**1**	6	11	12	12	**1**	4	10	11	9	**1**	4	9	10	9
A5	7	5	5	5	5	10	10	7	7	8	9	9	8	8	9	14	11	9	9	10	14	13	11	11	11
A6	**1**	6	6	7	7	**1**	2	4	5	5	**1**	2	**1**	2	3	**1**	2	**1**	2	4	**1**	2	**1**	2	4
A7	9	9	8	9	10	9	9	8	9	10	8	8	7	9	10	9	8	8	10	11	9	10	8	12	12
A8	12	12	11	11	11	12	12	12	11	11	13	10	9	7	7	10	10	7	5	3	10	9	5	4	3
A9	**1**	**1**	2	4	4	**1**	**1**	3	4	6	**1**	**1**	4	11	11	**1**	**1**	6	13	13	**1**	**1**	7	14	14
A10	13	13	13	13	13	13	13	13	13	13	14	14	14	14	14	13	14	14	14	14	12	11	14	13	13
A11	**1**	3	3	2	2	**1**	3	2	2	2	**1**	4	3	3	4	**1**	6	5	6	7	**1**	6	6	7	8
A12	6	4	4	3	3	8	7	6	3	3	11	12	12	10	8	11	13	13	8	8	11	14	13	8	7
A13	14	14	14	14	14	14	14	14	14	14	10	13	13	13	13	8	9	12	12	12	8	8	10	9	10
A14	8	8	9	8	8	7	6	9	8	7	7	7	6	5	5	7	7	4	4	5	7	7	4	5	5

**Note: In the table, the best alternative is highlighted using underlined bold text.*

8.1 Risk-seeking decision maker

In the case of risk-seeking decision maker, the evaluation of a municipality as "good" (similar to PIS) depends on its performance being similar to the PIS in at least "few" criteria. Conversely, a municipality is considered "bad" (similar to NIS), if it is similar to NIS in at least "many" criteria. The decision maker does not specify any particular criteria that the similarity needs to be found.

The results obtained from the comparison of the models indicate that A6 (Kouvola) and A3 (Hyvinkää) are the optimal municipalities for locating a new logistics center in Finland. These findings underscore the effectiveness of the employed method in reflecting the decision maker's preferences and in addressing the logistics center location problem. Furthermore, these results corroborate the presence of a recurring limitation observed in the Sustainability criteria integrated model, which has been previously discussed in this study.

To achieve the preferences of the risk-seeking decision maker, in Profitability model, the OWA weights used in calculating the overall similarity to PIS and to NIS are set as w^{+} = [0.823, 0.059, 0.037, 0.027, 0.021, 0.018, 0.015] and w^{-} = [0.020, 0.061, 0.102, 0.143, 0.184, 0.224, 0.265] respectively. Table 32 presents the similarities of the municipalities to the PIS and NIS, as well as the relative closeness values of the municipalities to the PIS for the Profitability model.

The suggested order of municipalities for the Profitability model, under the risk-seeking attitude of the decision maker, is as follows: A6 $\rightarrow$ A3 $\rightarrow$ A2 $\rightarrow$ A14 $\rightarrow$ A8 $\rightarrow$ A11 $\rightarrow$ A7 $\rightarrow$ A5 $\rightarrow$ A10 $\rightarrow$ A13 $\rightarrow$ A1 $\rightarrow$ A4 $\rightarrow$ A12 $\rightarrow$ A9.

Considering the risk-seeking attitude, A6 emerges as the most suitable municipality for locating a new logistics center, as it has the highest value of relative closeness among all the municipalities. However, it is important to note that the relative closeness values of the municipalities are quite close to each other, with no significant differences observed compared to the minimum relative closeness. In this context, the relative closeness values of A6 and A3 are very similar, indicating that these two municipalities can be considered comparable in terms of their suitability for the logistics center location. This suggestion is from the author's opinion. However, due to the small differences in relative closeness values between all alternatives, it is also possible for other individuals with a risk-seeking attitude to conclude that these municipalities are all comparable and exhibit similar levels of suitability.

Table 32. Similarities of the municipalities to PIS and NIS and relative closeness values of the municipalities to PIS in Profitability model with the pair of “few” – “many” linguistics requirements

	S+	S-	RC	Rank	RCi/RCmin	Land price
A1	0.495	0.182	0.731	11	1.142	Low
A2	**0.547**	**0.098**	**0.849**	**3**	**1.325**	**Medium**
A3	**0.529**	**0.074**	**0.878**	**2**	**1.371**	**Medium**
A4	0.475	0.185	0.720	12	1.124	Low
A5	0.425	0.138	0.755	8	1.178	Medium
A6	**0.553**	**0.064**	**0.897**	**1**	1.400	**Medium**
A7	0.429	0.124	0.776	7	1.211	Medium
A8	0.537	0.120	0.818	5	1.277	High
A9	0.259	0.146	0.641	14	1.000	Low
A10	0.414	0.142	0.744	9	1.161	Medium
A11	0.458	0.126	0.784	6	1.225	Medium
A12	0.495	0.193	0.719	13	1.123	Low
A13	0.508	0.180	0.738	10	1.153	Medium
A14	0.496	0.102	0.830	4	1.296	High

**Note: In the table, the best alternative and its values is highlighted using red bold text, while the second and third best alternatives and their values is highlighted with bold text.*

In Social-Environmental model, the OWA weights used in calculating the overall similarity to PIS and to NIS are set as w^+ = [0.836, 0.060, 0.037, 0.027, 0.022, 0.018], representing a preference for "few" criteria, and w^- = [0.028, 0.083, 0.139, 0.194, 0.250, 0.306], representing a preference for "many" criteria. Table 33 presents the similarities of the municipalities to the PIS and NIS, as well as the relative closeness values of the municipalities to the PIS for the Profitability model.

According to the results presented in Table 33, the suggested order of municipalities for Social-Environmental model, under the risk-seeking attitude of the decision maker, is as follows: A6 → A3 → A8 → A2 → A14 → A7 → A13 → A11 → A4 → A5 → A1 → A12 → A9 → A10.

Table 33. Similarities of the municipalities to PIS and NIS and relative closeness values of the municipalities to PIS in Social-Environmental model with the pair of “few” – “many” linguistics requirements

	S^+	S^+	RC	Rank	RC/RCmin
A1	0.530	0.169	0.759	11	1.084
A2	0.579	0.101	0.851	4	1.217
A3	**0.564**	**0.066**	**0.895**	**2**	**1.279**
A4	0.505	0.150	0.771	9	1.102
A5	0.445	0.137	0.764	10	1.092
A6	**0.586**	**0.058**	**0.910**	**1**	**1.301**
A7	0.449	0.108	0.807	6	1.153
A8	**0.579**	**0.094**	**0.860**	**3**	**1.228**
A9	0.305	0.116	0.725	13	1.035
A10	0.422	0.181	0.700	14	1.000
A11	0.485	0.127	0.792	8	1.132
A12	0.527	0.191	0.734	12	1.049
A13	0.548	0.140	0.797	7	1.139
A14	0.530	0.097	0.845	5	1.207

**Note: In the table, the best alternative and its values is highlighted using red bold text, while the second and third best alternatives and their values is highlighted with bold text.*

Similar to the Profitability model, in this case of Social-Environmental model, the author suggests that A6 and A2 are the most favorable options for implementing a new logistics center from the social and environmental perspective. These municipalities have the highest values of relative closeness to PIS. They are comparable alternatives as the difference in relative closeness values between A6 and A2 is very small. However, it is significant to acknowledge that the differences in relative closeness values between all the alternatives in this case are relatively small, thus other risk-seeking decision makers may conclude that these municipalities are all comparable and exhibit similar levels of suitability for the logistics center location from a social and environmental standpoint.

In the case of the Sustainability criteria integrated model, the OWA weight sets used in calculating the overall similarity to PIS with linguistics requirement “(at least) few” is w^{+} = [0.794, 0.057, 0.035, 0.026, 0.021, 0.017, 0.015, 0.013, 0.012, 0.010]. On the other hand, the OWA weight sets for the calculation of the overall similarity to NIS with linguistics requirement “(at least) many” is w^{-} = [0.010, 0.030, 0.050, 0.070, 0.090, 0.110, 0.130, 0.150, 0.170, 0.190] in respective. In this case, the optimal alternatives for locating a new logistics center differ slightly from the previous models. The municipalities A6, A2, and A3 are identified as the optimal alternatives. According to the results presented in Table 34, A6 is once again deemed the most suitable municipality, having the highest relative closeness value.

Table 34. Similarities of the municipalities to PIS and NIS and relative closeness values of the municipalities to PIS in Sustainability criteria integrated model with the pair of “few” – “many” linguistics requirements

	S+	S-	RC	Rank	RC/RCmin	Land Price
A1	0.437	0.139	0.758	12	1.038	Low
A2	**0.481**	**0.077**	**0.863**	**2**	**1.181**	**Medium**
A3	**0.465**	**0.080**	**0.853**	**3**	**1.168**	**Medium**
A4	0.418	0.109	0.793	9	1.086	Low
A5	0.386	0.114	0.772	11	1.057	Medium
A6	**0.485**	**0.055**	**0.898**	**1**	**1.230**	**Medium**
A7	0.390	0.101	0.794	8	1.087	Medium
A8	0.474	0.105	0.819	5	1.121	High
A9	0.307	0.073	0.807	7	1.105	Low
A10	0.369	0.136	0.730	14	1.000	Medium
A11	0.404	0.093	0.813	6	1.114	Medium
A12	0.434	0.153	0.739	13	1.011	Low
A13	0.453	0.121	0.789	10	1.080	Medium
A14	0.438	0.087	0.835	4	1.143	High

**Note: In the table, the best alternative and its values is highlighted using red bold text, while the second and third best alternatives and their values is highlighted with bold text.*

Interestingly, A2 achieves the second-highest relative closeness, despite the relatively small difference between its relative closeness value and that of A3. This finding suggests that A2 and A3 can be considered comparable alternatives in terms of their suitability for locating the logistics center. The suggested order of municipalities for Sustainability criteria integrated model is A6 → A2 → A3 → A14 → A8 → A11 → A9 → A7 → A4 → A13 → A5 → A1 → A12 → A10.

It is important to note that, similar to the previous models, the differences of relative closeness values between all the alternatives are relatively small, which can indicate that some risk-seeking individuals may conclude that these municipalities are all comparable.

The integration of the Profitability and Social-Environmental models suggests that municipalities A6 and A3 are the most suitable options for establishing a new logistics center in Finland. A6 is identified as the most appropriate location, while A3 ranks second in terms of suitability. In the case of the Sustainability criteria integrated model, which incorporates all sustainability criteria into a single model, A6, A2, and A3 emerge as the top 3 optimal options. A6 is considered the most suitable location, followed by A2 as the second appropriate choice, and A3 as the third appropriate option.

Table 35 provides an overview of the optimal municipalities suggested by each model:

Table 35. Optimal municipalities suggestions by models for the risk-seeking decision maker

Optimal municipalities	Profitability model		Social-Environmental model		Sustainability criteria integrated model	
	RC	Municipality	RC	Municipality	RC	Municipality
1st	0.897	A6	0.910	A6	0.898	A6
2nd	0.878	A3	0.895	A3	0.863	A2
3rd	0.849	A2	0.860	A8	0.853	A3

Considering the integration of results from these three models, it can be concluded that A6 (Kouvola) is the most suitable choice for establishing a new logistics center in Finland. A3 (Hyvinkää) might be the second choice, surpassing A2 (Hämeenlinna) due to its higher rankings in both the Profitability and Social-Environmental models. In addition, caution may be required when considering A2 as it ranks lower in the Social-Environmental model, indicating potential risks in terms of social and environmental aspects.

When considering the preferences of a risk-seeking decision maker, the suggestions for the optimal location of a new logistics center differ slightly compared to the suggestions for a risk-avoidance decision maker. According to the risk-avoidance perspective, A2 (Hämeenlinna) is identified as the most suitable municipality, followed by A3 (Hyvinkää) as the second option. However, under the consideration of this decision maker, the optimal locations for constructing a new logistics center shift. In this case, A6 (Kouvola) emerges as the most appropriate municipality instead of A2. A3 retains its position as the second optimal location, remaining consistent across the two decision-making perspectives. This indicates that the different preferences of decision makers can result in variations in the rankings and suggested optimal locations for the logistics center.

For a risk-seeking decision maker, who requires (at least) "few" criteria of the given alternatives that are similar to PIS to be considered "good" and (at least) "many" criteria of the given alternatives that are similar to NIS to be considered "bad," A6 aligns well with these requirements. A6 possesses certain advantages, such as the largest number of labor forces and a reasonably good proximity to the harbor. These factors might be sufficient for a risk-seeking decision maker to consider it a "good" choice regarding profitability concerns. In terms of social and environmental factors, A6 showcases the second-best traffic situation and the third-highest percentage of unemployment rate, which could be deemed adequate for the risk-seeking decision maker to consider it "good." On the other hand, A6 only has two criteria, proximity to the airport and tax rate, that are close to NIS, which might not provide enough evidence for the risk-seeking decision maker to consider it "bad."

In this case, the risk-seeking decision maker may not assign as much importance to the greater number of advantages with an alternative. Instead, he/she consider the "few" advantages that are sufficient to consider it a good option. In light of this consideration, A6 outperforms A2 and A3 in terms of its overall performance, despite A2 and A3 possessing more advantages (i.e., a larger number of criteria that are considered better) in terms of profitability and social-environmental considerations. This leads to the suggestion of A6 as the most appropriate municipality. Similarly, A3, which has fewer advantages than A2 but more advantages than A6, is considered the second optimal option according to the decision maker's preferences.

The shifting of municipalities' ranking order based on a risk-seeking attitude can be considered a riskier approach compared to suggestions derived from a risk-averse attitude. Even though A2 and A3 have a larger number of criteria that are considered better than A6 in both profitability and social-environmental concerns, however, A6 is still suggested as the optimal option. The decision maker might expect that with some overweighted advantages of A6, the company will potentially yield greater rewards. A6 stands out due to its large labor force, its proximity to the capital region which accounts for a significant portion of Finland's population, its favorable traffic situation, and its unemployment rate. If the decision maker anticipates that population growth in Finland will primarily occur in the capital region rather than in other regions, locating a logistics center in A6 would be beneficial in terms of labor availability, accessibility to densely populated areas, smooth traffic flow, and its positive contribution to the unemployment situation. The fact that A6 has already been chosen as the location for approximately 300 logistics companies in Finland further supports its status as a favorable choice.

However, the value of A6 as a logistics center location may diminish in certain scenarios. Specifically, if the population in Finland is expected to disperse across other regions of the country, resulting in increased travel distances, the suitability of A6 may be compromised. The decision to select A6 as a logistics center location carries higher risk compared to A2 in such cases.

With the suggestion of A6 and A3 as the optimal municipalities, the method effectively reflects the preference of the risk-seeking decision maker in the evaluation process. However, this suggestion also highlights a similar limitation present in the Sustainability criteria integrated model, which integrates all sustainability criteria, as observed in the case of the risk-averse decision maker's suggestion. The employment of the Sustainability criteria integrated model may not furnish the decision maker with adequate information concerning profitability, social considerations, and environmental factors. Consequently, the model suggests A2 as the second most suitable municipality for locating logistics centers. However, if profitability and social-environmental concerns are evaluated separately, it becomes apparent that A3 would outperform A2.

In summary, the integration of results highlights A6 and A3 as the optimal choices for logistics center location. The method effectively captures the decision maker's preferences and addresses the complexity of the selection process. The limitation of the Sustainability criteria integrated model is remained. While this model integrates various sustainability criteria, it might not provide sufficient information or insights regarding the diverse aspects of sustainability.

8.2 Risk-neutral decision maker

In terms of risk-neutral attitude, the decision maker places equal importance on the similarity to PIS and similarity to NIS. The decision maker requires that an alternative should have in at least "many" criteria that are similar to PIS (or NIS) to be considered as a good (or bad) alternative. In this study, the author adopts the requirement of (at least) "many" for considering similarity to PIS or NIS under the risk-neutral attitude, as suggested by Luukka and Stoklasa (2021) in their original study on the Similarity-based TOPSIS with OWA. However, it is essential to note that the linguistics requirement of (at least) "most" for considering the similarity to PIS and to NIS is also acceptable under the perspective of a risk-neutral decision maker. Moreover, the decision maker does not specify any specific criteria for assessing similarity to PIS and NIS.

The integration of results from the three models suggests that A6 (Kouvola), A2 (Hämeenlinna) and A3 (Hyvinkää) are the optimal choices for locating a logistics center in Finland under risk-neutral preferences. The method effectively captures the decision maker's preferences and addresses the complexity of the selection process. The limitation of the Sustainability criteria integrated model is remained.

To align with the risk-neutral preference, in the Profitability model, the OWA weights used in calculating both the overall similarity to PIS and to NIS are set as $w^{+} = w^{-}$= [0.020, 0.061, 0.102, 0.143, 0.184, 0.224, 0.265], representing for the linguistics requirement of (at least) "many". Table 36 presents the similarities of the municipalities to PIS and NIS and the relative closeness values of the municipalities to PIS in the case of Profitability model under risk-neutral attitude.

Based on the results presented in Table 36, the suggested order of municipalities for the Profitability model, under the risk-neutral attitude of the decision maker, is as follows: A6 → A3 → A2 → A11 → A14 → A7 → A5 → A8 → A9 → A1 → A12 → A10 → A4 → A13.

Considering the profitability concerns under the risk-neutral attitude, the evaluation of municipalities for locating a new logistics center reveals that A6 is the most suitable option based on its highest relative closeness value among all the municipalities. Following A6, A2 and A3 are positioned as the second and third most suitable municipalities, respectively. However, it is important to note that the relative closeness values of A2 and A3 are very close to each other, indicating that these two municipalities can be considered comparable in terms of their suitability for the logistics center location.

Table 36. Similarities of the municipalities to PIS and NIS and relative closeness values of the municipalities to PIS in Profitability model with the pair of "many" – "many" linguistics requirements

	S+	S-	RC	Rank	RCi/RCmin	Land price
A1	0.140	0.182	0.434	10	2.344	Low
A2	**0.219**	**0.098**	**0.691**	**3**	**3.735**	**Medium**
A3	**0.166**	**0.074**	**0.693**	**2**	**3.744**	**Medium**
A4	0.113	0.185	0.380	13	2.051	Low
A5	0.160	0.138	0.537	7	2.899	Medium
A6	**0.182**	**0.064**	**0.741**	**1**	**4.000**	**Medium**
A7	0.158	0.124	0.560	6	3.024	Medium
A8	0.124	0.120	0.509	8	2.748	High
A9	0.141	0.146	0.491	9	2.654	Low
A10	0.099	0.142	0.411	12	2.221	Medium
A11	0.216	0.126	0.632	4	3.411	Medium
A12	0.145	0.193	0.428	11	2.311	Low
A13	0.041	0.180	0.185	14	1.000	Medium
A14	0.168	0.102	0.623	5	3.364	High

**Note: In the table, the best alternative and its values is highlighted using red bold text, while the second and third best alternatives and their values is highlighted with bold text.*

For Social-Environmental model, the OWA weights used in calculating both the overall similarity to PIS and to NIS are set as $w^{+} = w^{-}$ = [0.010, 0.030, 0.050, 0.070, 0.090, 0.110, 0.130, 0.150, 0.170, 0.190], representing for the linguistic requirement of (at least) "many". Table 37 presents the similarities of the municipalities to PIS and NIS and the relative closeness values of the municipalities to PIS under Social-Environmental consideration.

According to Table 37, the suggested order of municipalities for the Social-Environmental model, under the risk-neutral attitude decision maker's consideration, is A6 → A3 → A2 → A14 → A8 → A7 → A11 → A5 → A9 → A1 → A12 → A4 → A13 → A10.

Table 37. Similarities of the municipalities to PIS and NIS and relative closeness values of the municipalities to PIS in Social-Environmental model with the pair of "many" – "many" linguistics requirements

	S^+	S^+	RC	Rank	RC/RCmin
A1	0.223	0.169	0.570	10	1.974
A2	**0.259**	**0.101**	**0.719**	**3**	**2.491**
A3	**0.245**	**0.066**	**0.788**	**2**	**2.730**
A4	0.137	0.150	0.477	12	1.654
A5	0.231	0.137	0.627	8	2.173
A6	**0.251**	**0.058**	**0.813**	**1**	**2.816**
A7	0.224	0.108	0.675	6	2.341
A8	0.224	0.094	0.704	5	2.438
A9	0.163	0.116	0.584	9	2.025
A10	0.073	0.181	0.289	14	1.000
A11	0.248	0.127	0.661	7	2.291
A12	0.198	0.191	0.508	11	1.761
A13	0.096	0.140	0.406	13	1.408
A14	0.241	0.097	0.712	4	2.466

**Note: In the table, the best alternative and its values is highlighted using red bold text, while the second and third best alternatives and their values is highlighted with bold text.*

From the results presented in Table 37, it is evident that A6 is the most favorable location for the placement of a new logistics center from the social and environmental perspective, as it has the highest value of relative closeness to PIS. However, it is crucial to note that the difference in relative closeness values between A6 and A3 is relatively small. The closeness of their relative closeness values to the minimum value of relative closeness suggests that while A6 is suggested as the most optimal location, A3 closely follows in the second position. This implies that A3 may also be a viable alternative for the logistics center location, as it exhibits comparable performance to A6.

For Sustainability criteria integrated model under the consideration of the risk-neutral decision maker, the OWA weights used in calculating both the overall similarity to PIS and to NIS are set as $w^{+} = w^{-}$ = [0.028, 0.083, 0.139, 0.194, 0.250, 0.306], representing for the linguistic requirement of (at least) "many". The results of similarities of the municipalities to PIS and NIS, and relative closeness values of the municipalities to PIS are shown in Table 38.

Table 38. Similarities of the municipalities to PIS and NIS and relative closeness values of the municipalities to PIS in Sustainability criteria integrated model with the pair of "many" – "many" linguistics requirements

	S+	S-	RC	Rank	RC/RCmin	Land Price
A1	0.128	0.139	0.478	10	1.532	Low
A2	**0.183**	**0.077**	**0.705**	**2**	**2.257**	**Medium**
A3	0.140	0.080	0.636	5	2.037	Medium
A4	0.092	0.109	0.457	11	1.465	Low
A5	0.138	0.114	0.547	8	1.752	Medium
A6	**0.159**	**0.055**	**0.744**	**1**	**2.381**	**Medium**
A7	0.133	0.101	0.569	7	1.821	Medium
A8	0.104	0.105	0.497	9	1.592	High
A9	0.132	0.073	0.642	4	2.056	Low
A10	0.062	0.136	0.312	14	1.000	Medium
A11	**0.178**	**0.093**	**0.657**	**3**	**2.104**	**Medium**
A12	0.121	0.153	0.442	12	1.414	Low
A13	0.064	0.121	0.344	13	1.102	Medium
A14	0.137	0.087	0.612	6	1.959	High

**Note: In the table, the best alternative and its values is highlighted using red bold text, while the second and third best alternatives and their values is highlighted with bold text.*

According to the results from Table 38, the ordering of municipality for Sustainability criteria integrated model is A6 → A2 → A11 → A9 → A3 → A14 → A7 → A5 → A8 → A1 → A4 → A12 → A13 → A10.

Under the consideration of the risk-neutral decision maker, A6 is again located at the first position as the most appropriate location for implementing the logistics center. However, differences in relative closeness values between the top five alternatives is relatively small.

As seen from the rate of relative closeness values and the minimum value of relative closeness, the outstanding performance of A6 is not significantly higher than the other top alternatives. Therefore, it can be concluded that although A6 is suggested as the most optimal location, it is closely followed by other alternatives in the top 5 rankings, which means that other municipalities in the top 5 may also be viable options.

Table 39 provides an overview of the optimal municipalities suggested by each model. Based on the evaluation of the three models' results in Table 39, it can be concluded that A6 (Kouvola) is identified as the most suitable municipality for locating a new logistics center. However, determining the second most appropriate alternative is more challenging as there are variations in the suggestions provided by the different models. The integration of the Profitability and Social-Environmental models suggests A3 (Hyvinkää) as the second option, whereas the Sustainability criteria integrated model suggests A2 (Hämeenlinna) as the second most suitable alternative. A3 and A2 seems to be comparable, even A3 has higher relative closeness values than A2 when considering Profitability and Social-Environmental models separately. However, it can be observed that their relative closeness values are closely similar and A2 has a higher relative closeness value in Sustainability criteria integrated model. Hence, it can be considered that they are comparable.

This recommendation is partly similar to the suggestion from the consideration under the risk-seeking decision maker, which also suggest that A6 is the most appropriate location, followed by A3. However, it differs from the suggestion derived from the preference of a risk-averse decision maker, which indicates A2 as the optimal location, followed by A3.

Table 39. Optimal municipalities suggestions by models for the risk-neutral decision maker

Optimal municipalities	Profitability model		Social-Environmental model		Sustainability criteria integrated model	
	RC	Municipality	RC	Municipality	RC	Municipality
1st	0.741	A6	0.813	A6	0.744	A6
2nd	0.693	A3	0.788	A3	0.705	A2
3rd	0.691	A2	0.719	A2	0.657	A11

For a risk-indifferent decision maker, who places a similar requirement on both similarity to PIS and to NIS by considering at least "many" similar criteria of the given alternatives, A6, A2 and A3, which are among the top best alternatives, are very likely to meet these requirements. These three options exhibit many advantages, which are sufficient for the decision maker to consider them as good choices. Additionally, none of them possess many criteria with poor performances that would be considered bad by the decision maker. The specific ranking order among these options may depend on the overall performance of their respective criteria. The results suggested by the models in this case are reasonable and indicate that they somewhat can reflect the preferences of the decision maker.

Similar to the previous cases, the utilization of the Sustainability criteria integrated model, which incorporates all sustainability criteria, also reveals a similar limitation as observed in the recommendations for both the risk-averse and risk-seeking decision makers. The application of the Sustainability criteria integrated model may not provide the decision maker with sufficient information pertaining to profitability, social considerations, and environmental factors. Consequently, the model suggests A2 as the second most suitable municipality for locating logistics centers. However, when evaluating profitability and social-environmental concerns independently, it becomes apparent that A3 would outperform A2 in terms of suitability.

To conclude, the results from three models reveal A6, A2 and A3 as the optimal municipalities for the location of the logistics center in Finland. These findings align well with the preferences of a risk-neutral decision maker and are substantiated by the real-world choices made by numerous logistics companies in selecting these municipalities as the location for their logistics centers. Similar to previous arguments, the limitation of the Sustainability criteria integrated model is remained as it does not provide sufficient information or insights on the multiple facets of sustainability.

8.3 Examination of equal OWA weights

According to the previous section, variations in rankings and suggested optimal locations for the logistics center can arise from different preferences among decision makers. This raises the question of which municipalities would be considered optimal if the preferences of decision maker were not taken into account, meaning non-OWA weights are used as determinants of ranking order. In this case, the non-OWA weights are represented by ROC weights and the OWA weights are set to be uniform in each model. To be specific, in Profitability model with 7 criteria, the OWA weights used in calculating both the overall similarity to PIS and to NIS are set as $w^{+} = w^{-} = [\frac{1}{7}, \frac{1}{7}, \frac{1}{7}, \frac{1}{7}, \frac{1}{7}, \frac{1}{7}, \frac{1}{7}]$. For Social - Environmental model with 6 criteria, the OWA weights are set as $w^{+} = w^{-} = [\frac{1}{6}, \frac{1}{6}, \frac{1}{6}, \frac{1}{6}, \frac{1}{6}, \frac{1}{6}]$. For Sustainability criteria integrated model with 10 criteria, the OWA weights are set as $w^{+} = w^{-} = [\frac{1}{10}, \frac{1}{10}, \frac{1}{10}, \frac{1}{10}, \frac{1}{10}, \frac{1}{10}, \frac{1}{10}, \frac{1}{10}, \frac{1}{10}, \frac{1}{10}]$. To address this question, an analysis using equal OWA weights is conducted to examine changes in the ranking orders of municipalities.

The results of the comparison of ranking orders for three models: the Profitability model, the Social-Environmental model, and the Sustainability Criteria integrated model, are presented in Table 40. The OWA weights used in the analysis are represented by a risk averse decision maker's preference, a risk seeking decision maker's preference, a risk neutral decision maker' s preference, and equal weights. These pairs represent different combinations of linguistic requirements. The table shows the ranking orders for each municipality (A1 to A14) under the different models. The numbers in the table represent the rankings of the municipalities, with lower numbers indicating higher rankings.

From Table 40, it is evident that the ranking orders of municipalities vary across the different models and pairs of OWA weights. The ranking orders generated by equal OWA weights are not significantly similar to any ranking orders generated by other decision maker's preference. This disparity suggests that the OWA weights, which are based on decision maker's preferences, play a crucial role in determining the ranking order.

Table 40. Comparison of municipalities' ranking orders

	Profitability model				Social - Environmental model				Sustainability criteria integrated model			
	Risk averse	Risk seeking	Risk neutral	Equal weights	Risk averse	Risk seeking	Risk neutral	Equal weights	Risk averse	Risk seeking	Risk neutral	Equal weights
A1	7	11	10	9	6	11	10	9	6	12	10	9
A2	1	3	3	2	2	4	3	4	1	2	2	1
A3	3	2	2	3	3	2	2	1	2	3	5	3
A4	11	12	13	12	11	9	12	11	12	9	11	12
A5	9	8	7	8	9	10	8	8	9	11	8	8
A6	2	1	1	1	4	1	1	3	3	1	1	2
A7	10	7	6	7	10	6	6	7	10	8	7	7
A8	8	5	8	6	1	3	5	2	7	5	9	6
A9	12	14	9	13	12	13	9	12	11	7	4	10
A10	13	9	12	11	14	14	14	14	14	14	14	14
A11	4	6	4	5	7	8	7	6	4	6	3	5
A12	6	13	11	10	8	12	11	10	8	13	12	11
A13	14	10	14	14	13	7	13	13	13	10	13	13
A14	5	4	5	4	5	5	4	5	5	4	6	4

To be specific, when considering profitability concerns, the ranking order suggested by equal weights indicates that A6 should be the optimal location. This suggestion aligns with the recommendations of risk-seeking and risk-neutral decision makers but differs from the results obtained by the risk-averse decision maker, who suggests A2 as the best option. In terms of social-environmental concerns, the equal weights result in A3 being identified as the optimal location. However, this recommendation differs from all suggestions made by other decision maker's preferences. Under the Sustainability Criteria integrated model, A2 is identified as the most suitable municipality, which aligns with the recommendation of the risk-averse decision maker but diverges from the suggestions of the other two decision makers. Similarly, the recommendations for the second and third optimal municipalities based on equal weights differ from recommendations of at least one of the three types of decision makers.

The results of this examination demonstrate that the ranking orders generated by equal OWA weights, where non-OWA weights solely determine the municipalities' ranking order, differ from the orders generated when OWA weights or decision maker's preferences are incorporated. This suggests that relying solely on non-OWA weights may not be sufficient to address the logistics center location selection problem and the results can be less valuable, as different decision makers have distinct preferences that can impact the ranking orders. This further highlights the advantages of the proposed method, which flexibly incorporates decision maker's preferences into the decision-making process.

This examination does not explore all possible pairs of OWA weights. Nevertheless, the results are sufficient to conclude that OWA weights, which are derived from decision maker's preferences, significantly influence the ranking order. Therefore, considering the preferences of different decision makers is necessary in order to identify the optimal municipalities that align with their respective needs.

9. Conclusion and limitations

This thesis proposes a framework for solving the logistics center location problem with sustainability criteria by employing Similarity-based TOPSIS with OWA operators. The aim of the framework is to select the most appropriate municipality for implementing a new logistics center while considering sustainability criteria. The proposed framework's outcomes are analyzed and interpreted through two approaches: the integration of Profitability and Social-Environmental models, and the integration of all sustainability criteria in one single model. The integration of Profitability and Social-Environmental models is recommended as it can provide additional insights into the alternatives and is more flexible in reflection of distinct preferences of decision-makers. This advantageous approach overcomes the limitations of integrating all sustainability criteria into a single model, as highlighted in previous discussions.

The results obtained from the integrated model that considers all sustainability criteria and the integration of Profitability and Social-Environmental models indicate partial similarity. This suggests that the single model encompassing all sustainability criteria can to some extent capture both profitability and social-environmental factors during the evaluation process, utilizing the Similarity-based TOPSIS approach with OWA operators. However, separate models that consider different interests of different stakeholders might supply more information about the alternatives and reflect different preferences of decision makers in different sustainability dimensions with different linguistic requirements for the similarity to PIS and NIS.

The integrated model that incorporates all sustainability criteria remains valuable for selecting logistics center locations, as it can offer favorable choices in this study. Its effectiveness is also evident in its widespread utilization in multi-criteria decision-making problems related to logistics center location selection. However, as the number of criteria increases and the need for considering multiple dimensions of sustainability arises, incorporating all criteria into a single model becomes challenging, particularly in terms of managing and interpreting the trade-offs between various criteria as well as comprehending the implications revealed by the model's results.

This approach offers a new perspective for researchers and practitioners in sustainability considerations for logistics center location problems. Instead of using a single model that integrates all criteria as in previous literature, the proposed method evaluates the three dimensions of sustainability or different interests of different stakeholders through multiple models with different sets of criteria. By employing multiple models, this method enhances the comprehensiveness and granularity of the evaluation process. In addition, this method provides greater flexibility to decision makers in expressing their personal preferences and needs. The utilization of separate models allows decision makers to select linguistic requirements that align with their preferences for each individual model. This flexibility enables decision makers to tailor the evaluation process according to their unique perspectives, thereby ensuring a more accurate representation of their preferences and requirements.

Moreover, this proposed method not only provides a solution for handling numerical data with multiple criteria, which is particularly relevant in the current era of data explosion, but also offers a flexible and customizable approach for incorporating the decision maker's preferences, which has not been widely explored in previous literature. With the increasing availability of data, decision makers can rely on this method to support their location selection process for logistics centers, thereby supplementing the popular approaches that rely solely on expert opinions and recommendations. The significance of incorporating the decision maker's preferences in the decision-making process is emphasized by the results of this study. The findings underscore the importance of considering the diverse preferences of decision makers, as these preferences can lead to different rankings of the available alternatives. Neglecting the decision maker's preferences and relying solely on a fixed set of criteria weights can undermine the value and relevance of the suggestions provided by the evaluation process. Therefore, by utilizing the proposed method, decision makers can ensure that their individual preferences are appropriately accounted for, resulting in more valuable and personalized recommendations.

The effectiveness of the proposed method in reflecting decision maker’s preferences is demonstrated through a case study in Finland. The case study results indicate that the Similarity-based TOPSIS with OWA operators is an effective technique for location selection problem evaluation with various decision maker’s preferences. The method allows decision makers to select the linguistic requirements for the calculation of similarity to PIS and NIS based on their preference. This means that they can express their personal preference or needs instead of using any fixed preference. The case study results also demonstrate the possibility of different outcomes that can be obtained with different types of decision makers and their preferences.

While the proposed method has many advantages and provided more flexibility in the location selection problem and its evaluation process, it has a limitation that decision makers are not able to specify specific criteria that need to be highly similar to PIS or NIS to be considered good or bad. This limitation may not be problematic for decision makers who do not have any specific requirements or preferences with regard to certain criteria. However, for decision makers who have very particular requirements or preferences, this limitation may hinder the ability of the method to exactly reflect their preferences. Additionally, the advantages of the proposed framework can also potentially pose a disadvantage in certain contexts. The flexibility provided by the method can be effectively harnessed when decision makers possess a clear understanding and articulation of their preferences and needs. In such cases, the framework empowers decision makers to align the evaluation process with their specific requirements, enhancing the accuracy and relevance of the decision-making outcomes. However, if decision makers are not consciously aware of or fail to define their preferences and needs, the flexibility of the method may present a challenge. The absence of clear preferences and needs can potentially lead to ambiguous or suboptimal results, as the framework relies on decision makers' ability to express their preferences through linguistic requirements.

Further investigation can be conducted in the future to handle cases where decision makers have specific requirements or preferences for certain criteria. This could involve developing a modified version of the Similarity-based TOPSIS with OWA operator method that takes into account decision makers' specific requirements or preferences. Such a modified version could provide decision makers with more flexibility in selecting criteria that are highly similar to PIS or NIS, thereby improving the effectiveness of the evaluation process.

Overall, the proposed framework provides a new perspective for practitioners and researchers to evaluate the sustainability of logistics center location with multiple criteria and stakeholder interests. The Similarity-based TOPSIS with OWA operators can be a useful tool for practitioners and researchers in evaluating location selection problems where there is no clear preference for any specific criteria.

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