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CIRCULAR ECONOMY PERFORMANCE ASSESSMENT FOR LOGISTICS ACTIVITIES

YALÇIN BERBEROĞLU

THESIS ADVISOR: PROF.DR. YIĞIT KAZANÇOĞLU

LOGISTICS ENGINEERING

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ABSTRACT

CIRCULAR ECONOMY PERFORMANCE ASSESSMENT FOR LOGISTICS ACTIVITIES

Berberoğlu, Yalçın
MSc, Logistics Engineering
Advisor: Prof. Dr. Yiğit Kazançoğlu
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Growing world population and demand for products makes linear economy inadequate. So, there is a need for a circular economy. Circular economy is based on three subjects which are economic, social, and environmental. Logistics activities have a key role in circular economy. The goal of this paper is to create a framework that assesses the circular economy performances of logistics activities for companies. 30 experts are surveyed to create a criteria set. Fuzzy statements used for ranking the criteria. CFCS (Converting Fuzzy data into Crisp Scores) method is used for defuzzification. IBM ILOG CPLEX Optimization Studio version 20.1.0 is used for applying the selected multi-criteria decision-making method which is Data Envelopment Analysis.

keywords: circular economy, performance assessment, logistics activities, data envelopment analysis, fuzzy logic

ÖZ

LOJİSTİK FAALİYETLERİNİN DÖNGÜSEL EKONOMİ PERFORMANS DEĞERLENDİRMESİ

Berberoğlu, Yalçın
Yüksek Lisans Tezi, Lojistik Mühendisliği
Danışman: Prof. Dr. Yiğit Kazançoğlu
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Artan dünya nüfusu ve ürünlere olan talep doğrusal ekonomiyi yetersiz kılmaktadır. Dolayısıyla döngüsel bir ekonomiye ihtiyaç vardır. Döngüsel ekonomi, ekonomik, sosyal ve çevresel olmak üzere üç konuya dayanmaktadır. Lojistik faaliyetler döngüsel ekonomide kilit bir role sahiptir. Bu makale, şirketler için lojistik faaliyetlerin döngüsel ekonomi performanslarını değerlendiren bir çerçeve oluşturmayı amaçlamaktadır. Kriter setini oluşturmak için 30 uzman ile görüşüldü ve anket yapıldı. Kriterler bulanık ifadelerle puanlandı. Durulaştırma için CFCS (Bulanık verileri Crisp Score'a Dönüştürme) yöntemi kullanıldı. IBM ILOG CPLEX Optimization Studio sürüm 20.1.0, seçilen çok kriterli karar verme yöntemi olan Veri Zarflama Analizi'ni uygulamak için kullanıldı.

Anahtar Kelimeler: döngüsel ekonomi, performans değerlendirmesi, lojistik faaliyetleri, veri zarflama analizi, bulanık mantık

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I would like to show my appreciation to my parents, by thanking them for their unconditional love and support towards me.

Yalçın Berberoğlu
İzmir, 2021

TEXT OF OATH

I can honestly confirm and declare that my study, titled "CIRCULAR ECONOMY PERFORMANCE ASSESSMENT FOR LOGISTICS ACTIVITIES" and presented as a Master's/PhD Thesis, has been composed without applying to any help conflicting with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn specifically or indirectly from outside sources are demonstrated within the text and listed within the list of references.

Yalçın Berberoğlu
2021

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1. Introduction

Consuming of natural resources is getting more and more every day. Akhimien et al. (2020) mentioned the consumption rate is twice the production rate and it will be three times by 2050. The demands of people put a lot of pressure on natural resources (Ellen MacArthur Foundation 2013). On the other hand, the population of the world is growing exponentially. By 2030, there will be approximately 8.5 billion people in the world. This growth of the population will cause a much higher demand for scarce natural resources. The importance of reintroducing scarce resources into the production and supply chain is increasingly important. The increasing lifetime of the products and decreasing the waste amount are becoming significant targets of the supply chain management because of social, economic and environmental reasons.

Pearce and Turner (1989) presented the circular economy idea which clarifies financial and natural concerns fundamentally within the writing, but the roots of the circular economy idea are purely based upon both environmental and financial matters as well as industrial ecology that push the benefits of the reusing waste components (Jacobsen, 2006; Andersen, 2007; Ghisellini et al., 2016). Exercises over the past several years, clearly appear that circular economy is developing as a financial methodology instead of a purely environmental procedure (Yuan et al., 2006). Sustainability is the common goal of businesses, governments, and non-profit organizations. Organizations put on an effort to increase the circularity of the products and supply sustainability with the help of sustainable activities they established based on the circular economy concept. (Kirchherr et al., 2017). Futhermore, because of increasing awareness of the importance of sustainability, customers insist on organizations integrate the concept of sustainability into the supply chain. Supply chain management which is sustainable should be applied in order to have benefits to the triple bottom line which consists of social, environmental, and economic benefits.

Circularity involves sustainable supply chain management depending on reverse logiscts, recovery and closed-loop activities. (De Angelis et al., 2018) In the circular economy idea, reverse logistics takes a fundamental role which enables circularity of the products through ensuring the reverse flow. (Kazancoglu et al., 2021). The circular economy consists of the 6R concept (recycle, repair, reuse, reduce, refuse, and rethink). A very crucial dimension to have a sustainable supply chain is logistics. Logistics activities have a huge effect on environmental, economic, and social issues.

Simply put, transportation of the products which is one of the main logistics activities causes negative effects on the environment. Because of the necessity of the logistics role in the supply chain, making improvements in logistics activities that depend on the circular economy concept may lead towards a more supply chain management that is sustainable. The circular economy concept together with the applications of this idea are relatively newer in emerging economies. While sustainability is getting important for the businesses at the system level in emerging economies, circular economy performance should be measured to achieve useful managerial insights. There are not many articles about circular economy performance assessment of logistics activities in the literature. These three concepts; “circular economy”, “performance assessment” and “logistics activities” never intersected simulatenously. This research focuses mainly to establish a framework for circular economy performance assessment and to form a criterion set that depends on the triple bottom line and measuring the performance of circular economy using Data Envelopment Analysis. According to this point of view, the research questions that have been determined are as follows:

RQ1: How can a framework be generated for both policymakers and managers to measure the performance of the circular economy in logistics activities?

RQ2: Which set of criteria should be practiced for assessing the circular economy performance of logistics activities?

RQ3: Which methodology can be used to calculate the circular economy performances of logistics activities?

Before starting the thesis, a research framework was created. Various articles in various journals, books, and conference proceedings were examined. Many of the research is about either “logistics performance assessment” or “logistics circular economy”. There are no articles in the literature that includes these three notions at the same time.

In the beginning, a framework was created from scratch because there are not any research containing our three notions. The search questions for the research are; “circular economy”, “performance assessment”, “logistics”, “data envelopment analysis” and combinations of these terms. So, a framework is created according to many kinds of research. Then, a methodology is selected according to which is the best for our issue. So, Data Envelopment Analysis is selected because the method is one of the best methods in finding the efficiencies of the alternatives. The method compares alternatives relatively. The distinctive feature of the method is that each alternative has its own mathematical model.

The related researches about the circular economy, sustainability and their performance assessment are discussed in section 2. Framework and the criteria set can be seen in the third part of this paper. Literature review gives the main idea of the problem that was worked before by many researchers. Then the criteria set should be identified. According to the framework, these criteria should be validated by academic and industrial experts. After these steps, in section 4, according to data collected, performance assessment should be done by using Data Envelopment Analysis. In section 5, there is an application of sustainability performance assessment. In section 6, there is discussion and implication part. The issues are discussed there. Finally there is a conclusion part in section 7.

2. Theoretical Background

The Industrial Revolution, which affected the world in the 18th and 19th centuries, and the mass production model it provided, also affected the economic models in this direction. It has been established in many countries as the basic economic model during and after the Second World War. The production process is predominantly powered by fossil fuels such as oil and coal; It produces not only products but also wastes. In addition, the product also generates waste as the output of the production. Over time, the developments in fashion and technology, the curiosity created in the consumer, and the desire for consumption have caused the product to turn into waste before it can complete its life cycle. The consumer buys and consumes the product and the product cannot be recycled after use and becomes waste. This economic process, which works as a disposable, is called the linear economy. This system is also defined as a “take-make-dispose” system. Linear economy, also known as Linear economics, is a one-way system. The existence of natural resources in our world assumes that they are sufficient, that transportation is easy, and that the waste of these resources and their becoming waste does not cause any costs or problems. The system's assumptions have resulted in exceeding the limits of the resources that our planet has. The theoretical background about logistics operations and performance assessment issues under sustainability and circularity can be seen in the sections below.

2.1. Circular Economy

Nowadays, the linear economy creates a lot of challenges. Since the demand for production is getting bigger, major challenges are the lack of resources and a huge amount of waste in the world. These challenges are harmful to environmental, social, and economic issues all around the world. These issues are represented as sustainability's triple bottom line approach. The perception of sustainability appeared originally in the Brundtland report (Keeble, 1988). The report aimed to offer solutions to upcoming problems from industrialization and the growth of the population to be able to block the negative environmental results of the economic development. The commission of united nations unified environmentalism with social and economic issues of the world successfully. In order to specify circular economy models from other models such as business, linear and design strategies are classified bestowing to the mechanisms by which resources circulate over a system. It specifies among the "cradle-to-grave" material flows and cyclic, cradle-to-cradle flows while comparing cyclical and linear approaches to the establishment of systems and products. This specification clearly points out a different types in source flow patterns which characterize circular and linear. Furthermore, when referring to "closed-loop systems" rather than cyclical systems, it basically specificies two contrasting types of loops among a closed-loop system: (1) the recycling process of materials and (2) reuse of products. Re-use of means that are goods extending the useful life of goods in the life long goods' design; it's used to increase the life of an existing material, including service promotion, product reuse, repair, refurbishment, and technical upgrade, and a a merging sequence of these. The outcome of the goods' reuse is a slower flow of material from the start of the production process all the way to the end of the recycling process. Extending the product life and goods means a contrasting relationship over time. (Bocken et al., 2016)

A circular economy focuses on restructuring behaviors about production and consumption of products to provide long-term usage of materials as long as possible instead of scrapping materials after the single-use life cycle of the product (Circular Economy: Definition, Principles, Benefits and Barriers, 2020). Principles of circular economy aim to eliminate waste and pollution by providing materials being in use. Reike et al. (2018) defined the circular economy concept as a financial system which utilizes the reuse of items and materials and the preservation of characteristic assets as a beginning point” where financial, social and natural values are critical in each portion of the framework. The circular economy concept is also defined as a regenerative model that reduces waste and emissions (Geissdoerfer et al., 2017). A circular economy is beneficial for the economy and the society as an entirety in industrial ecology. Whereas lessening the utilization of common assets, guarantees the decrease of destructive remaining waste goods for the economy and society, and the establishment of profit for the economy at the same time.

Ellen MacArthur Foundation is one of the best-known foundations in the circular economy concept. This foundation proposed a circular economy approach to help sectors to reduce their environmental footprints, costs, delays, and some other bad outcomes. Footprints are the effect that companies have on the environment. It is a measure that endeavors to consider numerous impacts of action instead of center on one. Webster (2015) indicated the basic point of a circular economy as keeping the most noteworthy value of the materials, parts, and items within the generation framework. A circular economy rather than a direct generation framework (take-make-dispose) could be characterized as a business model that aims redefining production forms with the thought of utilizing rare goods and vitality more than once within the same or other production processes. To attain the goals of a circular economy, considerate the activities of the reverse manufacturing frameworks alike reusing, repair, remanufacturing, reuse, restoration, and support of the waste streams of goods is vital.

Kiviranta et al. (2020) indicate that a circular economy may give an extra control request at times when the provincial power supply surpasses. The circular economy idea has been set up in arrange to form a more economical human community (Sehnem et al., 2019; García-Quevedo et al., 2020). Organizations have set up maintainable exercises depend on circular economy situated manufacturing forms to supply maintainability of the framework by improving the circularity of items and natural sources (Kirchherr et al., 2017). The circular economy approach advances the utilize of green assets and innovation and is presented as an option to the "take, make and dispose" model of a linear economy (Ness, 2008; Dey et al., 2020). Nowadays circular economy principles started using recently in many countries like the USA, China, Japan, and the EU (Bag et al., 2020; Yadav et al., 2020).

Sustainability is a discipline that bypassed the reduction of natural resources to preserve ecologic stability (Sustainability – What Is It? Definition, Principles and Examples, 2020). Sustainability tries to secure the demand without affecting the future generations without giving up the triple bottom line, that are social development, environmental protection, and economic growth. Environmental sustainability is to keep the rate in the balance between natural resources and consumption of them by humans. Economical sustainability is to maintain the independence of the resources required financially. Finally, human rights and necessities are accessible to all people in order to keep their communities safe and healthy (What is sustainability?, 2020). This represents social sustainability. In order to attain sustainability, these three pillars should be accomplished. The pillars of sustainability have been mentioned in many studies on the CE. Geissdoerfer et al. (2017) mentioned that at least eight different similarities can be found between sustainability and the CE concept. These eight similarities are classified into three groups which are conditional, beneficial, and trade-off. Sustainability became a need within the approaches and methodologies of enterprises due to the termination of natural resources, researches, and significance of social subject (Mangla et al., 2013; Harangozó and Zilahy, 2015; Luthra and Mangla, 2018). Shareholders drive systems to coordinated supply chain techniques within sustainability concepts in arrange to supply synergy between management of product and data to improve the social, environmental and economic efficiencies (Luthra et al., 2018).

The circular economy is a sustainable system aimed to eliminate the waste amount and the continual of the current resources by creating the close loop systems (Geissdoerfer et al., 2017). Furthermore, it aims at minimizing the amount of waste, resource usage, pollution, and greenhouse gas emissions. Each waste should become a resource for another process. This approach opposes the linear model of resource reduction of "take-make-dispose" (Ellen MacArthur Foundation, 2013). While CE focuses on reducing the impacts of the linear economy, it also aims to build long-term flexibility, provide environmental and societal benefits, and create economic opportunities and businesses. Ellen MacArthur Foundation identifies the four essential building blocks of the circular economy. The first one is, to facilitate recycle and reuse, the companies need to build resources and capabilities in a circular design. Secondly, companies need new business frameworks to conversion to the circular economy. The third essential building block is to acquire skills desired for waterfalls and the return of goods either to the land or back into the plants. The last one is, market mechanisms, policymakers, educational associations and popular idea leaders have an important role in the reuse of materials and more efficient use of resources to become common. (Rudnicka, 2018)

The recent studies have presented a framework to increase the circularity of a linear economy which is known as R-strategies. The strategies are based on 3R (reduce, reuse, recycle) (King et al., 2006; Yong, 2007; Sakai et al., 2011; Yang et al., 2014; Brennan et al., 2015; Ghisellini et al., 2016), 6R (reduce, reuse, recycle, recover, remanufacture, redesign) (Kuik et al., 2012; Sihvonen and Ritola, 2015) and 9R (rethink, refuse, reuse, reduce, refurbish, repair, remanufacture, recycle, repurpose, recover) (van Buren et al., 2016; Potting et al., 2017). Refuse is to abandon a product's function to make it redundant. Rethink is to make a product multi-functional to make it more intensive. Reduce is to increase efficiency while manufacturing or consume fewer natural resources. Reuse is to provide a product that is in good condition to another consumer. Repair is to repair the defects of the product and make it usable again. Refurbish is to restore a used product that makes it up to date. Remanufacture is to use parts of a discarded product for the new one. Repurpose like the remanufacture, but the parts are used for a different function. Recycle is to process materials so that they can be used again. Recover is to transform the materials into energy by incineration. The more these strategies are used, the more circular the economy gets.

2.2. Sustainability and Sustainable Supply Chains

The substance of sustainable supply chain management comprises social, environmental, and economic gains based on the triple bottom line path (Carter and Rogers, 2008). It points to the devaluation of asset utilization, and negative natural results, and waste minimization (Genovese et al., 2017). Sustainable supply chains incorporate circularity undermost forward and closed-loop SCM, recovery, and reverse logistics, (Seuring and Müller, 2008; De Angelis et al., 2018). The reverse logistics model is the main column of the circular economy and covering the reverse stream of dispersion, repairing, remanufacturing, restoring, and reusing exercises (Kazancoglu et al., 2021). Inside this point of view, the circular economy gives the integration of sustainable supply chain management with a financial framework targeting at long durational sustainability (Schrödl and Simkin, 2014). A circular economy helps organizations move forward financial and natural sustainability through the assimilation of waste management and reverse and forward logistics (Winkler, 2011). In expansion, the sustainable supply chain performance is specifically related to the adjustment capability of the systems to the circular economy (Zeng et al., 2017). Circular economy not as it was giving the asset usage and life cycle expansion, but further plans a sustainable generation framework within the supply chain; thus, there is a need to adjust sustainable supply chain exercises with the circular economy (Genovese et al., 2017). Likewise, the major intention of change from conventional to feasible supply chains requires the expansion of the life cycle, that can only be accomplished by the affiliation of circular economy and sustainability, since these approaches are commonly steady (De Angelis et al., 2018; Liu et al., 2018).

A few numerous approaches and exercises utilize the standards of the circular economy and these change according to the definitions and countries considered. Circular financial exercises incorporate reuse, repair, reusing, eco-design, sustainable supply, and mindful utilization. The wealth of concepts causes the definition of the circular economy not to be put on the ground. In any case, an essential level of understanding can become through accessible literature. The Ellen MacArthur Foundation, which has made noteworthy contributions to the concept of circular economy in recent years, particularly on the characteristics of the considers, process, operations, and goals of the circular economy model give five essential structures to a circular economy.

- Designing waste,
- To create flexibility through diversity,
- Studies on energy from renewable sources,
- Planning in systems,
- Designing processes gradually

The big part of achieving a sustainable circular economy is to have strategic logistics activities. Meeting customer demands and avoiding environmental damage are the key concerns. (Stank et al., 2001; Bag et al., 2020) Also, green logistics should be considered as a key element of the circular economy concept. Green logistics combines circular economy concepts and underpins the idea of sustainable development. A critical perspective of the CE concept is the closed-loop circulation of matter ("green matter"), which is conceivable to be utilized within the improvement of green logistics. (Seroka-Stolka, 2014; Seroka-Stolka and Ociepa-Kubicka, 2019)

While the economies turning to a circularity, companies should consider the system in a closed-loop shape. (Kazancoglu et al., 2018) The circular economy includes the reverse logistics concept, which could be a process that empowers a producer to efficiently acknowledge previously sent items from the point of utilization for conceivable reusing, remanufacturing, or disposal. The Reverse logistics framework joins a supply chain that has been renewed to manage the stream of items or parts predetermined for remanufacturing, reusing, or transfer and to utilize resources successfully. (Dowlatshasi, 2000; Maheswari et al., 2020) In comparison with developed countries, emerging economies are more likely to destroy or burn the usable and desirable items, and products. For that issue, a complete collection process, which may be a crucial perspective of reverse logistics, is needed to handle environmental, economic, and social subjects. Understanding the reverse management systems like reuse, recycle, repair, refurbishment, remanufacturing, and conservation of the waste streams of goods is vital to accomplishing the goals of the circular economy.

2.3. Reverse Logistics Operations

There are 4 main activities in logistics which are order processing, inventory management, freight transport, and reverse logistics activities. Order processing which is the fundamental element of order management is the process of picking, packing, and delivery of the items before shipment. Companies work to handle effective and accurate order management to achieve their corporate goals. All these activities have high effects on the success of the company in the manner of cost and time. Order picking which consists of basically taking or collecting the goods in a specific number before shipment to satisfy the needs of the customers is one of the simple operations in warehouse management. However, this process has a huge impact on the productivity of the supply chain in which makes the process crucial. This requires accurate methods for picking. Pick-to-light, put-to-light, pick-to-voice are some of the widely known technologies are used in picking processes to increase the efficiency and accuracy of the process.

Inventory management includes materials handling, warehousing, and inventory control. Material handling is the development of products inside the warehouse. It includes dealing with the material in such a way that the warehouse is able to handle orders effectively. In spite of the fact that it may sound like an ordinary assignment, it is a vital one and a progressing action in any warehouse. Manufacturing of companies may be at one manufacturing center, but they might distribute their products all over the world. These situations increase the importance of warehousing processes. The critical point in warehousing is that the distribution center ought to be adjacent to the merchant or the distributors' put and it ought to facilitate the simple delivery of products. Inventory control is one of the most important parts of logistics activities. If a company produces way higher products than the demand means the company has wrong investments. This is cash that can be utilized as working capital and it is cash on which banks are applying interest. When thinking from the other side, the company produced way fewer products than demand means they are losing orders. It means they lost opportunity cost. Producing higher amounts than actual demand for this opportunity cost may lead to an expanse. Because these overages have a holding cost for the company. So, by these techniques, companies try to minimize the total expenses and maximize total income (Ghiani et al., 2005).

Packing is one of the costly and time-consuming operations in the order management process. Packing of the items may require more materials and time according to product diversity in a warehouse. Also, packing is an essential factor to increase the durability of consumer electronics or to decrease perishability of the products like food and beverages that may be perishable in some specific conditions. Companies try to decrease time and cost requirements while protecting items to satisfy their customers. Plastic, glass, steel, aluminum, paper, and wood are some of the packaging materials which are commonly used in packing processes.

Delivery of the packed items to a shipping carrier is also an essential part of order processing. When the delivery of the products-completed, then the shipping company fulfills the order. Orders can be delivered by vehicles to shipping stations or companies can outsource this activity to hand over the responsibility and the cost of delivery to shipping companies or 3rd parties. Weight of the order, modes of transportation, and cost/time of delivery determined at shipping stations. These transportation processes are costly processes due to fuel consumption. Transportation includes the physical delivery of products from the producer to the merchant. For the most part, companies are included as they were till the point delivery happens to the merchant. The merchant is at that point responsible for the delivery to the end client. In any case, transportation decreases the merchant's profit.

The last part of the logistics activities is the reverse logistics concept. Reverse Logistics can traditionally be expressed as the handle of recycling products. According to Flieschmann (2001), reverse logistics; is the method of arranging, implementing, and controlling the conventional supply chain to effectively and efficiently store and flow secondary items in order to recover value and achieve decent disposal. Reverse Logistics; It is the exercise of arranging, implementing and controlling the compelling stream of raw materials, semi-finished items, finished items, and related data from the point of utilization to the point of origin, in order to ensure that the value is gained or destroyed in an appropriate way. According to Dowlatshahi (2005), reverse logistics is “the handle by which a fabricating facility efficiently recovers previously transported items or parts from the point of utilization to implement one of the possible recycling, remanufacturing or disposal processes.”

The most common notion about reverse activities is the physical transport of used products back from the end-user to the manufacturer. Reverse Logistics is also known as environmentally friendly logistics in terms of recycling and reusing undesirable materials (waste, bottles, paper, cans, etc.). After the finished products are collected in various ways, they go through the disassembly processes. The parts that can be used are determined and included in partial use or reproduction. In this way, the harm of waste to the environment is minimized. As a result of economic factors, the importance of reverse logistics activities has increased. Because reverse logistics activities provide additional income to companies due to the decreasing consumption of raw materials, the value added to the recovered materials, and the reduction of waste materials.

Reverse logistics is of the most important parts of Circular Economy. It includes recycle, repair, reuse, reduce, refuse, and rethink. The primary objective of reverse logistics is to recoup value from resources to extend income and decrease costs. Setting up a reverse logistics network can boost the effectiveness of a conventional supply chain by isolating the operations. Companies should arrange and execute techniques to oversee items past manufacturing and the final deal to increase their efficiency. (Marchesini and Alcântara, 2016)

2.4. Performance Assessment

Measuring the circularity of logistics activities is a very hard job. There is one methodology to measure the performance of these activities which is the World Bank's Logistics Performance Index (LPI). Many authors use this index as a marker of green logistics execution. (Zaman and Shamsuddin, 2016; Aldakhil et al., 2018; Khan et al., 2018; Karaman et al., 2020) They use this indicator for comparing logistics performances of different countries. Also, environmentally sensitive industries proposed the scheme of the Global Reporting Initiative (GRI). GRI framework provides guidance on particular pointers of corporate social responsibility performance (CSR). (Boiral and Heras-Saizarbitoria, 2020; Karaman et al., 2020)

Performance assessment is measuring how well individuals or systems work agreeing to predefined markers (Bititci et al., 2012). First of all, parameters and measures are decided. Then, by using a strategy, the required performance measures are obtained. It is utilized for a variety of areas. As a rule, students are anticipated to create a result, such as a report. In industries, primarily a framework is measured. The most utilized strategies for the industry are explanatory and simulation strategies (Sassanelli et al., 2019). The most utilized explanatory tools are multi-criteria decision-making strategies life cycle assessment (Angelis-Dimakis et al., 2016; Huysman et al., 2017; Mardani et al., 2017; Kazancoglu et al., 2018). There are moreover a few simulation strategies utilization within the literature (Gbededo et al., 2018). Explanatory strategies are to make a scientific model and by having input parameters and output measures, system performance is calculated utilizing direct solutions. Simulation models are to reenact an actual process of a system (Sassanelli et al., 2019).

Recently, sustainability has been more in the center for both analysts and industrial organizations which moreover implies the performance evaluation of the sustainability as well. Most of the strategies utilized in this region require a set of indicators (Sassanelli et al., 2019). One of the foremost common strategies is multi-criteria decision-making strategies (MCDM) (Shen et al., 2013; Sassanelli et al., 2019). Multi-criteria decision-making phrasing may be a sub-discipline of operations research. These strategies change numerous indicator values into a single measurement. MCDM strategies are created to solve various decision-making issues. These strategies can be connected in various segments such as logistics, engineering, supply chain management, healthcare, production, sustainable development, etc. (Karthee et al., 2018).

Numerous researchers affirmed that MCDM strategies are effective in understanding complex multi-criteria issues (Kilic et al., 2015; Ishizaka and Resce, 2020). MCDM bargains with choosing the finest elective among distinctive potential options agreeing to different criteria or attributes. Decision-makers always want to choose the finest alternative to urge the foremost output. Their point is to find the ideal solution for their issue. However, cases that have various criteria, do not have an optimal solution due to a few conflicts. There is a need for a decision-making framework. Analytic hierarchy process (AHP) (Bentes et al., 2012; Sawaf and Karaca, 2018; Suganthi, 2018), analytic network process (ANP) (Kilic et al., 2015; Sakthivel et al., 2015; Liu et al., 2018), TOPSIS (Sakthivel et al., 2015; Gupta, 2018; Han & Trimi, 2018; Alao et al., 2020), ELECTRE (Chen et al., 2019), data envelopment analysis (DEA) (Basso et al., 2018; Suganthi, 2018), best-worst method (BWM) (Gupta, 2018), grey relationship analysis (GRA) (N. Li & Zhao, 2016), PROMETHEE (Kilic et al., 2015; Ishizaka & Resce, 2020), COPRAS (Zarbakhshnia et al., 2018), DEMATEL (Gardas et al., 2018; Torbacki and Kijewska, 2019) and VIKOR (Sakthivel et al., 2015; N. Li & Zhao, 2016; Suganthi, 2018) are the foremost common MCDM strategies utilized by numerous analysts. However, human judgments are commonly characterized by uncertain terminology, like ‘equally’, ‘moderately’, ‘strongly’, ‘very strongly’, ‘extremely’ and ‘significant degree’ (Jajimoggala et al., 2010). For this reason, Zadeh (1965) introduced the fuzzy set theory. The fuzzy set theory empowers DMs to handle the uncertainties included within the process of the linguistic statements of the information (N. Li & Zhao, 2016; Wibowo and Grandhi, 2017). The fuzzy set theory moreover empowers to include scientific operators and programming to execute to the fuzzy domain.

2.5. Circular Economy Performance Assessment

Assessing the circularity performance is one of the most important parts of achieving the circular economy concept. By assessing the performance, companies can improve their performances according to the results. Iakovou et al. (2009) created a “Multicriteria Matrix” technique for the producers to recognize the components and discover the ideal end-of-life options for their items. The strategy is based on multicriteria examination considering the components such as leftover value, environmental burden, ease of dismantling. Santini et al. (2010) considered the effect of pre-shredder treatment to attain an 85% recyclability rate by using a Plan for Recycling program. Olugu and Wong (2012) created a master fluffy rule-based framework for assessment for closed-loop supply chain administration. Shen et al. (2013) analyze a Green Supply Chain Management to propose a fuzzy multi-criteria decision making (MCDM) approach for green suppliers' assessment. Lee et al. (2014) proposed a novel Design for End-of-Life strategy for creators to design items with way better EoL performances. Eastwood and Haapala (2015) proposed a technique to progress the exactness of an item by utilizing unit handle modeling and life cycle stock strategies. Jamali-Zghal et al. (2015) consider the evaluation of the natural execution of metallurgical reusing by utilizing exergetic life cycle evaluation. Issa et al. (2015) distinguished and systemized product-related environmental performance markers by efficient literature review. Pagotto and Halog (2016) use input-output situated information envelopment model (I-O / DEA) and material stream examination to assess the eco-efficiency performance of subsectors in Australian agri-food frameworks to set up environmental and economic markers.

Angelis-Dimakis et al. (2016) use a life cycle assessment approach (LCA) and a set of eco-efficiency markers to form a system for surveying the eco-efficiency of water-use frameworks. Laso et al. (2016) utilized the life-cycle evaluation technique to survey the natural performance of two waste management frameworks that are utilized in the anchovy canning industry. Stop et al. (2016) inspected climatic outflow, environmental asset utilization, arrive, and water footprints of agricultural and nourishment sectors. They utilized an Ecologically based Life Cycle Assessment tool to perform a supply-chain connected ecological life cycle assessment (Eco-LCA). Ng and Martinez Hernandez (2016) propose a decision-making system for encouraging multi-criteria examination and process plans by taking into consideration of vitality, environmental, and economic criteria. Haghighi et al. (2016) propose an Adjusted Score Card-Data Envelopment Analyses crossover for performance assessment in sustainable supply chains. Franklin-Johnson et al. (2016) propose an unused indicator connected to Circular Economy for natural performance evaluation. They give a tool that can be appropriate for administrative and organizational levels of the life span of valuable materials. Skillet et al. (2016) clarify the five issues in assessing the supportability of mechanical frameworks and embraces the classic EA strategy to bargain with those issues. Voskamp et al. (2017) perform Material Flow Analysis to look at urban digestion systems by utilizing the Eurostat strategy. Huysman et al. (2017) create a marker for diverse plastic waste treatment alternatives to evaluate the circular economy performance. Grimaud et al. (2017) utilized Environmental Technology Verification rules to survey the economic, environmental, and social proficiency of forms. Martin et al. (2017) analyze the natural execution appraisal to see the impacts of biofuel frameworks on related cases. Fregonara et al. (2017) present a strategy for design exercises utilized in unused buildings or reestablishing existent buildings. They utilize indicators such as Life Cycle Assessment and Life Cycle Costing.

Wibowo and Grandhi (2017) propose a Multi-Criteria Decision Making (MCDM) approach for the assessment of the performance of recoverable end-of-life items that are utilized in the reverse supply chain. Triangular fuzzy number estimation is utilized to overcome the lack of quality of the performance assessment process. Akinade et al. (2017) considered viable material recovery for building deconstructions and distinguished Critical Success Factors by writing audit and Focus Group Discussion. Favi et al. (2017) propose an approach by comparing End-of-Life based on E-o-L records for item design to decrease landfill waste. Mardani et al. (2017) summarized the diverse models of Data Envelopment Analysis for surveying vitality effectiveness. Sénéchal (2017) proposes a set of components to conduct an investigation for sustainable performance in support. Petit et al. (2018) build modern sustainable performance measurements of a nourishment value chain by utilizing existing systems and markers. Gbededo et al. (2018) survey sustainable manufacturing approaches from 2006 to 2015 by utilizing an efficient literature review strategy. Pauliuk (2018) proposes a common framework definition for determining Circular Economy markers based on Material Flow Analysis (MFA) and Material Flow Cost Analysis (MFCA). Laso et al. (2018) combine Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) strategies to propose an appraisal of eco-efficiency for the angle canning industry. Biganzoli et al. (2018) use the Life Cycle Assessment strategy to evaluate the environmental impacts of middle bulk container rotation numbers. Hadzic et al. (2018) examine the bio-waste scenarios by utilizing the Life Cycle Assessment strategy. Kazancoglu et al. (2018) finds a gap for performance evaluation of circular economy in green supply chain administration and proposes an unused holistic conceptual system for GSCM performance evaluation. Xu et al. (2018) calculate the health risk evaluation of both non-carcinogenic and carcinogenic risks from chosen poisons put in China by utilizing MCDM. Oliveira et al. (2018) examined 23 companies in the wood furniture sector in Brazil to recognize the circular economy performances of the companies. Expósito and Velasco (2018) use a novel Data Envelopment Analysis (DEA) strategy to analyze the effectiveness of recycling advertise in Spain. In Table 1, the objectives and the methods used in the articles are summarized.

Table 1. Papers about Circular Economy Performance Assessment

Author (Year)	**Objective**	**Methods**
Iakovou et al. (2009)	"Multicriteria Matrix" methodology is developed for manufacturers to distinguish the components according to their highest potential value at End-of-Life.	Multi-Criteria Decision Methods (MCDM)
Santini et al. (2010)	Design of Recycling is used for End-of-Life performance of products and the impact of pre-shredder treatment could have.	Design for X (DfX)/Guidelines (GL)
Olugu and Wong (2012)	To evaluate the performance of a system of a closed-loop supply chain, an expert fuzzy rule-based system was developed using VB.Net for the automotive industry.	Multi-Criteria Decision Methods (MCDM)
Shen et al. (2013)	The fuzzy multi-criteria approach is examined for a Green Supply Chain Management (GSCM) system.	Multi-Criteria Decision Methods (MCDM)
Lee et al. (2014)	The end-of-Life methodology is proposed to design better products with better End-of-Life performances.	Design for X (DfX)/Guidelines (GL)
Eastwood and Haapala (2015)	Created a maintainable evaluation strategy to identify the sustainability impacts of products	Life cycle assessment (LCA)

	more accurately and to assist manufacturing decision-makers using LCA.	
Jamali-Zghal et al. (2015)	Uses the emergy approach and exergetic LCA to assess the environmental performance of metallurgical recycling.	Life cycle assessment (LCA), Emergy approach (Em), Exergy approach (Ex)
Issa et al. (2015)	Identifies and systematizes existing product-related natural performance markers by doing a systematic literature review. Developed a guideline for the selection of these indicators.	Design for X (DfX)/Guidelines (GL)
Pagotto and Halog (2016)	Evaluates the eco-efficiency execution of different subsectors within the Australian agri-food frameworks using I-O oriented DEA model and material flow analysis	Data Envelopment Analysis (DEA)/ Input-Output (I-O), Material flow analysis (MFA)
Angelis-Dimakis et al. (2016)	An LCA approach is used for presenting a framework to assess the eco-efficiency in water-use systems.	Life cycle assessment (LCA)
Laso et al. (2016)	Combined LCA and LCC to propose the assessment of eco-efficiency for the fish canning industry.	Life cycle assessment (LCA), Life cycle costing (LCC)
Park et al. (2016)	A combination of Ecological LCA, ReCiPe, and linear programming was performed to assess the impacts of agricultural and food production activities.	Life cycle assessment (LCA), Data Envelopment Analysis (DEA)/ Input-Output (I-O), Emergy approach

		(Em), Exergy approach (Ex)
Ng and Martinez Hernandez (2016)	Energy, environment, and economy (3E) metrics are used to present a process design and decision-making framework for the selection of process design.	Multi-Criteria Decision Methods (MCDM)
Motevali Haghighi et al. (2016)	A BSC-DEA framework to evaluate the performance in sustainable supply chains is proposed.	Balanced Score Card (BCA), Data Envelopment Analysis (DEA)/ Input-Output (I-O)
Franklin-Johnson et al. (2016)	A novel indicator to assess the environmental performance connected to CE is presented.	Material flow analysis (MFA) / Material cost analysis (MCA) / Material flow cost analysis (MFCA)
Pan et al. (2016)	EA method is applied to five issues for evaluating recycling and reuse benefit.	Emergy approach (Em), Exergy approach (Ex)
Voskamp et al. (2017)	The urban metabolism of Amsterdam is inspected by performing an MFA applying the Eurostat method. The method is updated to increase its performance for UM analyses.	Material flow analysis (MFA)
Huysman et al. (2017)	The cumulative Exergy Extraction from the Natural Environment (CEENE) method is used to assess the circular economy performance for plastic waste.	Life cycle assessment (LCA), Emergy approach (Em), Exergy approach (Ex)

Grimaud et al. (2017)	For ensuring environmental, economic, and social efficiency, the paper uses Environmental Technology Verification guidelines to guide designers.	Life cycle assessment (LCA), Design for X (DfX)/Guidelines (GL), Material flow analysis (MFA)
Martin et al. (2017)	LCA is applied to assess the environmental performance of the production of biofuel systems.	Life cycle assessment (LCA)
Fregonara et al. (2017)	LCA is used to propose a new methodology to support decisions in design activities in the building industry.	Life cycle assessment (LCA)
Wibowo and Grandhi (2017)	An MCDM approach is applied to evaluate restorable End-of-Life products' performances in the reverse supply chain.	Multi-Criteria Decision Methods (MCDM)
Akinade et al. (2017)	By using Design for Deconstruction, critical success factors needed for recovering materials more effectively are identified.	Design for X (DfX)/Guidelines (GL)
Favi et al. (2017)	Design for End-of-Life is used to help designers improve EoL performances.	Design for X (DfX)/Guidelines (GL)
Mardani et al. (2017)	Different models of DEA applied for the development of energy efficiency problems are reviewed.	Data Envelopment Analysis (DEA)/ Input-Output (I-O)
Sénéchal (2017)	Decision support for controlling sustainable performance induced by maintenance processes is proposed by the implementation of Sustainable Condition-Based Maintenance based on Remaining Sustainable Life	Discrete Event Simulation

Petit et al. (2018)	Examines existing frameworks and indicators for value chain sustainability by building new sustainable performance metrics.	Life cycle assessment (LCA), Multi-Criteria Decision Methods (MCDM)
Gbededo et al. (2018)	A systematic literature review has been made for sustainable manufacturing approaches between 2006 and 2015.	Life cycle assessment (LCA)
Pauliuk (2018)	General system definitions to derive CE indicators are proposed.	Life cycle assessment (LCA), Material flow analysis (MFA) / Material flow cost analysis (MFCA)
Laso et al. (2018)	Combines LCA and LCC methods and proposes the assessment of eco-efficiency for the fish canning industry.	Life cycle assessment (LCA), Life Cycle Costing (LCC)
Biganzoli et al. (2018)	By using LCA, the environmental impacts of Intermediate Bulk Containers are assessed.	Life cycle assessment (LCA)
Hadzic et al. (2018)	LCA software EASETECH is used for the performance evaluation of municipal solid-waste administration systems.	Life cycle assessment (LCA)
Kazancoglu et al. (2018)	Proposes a new framework for Green Supply Chain Management (GSCM) performance evaluation that integrates economic, environmental, organizational, operational, promoting, and logistics performances.	Multi-Criteria Decision Methods (MCDM)

Xu et al. (2018)	Risk assessment and residual levels of potentially toxic elements are studied.	Multi-Criteria Decision Methods (MCDM)
Oliveira et al. (2018)	23 companies in the wooden furniture industry were examined to assess the circular economy of the companies.	Design for X (DfX)/Guidelines (GL)
Expósito and Velasco (2018)	DEA method is used to analyze the efficiency of municipal solid-waste management in Spanish regions.	Data Envelopment Analysis (DEA)/ Input-Output (I-O)

Ling et al. (2013) assessed the effectiveness of performance assessment. According to the paper, there are two starting points for performance assessment which are dynamic and static levels. The dynamic level focuses on the framework to achieve a goal and the static level focuses on the effectiveness of the method. Gani (2017) assessed the logistics performance effect on international trade. They got data from a large sample of countries. After the analysis, they came up with that logistics activities have positive and statistically significant effects on international trade. Marti et al. (2017) proposed a different Data Envelopment Analysis (DEA) for the logistics performance index which is DEA-LPI to assess and benchmark the logistics performance index. They found out that the performance of logistics depends on the environment and income. Developed countries' performance is higher than non-developed or emerging countries. Roy et al. (2017) facilitate extended experiences into logistics performance. They mentioned a two-stage framework that contains MARS regression and Cluster analysis. Ha et al. (2018) proposes a mixed method to increase the port performance of container transport logistics. They used Analytical Hierarchy Process (AHP) and Importance-performance analysis (IPA). Han and Trimi (2018) assessed the performance of reverse logistics in social commerce stages. They used the Fuzzy TOPSIS (The Technique for Order of Preference by Similarity to Ideal Solution) method to assess the performance. Then they perform a sensitivity analysis of the results. Kabak et al. (2018) examined the correlation between logistics performance and exports at the country level by using holistic scenario analysis. Similarly, Liu et al. (2018) examined the correlation between environmental issues and logistics performance in Asian countries. They used the Generalized Method of Moments (GMM) regression method for their calculations. They came up with there is a significant relationship between logistics and the environment to ensure sustainability in Asian countries. Rezaei et al. (2018) assessed the importance of logistics performance indicators in freight transport systems using the Best-Worst method (BWM). Beysenbaev and Dus (2019) mentioned the importance of the logistics performance index (LPI). They got the data from the publication of the World Bank and they proposed some methods to increase the logistics performance index of 159 countries. Bottani et al. (2019) worked on the collection of food wastes. Collection of the wastes mean there is a reverse logistics network. And they gave a couple of scenarios of reverse logistics networks in the Emilia-Romagna region (Italy). They used Life Cycle Assessment (LCA) to assess the economic and environmental gains of collecting food waste. Ekici et al. (2019) worked on improving the logistics performance by proposing a methodology. They analyzed the pillars affecting the logistics performance according to the Logistics Performance index. Finally, they came up with the governments should consider education, technology, infrastructure, and market size to improve logistics performance. Hammes et al. (2019) worked on civil construction. They analyzed the performance of reverse logistics networks in developing countries. And they proposed a methodology to improve reverse logistics performance for these countries specifically for Brazil and Colombia. They prioritized 12 indicators by using Analytical Hierarchy Process. Khan et al. (2019) worked on logistics performance to ensure sustainability in South Asia. Lam et al. (2019) mentioned that how hydrogen is an environmentally friendly fuel for the world. However, there are some risks to use hydrogen as a primary fuel source. This study assessed these risks and tried to eliminate them. Tang and Abosedra (2019) worked on deciding whether the legitimacy of the export-led development speculation is unexpected on logistics execution in Asia. They got the data from 23 Asian countries. They came up with the logistics performance have a serious effect on economic growth in these countries. Torbacki and Kijewska (2019) examined the key indicators for Industry 4.0 and Logistics 4.0 for ensuring sustainability. They used the DEMATEL method to analyze the indicators they mentioned. Julianelli et al. (2020) worked on the relation between circular economy and logistics activities. They proposed a framework to ensure circularity according to critical success factors (CSFs). Melkonyan et al. (2020) assessed distribution strategies to attain sustainability in local food networks.

They proposed a framework consisting of multi-criteria decision-making (MCDM) methods to reach the sustainability potential. Nathanail et al. (2020) worked on smart city issues. They performed logistics performance assessment by using one of the multi-criteria decision-making (MCDM) methods which is Life Cycle Sustainability Analysis (LCSA). Finally, they mentioned that their proposal can improve Logistics Sustainability Index (LSI) by 24.5% on average. Somuyiwa et al. (2020) assessed the performance of logistics graduates in South-western Nigeria by using descriptive analysis. Stojanovic and Ivetic (2020) assessed the possibility of utilizing International commercial terms to improve logistics performance. Töngür et al. (2020) examined the effects of logistics performance on export diversity. They came up with the logistics performance has positive effects on exports. Zheng et al. (2020) worked on logistics performance in China. They assessed the logistics performance by using hierarchical regression and Data Envelopment Analysis methods.

Table 2. Papers about Logistics Performance Assessment

Author (Year)	Objective	Method
Ling et al., 2013	Assessing the effectiveness of logistics performance assessment	Research Paper
Gani, 2017	Assessing the effect of logistics execution in universal trade	Linear Programming
Marti et al., 2017	Proposes Data Envelopment Analysis (DEA) method to compute logistics performance index	Data envelopment analysis (DEA)
Roy et al., 2017	Facilitates extended experiences into logistics performance	MARS regression and Cluster analysis
Ha et al., 2018	Proposing a method to increase the port performance of container transport logistics	Analytical Hierarchy Process (AHP) and Importance-performance analysis (IPA)

Han and Trimi, 2018	Performance assessment of reverse logistics in social commerce platforms	Fuzzy TOPSIS Method and Sensitivity Analysis
Kabak et al., 2018	Investigates logistics performance and exports at country level	Scenario Analysis
Liu et al., 2018	Analyses the relationship between logistics execution and environment	Generalized Method of Moments (GMM)
Rezaei et al., 2018	Assesses the significance of the logistics performance indicators	Best-Worst Method (BWM)
Beysenbaev and Dus, 2019	Giving proposals for improving Logistics Performance index given by the World Bank	The Integrated Logistics Performance Index (ILPI)
Bottani et al., 2019	Giving several scenarios of reverse logistics for the collection of food waste	Life Cycle Assessment
Ekici et al., 2019	Logistics performance improvements by rearranging Global Competitiveness Index pillars	Bayesian network (BN-TAN) model
Hammes et al., 2019	Performance assessment of reverse logistics in civil construction	Analytic Hierarchy Process (AHP)
Khan et al., 2019	Examines the sustainability indicators South Asian association for regional cooperation	Statistical Analysis
Lam et al., 2019	Assessing the risk factors of hydrogen logistics cases	Network Modelling
Tang and Abosedra, 2019	Determines the efficacy of the export-led growth (ELG)	The Cobb-Douglas production function

	theory on logistics performance in Asia	
Torbacki and Kijewska, 2019	Determines the key performance indicators for Logistics 4.0	Dematel
Julianelli et al., 2020	Framework for creating value to companies in the circular economy	Content Analysis
Melkonyan et al., 2020	Framework for investigating the maintainability potential of last-mile coordinations and distribution techniques	PROMETHEE
Nathanail et al., 2020	Sustainability assessment of City Logistics	Life Cycle Sustainability Analysis (LCSA)
Somuyiwa et al., 2020	Performance assessment of logistics graduates	Statistical Analysis
Stojanovic and Ivetic, 2020	Assessing the possibility of using International commercial terms to improve logistics performance	Benchmarking
Töngür et al., 2020	Examines the effects of logistics performance on export diversity	Decomposition Methodology
Zheng et al., 2020	Regional logistics performance assessment in China	Data envelopment analysis (DEA), Hierarchical regression, and Benchmark analysis

Ling et al. (2013) mentioned about the importance of assessing logistics performances in companies. They mentioned about how to assess their efficiencies and how to validate the results. Gani (2017) was on the economic side of the logistics activities. The paper assessed the logistics performance effect on international trade by using linear programming. In the end, Gani (2017) found out that logistics activities have a positive effect on international trade. Marti et al. (2017) proposed to use Data Envelopment Analysis to compute logistics performance index (LPI). The findings show the performance of the logistics depends on the economic and ecological power. Roy et al. (2017) used MARS regression and Cluster analysis to analyze logistics performance. Ha et al. (2018) worked on container transport logistics. They proposed a hybrid method including Analytical Hierarchy Process (AHP) and Importance-performance analysis (IPA) to increase port performance. Han and Trimi (2018) worked on a different concept which is reverse logistics. They assessed the reverse logistics performance in social commerce platforms by using the Fuzzy TOPSIS method. Kabak et al. (2018) performed scenario analysis and investigated the logistics and export performances at the country level. Liu et al. (2018) were mostly worked on environmental parts of the logistics activities. They analyzed the relationship between environment and logistics performances. They dealt with the problem by using the Generalized Method of Moments (GMM). Rezaei et al. (2018) mentioned the importance of the indicators of logistics activities. They assessed the logistics performance by using Best-Worst Method (BWM). Beysenbaev and Dus (2019) proposed a method called The Integrated Logistics Performance Index (ILPI) to improve the World Bank's logistics performance index. Bottani et al. (2019) worked on reverse logistics and food wastes. They created several scenarios and applied Life Cycle Assessment (LCA). Ekici et al. (2019) tried to improve logistics performance according to Global Competitiveness Index pillars by using the Bayesian network (BN-TAN) model. Hammes et al. (2019) assessed the reverse logistics performance in civil construction by using Analytic Hierarchy Process (AHP). Khan et al. (2019) examined the sustainability indicators in South Asia according to their association for regional cooperation. Lam et al. (2019) created a network model for assessing the risk factors in hydrogenous transportation cases. Tang and Abosedra (2019) tried to validate the export-led growth (ELG) hypothesis in the logistics area in Asia by using The Cobb-Douglas production function. Torbacki and Kijewska (2019) examined the key performance indicators under Logistics 4.0 by using the Dematel method. Julianelli et al. (2020) created a framework for companies to create value for the circular economy. Melkonyan et al. (2020) created a framework to see the sustainability potential of last-mile logistics and distribution strategies by using the PROMETHEE method. Nathanail et al. (2020) assessed the sustainability of City Logistics. They used Life Cycle Sustainability Analysis (LCSA) to assess sustainability. Somuyiwa et al. (2020) create a guideline for logistics graduates. They assess the performance of the graduates by using Statistical Analysis. Stojanovic and Ivetic (2020) done a benchmarking of logistics activities to assess the potential of using International commercial terms to improve the performance of logistics. Töngür et al. (2020) examined how logistics activities affect export diversity by Decomposition Methodology. Zheng et al. (2020) assess the regional logistics performance in China by using Data envelopment analysis (DEA), Hierarchical regression, and Benchmark analysis.

It can be seen that there are not any papers worked on the whole logistics activities in the literature. All the papers investigated specific issues. There should be a framework for comparing companies' logistics circularity performances among them. The framework should show companies which part of their activities they should improve to ensure sustainability and circularity. In the end, after applying this framework, companies help to improve the circular economy at the country level. This will improve the country's sustainability and circularity. The proposed framework for the paper is in section 3.

3. Proposed Framework Assessing Circular Economy Performance

In this part, a framework is developed. Figure 1 represents the framework given. In the first step, the literature was reviewed. Then, the criteria set was created according to the literature review. In the criteria set, there are 3 main criteria and 16 sub-criteria. These 3 main criteria are organized as the triple bottom line of the circular economy. These are economic, social, and environmental criteria, respectively. Then, based on the literature, these 16 criteria are validated with 8 academicians and 22 industry experts from 6 companies. The industry experts are from the companies analyzed in this paper. The criteria set was discussed with these 30 experts. After the validations, the data was collected from the selected companies and experts. With these data collected, Data Envelopment Analysis is applied to assess the circular economy performances of logistics activities of the companies. Then again the results were discussed and validated with the experts.

This novel framework is a guideline to clarify how to assess circular economy performance of logistics activities. In this study, related literature about circular economy and performance assessment is reviewed widely. Then, a criterion set is formed with the help of the findings from the existing literature. As mentioned before, there are no existing literature about the intersection of all three notions at the same time. At this point, circularity performance of the logistics activities is measured by using DEA. DEA is selected because of its competencies to measure the efficiency of the alternatives for the issue. This study becomes distinct from past studies since mainly focuses on logistics activities. Logistics companies can use this framework and this method to measure the circular performance of their activities and they may improve their activities that show poor circular performance. Besides of managerial utility, the framework may also be useful for government to monitor the circular economy environment in the country.

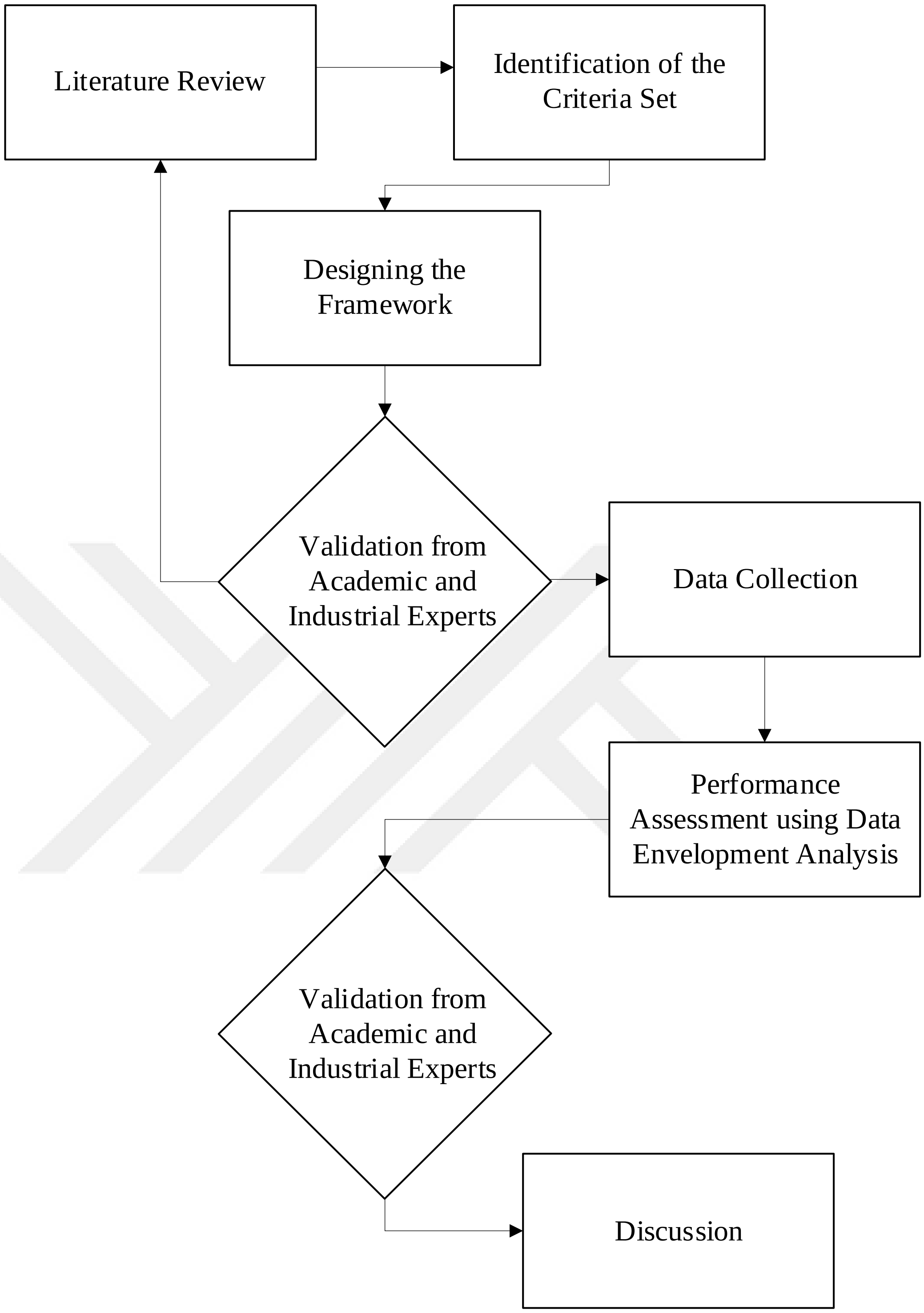


Figure 1. The Framework for Assessing the Circular Economy Performance

There are 16 criteria under 3 main criteria which are the triple bottom line of sustainability: economic, social, and environmental criteria. These 16 criteria are shown in the table below.

Table 3. The Criteria Set

Criteria	References
Economic	
Holding Cost	Tagaras and Zikopoulos, 2008; Malik et al., 2015; Nathanail et al., 2020
Transportation Cost	Kannan et al., 2008; Gołebiewski et al., 2013; Ayvaz et al., 2015; Ha et al., 2018; Hammes et al., 2019; Nathanail et al., 2020
Collection Cost	Sangwan, 2017; Kusakci et al., 2019
Personnel Cost	Kannan et al., 2008; Nathanail et al., 2020; Sagnak et al., 2021
Operation Cost	Temur et al., 2014; Sangwan, 2017; Ha et al., 2018
Vehicle Capacity	Bottani et al., 2019; Hammes et al., 2019
Technological Readiness	Ha et al., 2018; Han and Trimi, 2018; Ekici et al., 2019; Torbacki and Kijewska, 2019
Social	
Generating Job Opportunities	Ozceylan et al. 2016; Sagnak et al., 2021
Community Engagement	Liu et al., 2018; Sagnak et al., 2021
Work Safety	Kheybari et al., 2019; Sagnak et al., 2021
Education and Qualification	Ha et al., 2018; Kheybari et al., 2019; Hammes et al., 2019; Nathanail et al., 2020; Sagnak et al., 2021
Environmental	
Greenhouse Gas Emission	Kannan et al., 2008; Liu et al., 2018; Kheybari et al., 2019; Torbacki and Kijewska, 2019
Connection with City Centers	Ha et al., 2018; Sagnak et al., 2021
Proximity to Customers	Kannan et al., 2008; Malik et al., 2015
Proximity to Suppliers	Kannan et al., 2008; Malik et al., 2015
Pollution Prevention and Control	Chang and Chung, 2000; Khan et al., 2019; Sagnak et al., 2021

According to the given framework, there should be an appropriate method to assess the circular economy performances. The selected method for this issue is given in the section below.

4. Methodology

Multi-criteria decision-making (MCDM) techniques are a few of the foremost great techniques in overseeing different decision-making issues. These techniques can be executed in various zones such as engineering, production, supply chain management, healthcare, logistics, etc. Numerous analysts affirmed that MDCM techniques are successful in understanding complex multi-criteria issues. MCDM bargains with choosing the finest elective among different potential options agreeing to different attributes or criteria.

4.1. Data Envelopment Analysis

MCDM methods are developed to solve various decision-making problems. Data Envelopment Analysis (DEA) can be applied in various sectors such as logistics, engineering, healthcare, supply chain management, production, sustainable development, etc. Numerous researchers affirmed that MDCM strategies are effective in tackling complex multi-criteria issues. MCDM bargains with choosing the finest elective among different potential options concurring to different criteria or attributes. Decision-makers always want to select the best alternative to get the most output. Their aim is to find the optimal solution for their problem. However, cases that have various criteria, do not have an optimal solution due to some conflicts. There is a need for a decision-making system.

DEA is one of the most popular decision-making methods in the literature. DEA is a direct programming application pointed to assess the efficiencies of decision-making units (DMUs) based on the inputs and outputs related with the DMUs. A DMU is considered efficient if it gets the most output from its inputs. DEA can be used to evaluate the relative performances and identify the top performances.

Efficiency can be represented as maximizing output while keeping input constant, minimizing input while keeping output constant, or both at the same time. In DEA, efficiency Scores are ranging from 0 to 1, with 1 being the most efficient. The formula of the efficiency is total weighted output divided by total weighted input. DEA method decides the most effective DMU in the problem. It can also give the best possible efficiency with inputs and outputs while handling multiple inputs and outputs.

Benefits of Data Envelopment Analysis:

- Decides the most effective DMU.
- Gives the best possible efficiency with inputs and outputs.
- Handles multiple inputs and outputs.
- No need to use various assumptions and formulations for different inputs and outputs.

In the literature, there are a lot of application areas of Data Envelopment Analysis such as aerospace industry, food industry, transportation industry, banking, etc. DEA is commonly using in performance and efficiency assessments. Usage of Data Envelopment Analysis is increasing continuously. Al-Mezeini et al. (2019) used Data Envelopment Analysis for investigating the efficiency of greenhouse production in Oman. They use DEA for estimating the efficiencies of farmers. Atris et al. (2020) performed a performance assessment of oil refineries in Japan. Ullah et al. (2019) used Data Envelopment Analysis for analyzing the efficiencies of sugarcane production systems in Thailand. They worked on different sugarcane production systems. They performed DEA and compared relative efficiencies of six sugarcane production systems over each region of Thailand. Visani et al. (2019) performed a purchasing price assessment of leverage items. They compared several alternatives under relative efficiencies. Yu et al. (2019) used Data Envelopment Analysis for measuring Taiwanese bank performances. They used real data of Taiwanese banks from 2008 to 2016 under lending period and deposit period. Li et al. (2019) performed highway asset investment assessment in the USA by using Data Envelopment Analysis. Telles et al. (2019) analyze an aerospace manufacturer by using Data Envelopment Analysis. As it can be seen, there are a lot of areas that can use Data Envelopment Analysis. Most of the research in Data Envelopment Analysis is new. So, Data Envelopment Analysis is still a rising method.

Table 4. Data Envelopment Analysis Studies in the Literature

Author	Method	Problem	Data

Al-Mezeini et al. (2019)	DEA	Estimating Efficiencies of Farmers	Deterministic
Atris et al. (2020)	DEA	Performance Assessment of Oil Refinery	Deterministic
Ullah et al. (2019)	DEA	Estimating Efficiencies Production Systems	Deterministic
Visani et al. (2019)	DEA	Purchasing Price Assessment	Deterministic
Yu et al. (2019)	DEA	Bank Performance Assessment	Deterministic
Li et al. (2019)	DEA	Investment Assessment	Deterministic
Telles et al. (2019)	DEA	Performance Assessment	Deterministic
Talluri et al. (2006)	DEA	Performance Assessment	Stochastic
Mahdiloo et al. (2015)	DEA	Supplier Selection	Stochastic
Azadi et al. (2015)	DEA	Supplier Selection	Fuzzy
Chen et al. (2017)	DEA	Efficiency Analysis	Stochastic
Tavassoli et al. (2020)	DEA	Sustainability Assessment of Suppliers	Stochastic and Fuzzy

Data Envelopment Analysis is one of the most important Multi-Criteria Decision-Making tools applying to calculating the efficiency levels within a group of DMUs. The method aims to find the DMU that gets the most output from its inputs. The method can be applied to various sectors such as production, healthcare, government services, etc. There are a lot of deterministic applications of Data Envelopment Analysis in the literature. Also, there are some stochastic studies and fuzzy studies in various areas. In the DEA method, there are two types of mathematical modeling approaches are using which are CCR (Charnes-Cooper-Rhodes) and BCC (Banker-Charnes-Cooper). These methods are using for measuring the relative efficiency of DMUs that have multiple inputs and outputs. DEA permits the utilization of different inputs/outputs without forcing any functional frame on information or making presumptions of inefficiency. The input-oriented model minimizes the input while keeping output constant and the output-oriented model maximizes the outputs while keeping the input constant. Both models maximize efficiency. (Rajasekar and Deo, 2014)

4.1.1. Input Oriented CCR Model

$g_k = \max\,(\sum_{r=1}^{s} u_r \,.\, y_{rk})$

Subject to {

$\sum_{r=1}^{s} u_r \,.\, y_{rk}$ - $\sum_{i=1}^{m} v_i \,.\, x_{ik} \leq 0$

$\sum_{i=1}^{m} v_i \,.\, x_{ik} = 1$

$u_r \geq 0$, r = 1,…,s

$v_i \geq 0$, I = 1,…,m }

4.1.2. Output Oriented CCR Model

$g_k = \min\,(\sum_{i=1}^{m} v_i \,.\, x_{ik})$

Subject to {

$- \sum_{r=1}^{s} u_r \,.\, y_{rk} + \sum_{i=1}^{m} v_i \,.\, x_{ik} \geq 0$

$\sum_{r=1}^{s} u_r \,.\, y_{rk} = 1$

$u_r \geq 0$, r = 1,…,s

$v_i \geq 0$, I = 1,…,m }

n = number of alternative/DMU;

m = number of input criteria

s = number of output criteria

x_{ik} and y_{rk} denote the values of i^{th} input criterion and r^{th} output criterion for k^{th} alternative.

u_r and v_i are the weights to be determined by the solution of the minimization problem.

4.1.3. Efficient Frontier

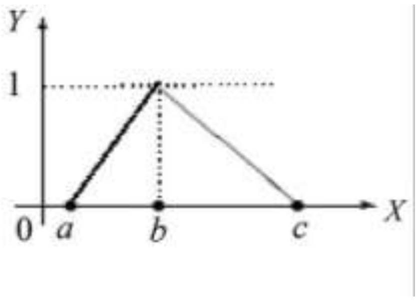
The efficient frontier is the set of ideal portfolios that offer the most noteworthy anticipated return for a characterized level of risk or the least risk for a given level of anticipated return. Portfolios that lie underneath the proficient wilderness are sub-optimal since they don't give enough return for the level of chance. Portfolios that cluster to the right of the efficient frontier are sub-optimal since they have a better level of chance for the characterized rate of return.

4.2. Fuzzy Logic

The fuzzy set theory was presented by Zadeh (1965). It is reasonable for managing the instability and imprecision related to data concerning different parameters. Human judgment is for the most part characterized by uncertain terminologies, like ‘equally’, ‘moderately’, ‘strongly’, ‘very strongly’, ‘extremely’ and ‘significant degree’. Utilizing such terminologies, DMs evaluate uncertain occasions and objects. Fuzzy set theory empowers DMs to handle the instabilities included within the handle of the linguistic appraisal of the information. The theory moreover permits scientific operators and programming to apply to the fuzzy space.There are triangular and trapezoidal fuzzy numbers.

Membership function of triangular fuzzy numbers;

$$\mu(x) = \begin{cases} 0, & x \leq a \\ \dfrac{x-a}{b-a}, & a < x \leq b \\ 1, & x = b \\ \dfrac{c-x}{c-b}, & b < x \leq c \\ 0, & x \geq c \end{cases}$$



Basic operations of fuzzy numbers;

$$\tilde{A} \oplus \tilde{B} = (a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4)$$

$$\tilde{A} \otimes \tilde{B} = (a_1 b_1, a_2 b_2, a_3 b_3, a_4 b_4)$$

$$\tilde{A} \ominus \tilde{B} = (a_1 - b_4, a_2 - b_3, a_3 - b_2, a_4 - b_1)$$

$$\tilde{A} \emptyset \tilde{B} = \left(\frac{a_1}{b_4}, \frac{a_2}{b_3}, \frac{a_3}{b_2}, \frac{a_4}{b_1}\right)$$

The Vertex Method is used to find the distance between the two positive trapezoidal fuzzy numbers. Using the Vertex method, the distance between two positive trapezoidal fuzzy numbers is calculated as follows;

$$d_v\,(\tilde{m}\,,\tilde{n}) \;=\; \sqrt{\frac{1}{4}\,[\,(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2 + (m_4 - n_4)^2]}$$

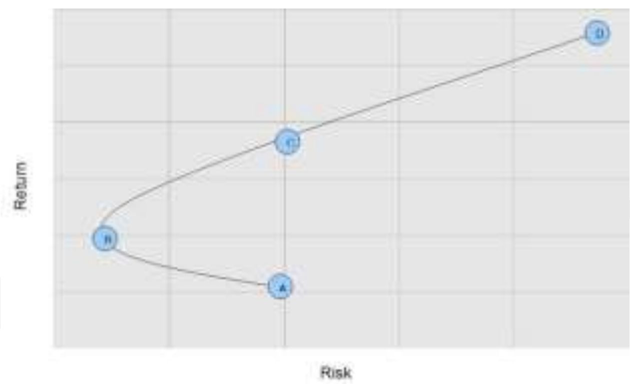


Figure 2. Risk and Return

4.3. Fuzzy Data Envelopment Analysis

Fuzzy numbers discussed in the section above can be represented as triangular fuzzy numbers. The rule for the numbers is $l \leq m \leq u$. l and u represent the lower bound and the upper bound of the fuzzy numbers and m represent the mid-value. Experts usually rank the alternatives in linguistic statements. So, the linguistic statements should be converted to numbers. At that point, our methodology Data Envelopment Analysis contains fuzzy logic. There is also a program called Frontier Analyst for applying the Data Envelopment Analysis. After the mathematical model, it will be compared with the program.

5. Case Study

There are 5 different companies investigated in the Aegean Region. The companies are defined as A, B, C, D, and E because of the privity. Some of the information of the companies are classified. So, there is limited information about them in this study. Company A is in the electronics sector. It has 375 thousand employees. It has company operations in 60 countries, and it has its own logistics operations in 150 countries. Company B is also in the electronics sector. It has almost 23 thousand employees. It has 28 fabrics, and it has exports to 155 countries. Company C is in the foam sector. It has 3 fabrics in Turkey. It has exports to 25 countries. It has 10 thousand employees. Company D is in the tobacco sector. It has exports in over 180 countries. It has almost 78 thousand employees. Company E has 15 thousand employees. It has exports to 35 countries.

5.1. Implementation

In the study, it is decided to have 16 criteria under 3 main criteria which are economic, social, and environmental. These criteria set is designed for the circular economy approach. The criteria set is validated with 8 academicians and 22 experts from industries. These 8 academicians are from logistics, operations, and management professors. The industry experts are selected from the investigated companies. The information about these experts are given in table 5. Then the criteria set is defined, and all these experts scored the criteria one by one in a linguistic way. They scored the criteria like “Very Low”, “Low”, “Average”, “High”, “Very High”. All the experts had given the blank survey above, in table 4. And asked them to fill with given linguistics. So, it turned the problem into fuzzy dimension and fuzzy Data Envelopment Analysis. DEA analysis is a nonparametric strategy in operations research (OR). It is utilized to experimentally measure the productive performance of decision-making units. It allows the utilization of numerous inputs and outputs without forcing any functional frame on information or making presumptions of inefficiency. There are two types of Data Envelopment methods in this study which are input-oriented and output-oriented. The input-oriented model minimizes the input values while keeping output unchanged and the output-oriented model maximizes the value of the outputs while keeping the input unchanged. Both models are equally efficient in these kinds of problems. (Rajasekar and Deo, 2014)

Table 5. Information about Experts

Expert No	Job	Experience	Age
1	Professor	35	57
2	Associate Prof.	19	41
3	Associate Prof.	15	37
4	Professor	33	55
5	Associate Prof.	14	36
6	Professor	29	51
7	Associate Prof.	18	40

8	Associate Prof.	17	39
9	Planning Specialist	8	33
10	Planning Engineer	13	35
11	Warehouse Manager	24	49
12	Production Manager	15	42
13	Stock Management Engineer	11	37
14	Planning Manager	15	40
15	Sales Engineer	12	34
16	Planning Engineer	8	35
17	Demand Planning Specialist	10	36
18	Operations Control Specialist	13	41
19	Sales Engineer	14	44
20	Supply Chain Data Analyst	14	39
21	Purchasing Specialist	18	40
22	Supply Chain Manager	23	49
23	Project Coordinator	20	47
24	Supply Chain Specialist	15	38
25	Demand Planning Specialist	7	32
26	Supply Chain Specialist	14	40
27	Production Engineer	6	30
28	Sales Manager	35	55
29	Supply Chain Specialist	16	42
30	Planning Manager	17	39

Table 6. The Survey of the Criteria Set

Comp/Crit	v1	v2	v3	v4	v5	u1	u2	u3	u4	u5	u6	u7	u8	u9	u10	u11
A																
B																
C																
D																
E																

Five of these criteria are input criteria and 11 of them are output criteria. Input criteria are holding cost, transportation cost, collection cost, personnel cost, and operation cost.

All the other criteria are output criteria. The survey taken is shown in the appendices. Then the scores should be changed to fuzzy numbers according to triangular fuzzy numbers according to table 7.

Table 7. Fuzzy Equalities of Linguistic Statements

Term	Fuzzy Number
Very Low	1,1,3
Low	1,3,5
Average	3,5,7
High	5,7,9
Very High	7,9,9

The first expert's survey given in table 8 and the fuzzy translation, according to the triangular fuzzy numbers given in table 7, is in table 9. All 20 experts' surveys are given in appendix 1.

Table 8. Survey of the Expert 1

u5	u6	u7	u8	u9	u10	u11
Low	Very Low	Low	Very Low	Low	Very Low	Low
Average	Very Low	Average	Average	Average	Average	Low
Low	Very Low	Average	Average	Very Low	Very Low	Low
High	High	High	Average	Very Low	Low	Low
Very High	High	High	Very High	Very High	Very High	Low

Expert 1	v1	v2	v3	v4	v5	u1	u2	u3	u4
A	Low	High	High	High	High	Very Low	Low	Very Low	Average
B	Low	High	Average	Average	High	Average	Very Low	Average	High
C	High	High	High	High	Low	Very Low	Very Low	Low	Very Low
D	Average	Very Low	Very Low	Low	Average	High	High	High	Very Low
E	Very Low	Low	Very Low	Low	Very Low	High	Very High	Very High	High

Table 9. Fuzzy Translation of Expert 1's Survey

u5	u6	u7	u8	u9	u10	u11
1,3,5	1,1,3	1,3,5	1,1,3	1,3,5	1,1,3	1,3,5
3,5,7	1,1,3	3,5,7	3,5,7	3,5,7	3,5,7	1,3,5
1,3,5	1,1,3	3,5,7	3,5,7	1,1,3	1,1,3	1,3,5
5,7,9	5,7,9	5,7,9	3,5,7	1,1,3	1,3,5	1,3,5
7,9,9	5,7,9	5,7,9	7,9,9	7,9,9	7,9,9	1,3,5

Expert 1	v1	v2	v3	v4	v5	u1	u2	u3	u4
A	1,3,5	5,7,9	5,7,9	5,7,9	5,7,9	1,1,3	1,3,5	1,1,3	3,5,7
B	1,3,5	5,7,9	3,5,7	3,5,7	5,7,9	3,5,7	1,1,3	3,5,7	5,7,9
C	5,7,9	5,7,9	5,7,9	5,7,9	1,3,5	1,1,3	1,1,3	1,3,5	1,1,3
D	3,5,7	1,1,3	1,1,3	1,3,5	3,5,7	5,7,9	5,7,9	5,7,9	1,1,3
E	1,1,3	1,3,5	1,1,3	1,3,5	1,1,3	5,7,9	7,9,9	7,9,9	5,7,9

All surveys are translated to fuzzy numbers as it is in table 8. The next step is to combine these fuzzy surveys according to the following formula:

$x_{ij} = (a_{ij}, b_{ij}, c_{ij})$

$a_{ij} = \min\{a_{ij}\}, b_{ij} = average\{b_{ij}\}, c_{ij} = \min\{c_{ij}\}$

The combination of 30 surveys shown in table 10.

Table 10. Combined Fuzzy Survey

u	u7			u8			u9			u10			u11		
9	1	2	5	1	2,2	7	1	3,1	9	1	1,8	5	1	2,3	5
7	1	4,1	7	1	3,5	7	1	2,9	7	1	3,9	7	1	3,9	7
5	1	2,1	5	1	2,1	5	1	2,5	5	1	2,4	5	1	2,9	7
9	1	5,9	9	1	5,4	9	1	4,1	9	1	6,6	9	1	5,9	9
9	3	8,1	9	3	8,2	9	3	7,7	9	3	8	9	1	7,6	9

Combined	v1			v2			v3			v4			v5			u1			u2			u3			u4			u5				
A	3	6,9	9	3	7,1	9	3	6,9	9	3	7,8	9	3	7,4	9	1	2,2	5	1	2,6	5	1	2,2	7	1	2,6	5	1	2,3	5	1	3,3
B	3	6,2	9	3	6,8	9	3	6,6	9	3	7,3	9	3	6,7	9	1	3,1	7	1	4,2	7	1	3,6	7	1	4,1	9	1	3,7	7	1	3,2
C	3	7,7	9	3	6,9	9	3	7,2	9	5	8,9	9	3	7,8	9	1	2,1	5	1	2,7	7	1	2,5	5	1	2,7	7	1	1,8	5	1	2,5
D	1	4,1	9	1	3,5	9	1	3,9	9	1	4,8	7	1	4,1	9	1	5,9	9	1	6,9	9	1	6,2	9	1	5,8	9	1	5,6	9	1	4,7
E	1	3,1	7	1	2,3	7	1	2,9	7	1	3,3	5	1	3,2	7	1	7,4	9	3	8,7	9	3	8,3	9	3	8,1	9	3	7,9	9	1	7,5

The next step is defuzzification. In this paper, the selected defuzzification method is CFCS (Converting Fuzzy data into Crisp Scores) method. CFCS method was introduced by Opricovic and Tzeng, (2003). The method identifies the right and left scores by fuzzy maximum and fuzzy minimum values. The overall score is identifying by taking a weighted average within the membership functions. (Kazancoglu et al., 2017)

The fuzzy judgments

$$\tilde{z}_{ij}^{k} = (l_{ij}^{k}, m_{ij}^{k}, r_{ij}^{k}) \qquad k(k = 1, 2, \dots, \rho)$$

The normalization step:

$xl_{ij}^k = (l_{ij}^k - min\ l_{ij}^k)/\Delta_{min}^{max}$

$xm_{ij}^k = (m_{ij}^k - min\ l_{ij}^k)/\Delta_{min}^{max}$

$xr_{ij}^k = (r_{ij}^k - min\ l_{ij}^k)/\Delta_{min}^{max}$

$where\ \Delta_{min}^{max} = max\ r_{ij}^k - min\ l_{ij}^k$

Calculation of right and left values:

$xls_{ij}^k = xm_{ij}^k/(1 + xm_{ij}^k\ -\ xl_{ij}^k)$

$xrs_{ij}^k = xr_{ij}^k/(1 + xr_{ij}^k\ -\ xm_{ij}^k)$

Calculation of total crisps value:

$x_{ij}^k = [xls_{ij}^k(1\ -\ xls_{ij}^k) + xrs_{ij}^k\ xrs_{ij}^k]/[1\ -\ xls_{ij}^k + xrs_{ij}^k]$

Calculation of crisp values:

$z_{ij}^k = min\ l_{ij}^k + x_{ij}^k \Delta_{min}^{max}$

The final integrated crisps values:

$z_{ij}^k = \frac{1}{\rho}\ (z_{ij}^1 + z_{ij}^2 + \ldots + z_{ij}^\rho$

Based on these calculations, the defuzzified decision matrix can be set. The normalized decision matrix is shown in table 11.

Table 11. The Normalized Decision Matrix

Normalized	v1	v2	v3	v4	v5	u1	u2	u3	u4	u5	u6	u7	u8	u9	u10	u11
A	6,87	7,02	6,86	7,51	7,23	2,80	3,08	3,25	3,06	2,90	4,41	2,60	3,24	4,26	2,46	2,83
B	6,45	6,79	6,65	7,17	6,71	3,89	4,60	4,19	4,92	4,26	3,96	4,52	4,17	3,74	4,37	4,39
C	7,41	6,86	7,09	8,63	7,49	2,72	3,58	3,02	3,58	2,45	2,98	2,73	2,73	2,98	2,96	3,78
D	4,91	4,50	4,77	4,92	4,92	5,98	6,60	6,18	5,91	5,82	5,25	5,97	5,69	4,92	6,44	5,98
E	3,90	3,27	3,74	3,56	3,93	7,00	8,24	7,93	7,77	7,58	7,03	7,76	7,84	7,42	7,64	7,14

IBM ILOG CPLEX Optimization Studio version 20.1.0 is used to solve the problem with output-oriented Data Envelopment Analysis. There are 5 models and outputs as g_1 , g_2 , g_3 , g_4 , g_5 for each alternative. The first model is shown in figure 3. The other models are in the appendices. After getting the g_k values, the following formula should be applied to get the efficiencies.

$$H_k = 1 / g_k$$

```
dvar float+ v1; dvar float+ v2; dvar float+ v3;
dvar float+ v4; dvar float+ v5; // inputs

dvar float+ u1; dvar float+ u2; dvar float+ u3; dvar float+ u4; dvar float+ u5;
dvar float+ u6; dvar float+ u7; dvar float+ u8; dvar float+ u9; dvar float+ u10;
dvar float+ u11; // outputs

dvar float g1;

minimize g1 ;

subject to {

(6.87*v1 + 7.02*v2 + 6.86*v3 + 7.51*v4 + 7.23*v5) == g1;

(6.87*v1 + 7.02*v2 + 6.86*v3 + 7.51*v4 + 7.23*v5) - (2.80*u1 + 3.08*u2 + 3.25*u3 + 3.06*u4 + 2.90*u5 + 4.41*u6 + 2.60*u7 + 3.24*u8 + 4.26*u9 + 2.46*u10 + 2.83*u11) >= 0;
(6.45*v1 + 6.79*v2 + 6.65*v3 + 7.17*v4 + 6.71*v5) - (3.89*u1 + 4.60*u2 + 4.19*u3 + 4.92*u4 + 4.26*u5 + 3.96*u6 + 4.52*u7 + 4.17*u8 + 3.74*u9 + 4.37*u10 + 4.39*u11) >= 0;
(7.41*v1 + 6.86*v2 + 7.89*v3 + 8.63*v4 + 7.49*v5) - (2.72*u1 + 3.58*u2 + 3.02*u3 + 3.58*u4 + 2.45*u5 + 2.98*u6 + 2.73*u7 + 2.73*u8 + 2.98*u9 + 2.96*u10 + 3.78*u11) >= 0;
(4.91*v1 + 4.58*v2 + 4.77*v3 + 4.92*v4 + 4.92*v5) - (5.98*u1 + 6.60*u2 + 6.18*u3 + 5.91*u4 + 5.82*u5 + 5.25*u6 + 5.97*u7 + 5.69*u8 + 4.92*u9 + 6.44*u10 + 5.98*u11) >= 0;
(3.90*v1 + 3.27*v2 + 3.74*v3 + 3.56*v4 + 3.93*v5) - (7.80*u1 + 8.24*u2 + 7.93*u3 + 7.77*u4 + 7.58*u5 + 7.83*u6 + 7.76*u7 + 7.84*u8 + 7.42*u9 + 7.64*u10 + 7.14*u11) >= 0;

(2.80*u1 + 3.08*u2 + 3.25*u3 + 3.06*u4 + 2.90*u5 + 4.41*u6 + 2.60*u7 + 3.24*u8 + 4.26*u9 + 2.46*u10 + 2.83*u11) == 1;

}
```

Figure 3. DEA Model of the Company A

The mathematical model for the first alternative which is “A” is shown in figure 3. There are 4 more mathematical models like that one for the other alternatives. These are given in the appendix 2. The results of the models are discussed in section 5.2.

5.2. Results and findings

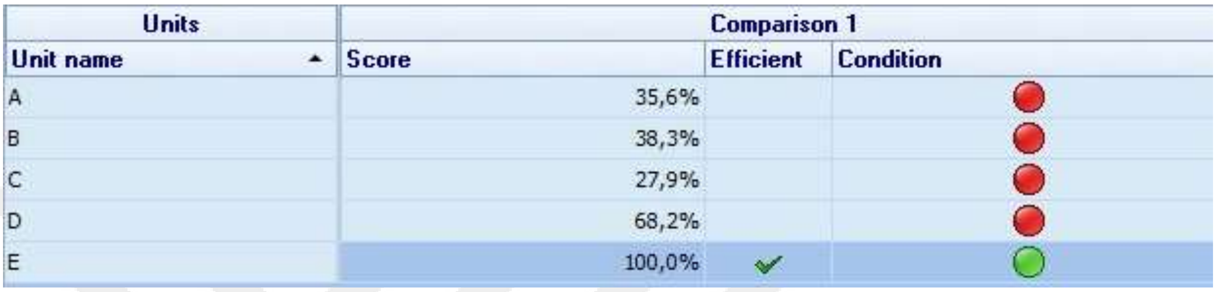
After creating and solving the mathematical models the results have been reached. The results found are shown in Table 12.

Table 12. Final Results

	g_k	H_k	H_k %
A	2.81	0.36	35.61%
B	2.61	0.38	38.29%
C	3.58	0.28	27.93%
D	1.47	0.68	68.24%
E	1.00	1.00	100.00%

The results show that Company E has the most efficient logistics activities according to the circularity with 100 percent. Company D is in second place with 68 percent. Company B is at the third place with 38,29 percent and company A is at fourth place with 35,61 percent efficiency. Company C has the lowest efficiency with 27,93 percent, and they should improve their logistics activities to ensure circularity. All these 4 companies A, B, C, D should improve their performances according to the criteria set. Also, they can send researchers to company E and learn how to improve their efficiencies.

The case study also tried to solve in the program called Frontier Analyst. The results were the same as the mathematical model. The program output is shown in figure 4.



Units	Comparison 1		
Unit name	Score	Efficient	Condition
A	35,6%		
B	38,3%		
C	27,9%		
D	68,2%		
E	100,0%	✓	

Figure 4. Frontier Analyst Output

As it can be seen from figure 4, the results are the same as the mathematical models.

The actual scores can be seen in table 13. The analysis shows the targeted scores for the criteria in table 14. The companies can improve their performances according to these values. The needed improvement percentages are shown in table 15. These tables can be a guide for the companies. As it can be seen from the tables, Company E has 0 percentage for all criteria because it has 100% performance when comparing to other companies.

Table 13. Actual Scores

Unit	Act. v1	Act. v2	Act. v3	Act. v4	Act. v5	Act. u1	Act. u2	Act. u3	Act. u4	Act. u5	Act. u6	Act. u7	Act. u8	Act. u9	Act. u10	Act. u11
A	6,87	7,02	6,86	7,51	7,23	2,80	3,08	3,25	3,06	2,90	4,41	2,60	3,24	4,26	2,46	2,83
B	6,45	6,79	6,65	7,17	6,71	3,89	4,60	4,19	4,92	4,26	3,96	4,52	4,17	3,74	4,37	4,39
C	7,41	6,86	7,09	8,63	7,49	2,72	3,58	3,02	3,58	2,45	2,98	2,73	2,73	2,98	2,96	3,78
D	4,91	4,50	4,77	4,92	4,92	5,98	6,60	6,18	5,91	5,82	5,25	5,97	5,69	4,92	6,44	5,98
E	3,90	3,27	3,74	3,56	3,93	7,00	8,24	7,93	7,77	7,58	7,03	7,76	7,84	7,42	7,64	7,14

Table 14. Target Scores

Unit	Trgt v1	Trgt v2	Trgt v3	Trgt v4	Trgt v5	Trgt u1	Trgt u2	Trgt u3	Trgt u4	Trgt u5	Trgt u6	Trgt u7	Trgt u8	Trgt u9	Trgt u10	Trgt u11
A	2,45	2,05	2,35	2,23	2,47	4,39	5,17	4,97	4,87	4,75	4,41	4,86	4,92	4,65	4,79	4,48

B	2,47	2,07	2,37	2,25	2,49	4,43	5,22	5,02	4,92	4,80	4,45	4,91	4,96	4,70	4,84	4,52
C	2,06	1,73	1,98	1,88	2,08	3,70	4,36	4,20	4,11	4,01	3,72	4,10	4,15	3,93	4,05	3,78
D	3,33	2,79	3,20	3,04	3,36	5,98	7,04	6,78	6,63	6,48	6,00	6,63	6,70	6,34	6,53	6,10
E	3,90	3,27	3,74	3,56	3,93	7,00	8,24	7,93	7,77	7,58	7,03	7,76	7,84	7,42	7,64	7,14

Table 15. Needed Improvement Percentages

Unit	% v1	% v2	% v3	% v4	% v5	% u1	% u2	% u3	% u4	% u5	% u6	% u7	% u8	% u9	% u10	% u11
A	-64,4	-70,8	-65,8	-70,3	-65,9	56,7	68,0	52,9	59,0	64,1	0,0	86,9	51,9	9,4	95,0	58,1
B	-61,7	-69,5	-64,4	-68,6	-62,9	14,0	13,4	19,8	0,0	12,7	12,4	8,6	19,1	25,8	10,7	3,0
C	-72,2	-74,8	-72,1	-78,2	-72,2	36,0	21,7	39,0	14,6	63,8	24,6	50,3	51,9	31,9	36,8	0,0
D	-32,2	-37,9	-33,0	-38,2	-31,8	0,0	6,6	9,7	12,2	11,3	14,2	11,1	17,8	28,9	1,3	2,0
E	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

After getting the final findings, the discussion and implications are mentioned in the section below

6. Discussion and Implications

In the literature, there are many pieces of research about performance assessment of logistics activities and circular economy in logistics activities. Since logistics activities have negative effects on the environment, the significance of the concept of green logistics is increasing for all stakeholders. In recent years, implications on green logistics are appearing in both managerial, public, and consumer sides. Besides this performance assessment of the logistics activities is significant to achieve efficient sustainable performance for managers and public authorities. This study considers the relations between circular economy and logistics activities by measuring the performance of logistics activities based on the formed set of criteria with respect to the triple bottom line. In this respect, the performance assessment of the logistics activities issue is solved by the affiliation of circular economy and sustainability. The discoveries of this paper are further created with administrative implications, upheld by past papers. The main difference with other papers is that this thesis is about the whole logistics activities of the companies. This thesis investigates the logistics activities to see the companies' circular economy performances. At the end of the case study, it can be seen that to companies, which part of their activities they should improve to help to the growth of the circular economy.

Slow steaming may increase the efficiency of transportation in terms of the circular economy. Transportation of products is one of the most impactful logistics activities which has high negative effects on the environment. Slow steaming is one of the simplest ways to decrease fuel consumption and CO^2 emissions by simply running ships at a lower speed. Also, this practice leads to decreases in the cost of transportation. This is in accordance with the contributions of Cariou (2011), who argued that slow steaming practices decrease the cost of fuel and CO^2 emissions by providing effective use of sources.

Moreover, smart routing may provide route optimization to reduce fuel consumption, the number of traveled distances, traffic congestions, CO^2 emissions. Route optimization is provided by using current technologies such as radio frequency identification (RFID) and global positioning system (GPS) through traffic exchanges that are in line with the suggestions of Kazancoglu et al. (2021). Besides that, the Automatic Identification System (AIS) helps to ensure historical data to optimize the route. Route optimization helps managers to increase efficiency in the use of sources and also decrease the negative effects of the voyages on the environment.

Furthermore, smart material handling systems may allow to decrease the number of employees working in the production area and to increase machine efficiency while decreasing idle time. Automated material handling technologies have been using by companies in recent years. Any automation in material handling systems may provide efficiency in terms of decreasing time, cost, or the number of employees working in manual handling operations. An automated material handling system that is integrated with sensors may distinguish and distribute objects to ensure safety in operations and increase efficiency which is in line with the research of Azizi et al. (2018).

In this paper, a novel framework is presented to determine the performance of logistics activities based on circularity. The data envelopment analysis (DEA) method is used to assess the efficiencies of the logistics activities of the companies in terms of the criteria set which is formed according to the triple bottom line. From policymakers' viewpoints, the taking after implications can be created.

Governments should force logistics companies for reporting the carbon footprint created by their activities in a specific period of time. By considering the average level of the carbon footprint created by all logistics firms and the targets of the government, regulations on carbon footprint should be forced. Also, policymakers should take into account major economic conditions which highly affect logistics companies and the economic results of these obligations that are defined in regulations. Therefore, they have a significant role in achieving these objectives. They may give some incentives such as tax reduction, low-interest loans, or allowances to support the changes in logistics activities that aims to achieve the target levels of carbon footprint.

The policymakers can also regulate the guidelines about assessing the performance level of the activities on circularity. The proposed framework can be used both for assessing the performance level of logistics activities and other industrial activities.

In this thesis, the circularity performances of logistics activities are investigated throughout the companies according to the triple bottom line of the circular economy. This triple bottom line approach is based on social, environmental, and economic issues. The criteria set are determined according to this idea. As it can be seen in Table 3, all the criteria set are determined according to past research reviewed. According to the systems approach theory, these individual criterions cannot address creating value by themselves. So, all the criteria should be used together to create value. Companies can measure the circularity performance of their logistics activities by following this presented novel framework. This leads to determine the circularity performance level of the companies and they can create a benchmarking by monitoring the other successful companies. They can improve their performances according to this benchmarking.

Governments can assess the companies' circularity performances according to the novel framework. They can set a target to make improvements to the circular economy of the country. Emerging countries can improve their circularity in the line of universal standards. The companies that fulfill the obligations determined by regulations of the government can be rewarded by the government. Besides that, the companies that have negative regression on their circularity can be penalized by the authority. This performance assessment is not just beneficial for economics, it is also beneficial for environmental and social factors. Data Envelopment Analysis is one of the finest approaches that can be utilized to assess the performance level of the circular economy.

Data Envelopment Analysis is selected because the method is one of the best methods in finding the efficiencies of the alternatives. The distinctive feature of the method is that each alternative has its own mathematical model.

The circular economy concept and applications of this idea are relatively newer in emerging economies. While sustainability is getting important for the businesses at the system level in emerging economies, circular economy performance should be measured to achieve useful managerial insights. There are not many articles about circular economy performance assessment of logistics activities in the literature. These three concepts; “circular economy”, “performance assessment” and “logistics activities” never intersected at the same time.

7. Conclusion

These days, a linear economy is not enough due to the exponential growth rate of the world population. When there are more people, there is going to be more waste. The consumption rate is higher than the production rate. This is causing to be more and more waste amount around the world (Akhimien et al., 2020). Also, there is a danger to natural resources. If the companies still use the linear economy system, there are not going to be enough resources (Ellen MacArthur Foundation 2013). The lifetime of the products should be increased, and the waste amount should be decreased in supply chains for companies. In the late 1980s, Pearce and Turner (1989) introduced the circular economy idea. The idea is based on environmental matters (Andersen, 2007). Yuan et al. (2006) said the latest studies show that circular economy is also developing as an economic methodology too. Most companies try to achieve sustainability in their field. The circular system created should be sustainable too. Sustainability-based on the Circular Economy concept (Kirchherr et al., 2017). In a circular economy, there are 3 main objectives which are economic, social, and environmental benefits. Nowadays circular economy has a concept named 6R. 6R includes recycle, repair, reuse, reduce, refuse, and rethink. In the circular economy concept, logistics have an important role. Logistics activities have a serious effect on the environment. It is also very important to the economic and social parts. Companies should arrange their logistics activities according to the circular economy concept. In this paper, a novel framework is created to assess the circular economy performance of the logistics activities of companies. 5 companies (A, B, C, D, and E) are selected from the Aegean Region, Turkey, and contacted with 30 experts from sectors and academies. The criteria set is clearly defined with these experts. The criteria set is created according to the triple bottom line (economic, social, and environmental). A survey is created, and these experts are surveyed according to their knowledge. They used linguistic statements like “Very Low”, “Low”, “Average”, “High”, “Very High”. Then these statements are converted to fuzzy numbers according to table 6. There were 30 surveys done and after the conversion, they combined. Calculation continued from that combined fuzzy survey. Then CFCS (Converting Fuzzy data into Crisp Scores) method is used for defuzzification. The selected method to get the efficiencies of the companies is Data Envelopment Analysis. Created DEA models solved in IBM ILOG CPLEX Optimization Studio version 20.1.0. The results showed us the company E has the highest efficiency in circularity. The other companies should work on their supply chains and create more efficiency in their circularity.

In the future, this study can be expanded to the country level. For example, all the companies in Turkey can be investigated. These big data can help to improve a country’s circularity. After the framework is applied all the companies can see their performances and try to improve their performance. By this application, the country can be more sustainable and circular. However, there are some limitations to this framework. It is hard to reach some company data. Some of the information is classified. So, some companies cannot be investigated in this research. Another limitation is some of the companies do not want their names to appear in such research.

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APPENDIX 1 – Scores taken by experts

Expert 1	v1	v2	v3	v4	v5	u1	u2	u3	u4	u5	u6	u7	u8	u9	u10	u11
A	Low	High	High	High	High	Very Low	Low	Very Low	Average	Low	Very Low	Low	Very Low	Low	Very Low	Low
B	Low	High	Average	Average	High	Average	Very Low	Average	High	Average	Very Low	Average	Average	Average	Average	Low
C	High	High	High	High	Low	Very Low	Very Low	Low	Very Low	Low	Very Low	Average	Average	Very Low	Very Low	Low
D	Average	Very Low	Very Low	Low	Average	High	High	High	Very Low	High	High	High	Average	Very Low	Low	Low
E	Very Low	Low	Very Low	Low	Very Low	High	Very High	Very High	High	Very High	High	High	Very High	Very High	Very High	Low

Expert 2	v1	v2	v3	v4	v5	u1	u2	u3	u4	u5	u6	u7	u8	u9	u10	u11
A	High	Low	Very High	Very High	Very High	Very Low	Low	Low	Very Low	Low	Very Low	Average	Very Low	Average	Average	Very Low
B	High	Very High	Very High	Average	Average	Very High	Very Low	Average	Very High	Very High	Low	Average	Very Low	Average	Average	Low
C	Very High	Very High	Very High	High	Very High	Very Low	Very Low	Low	Low	Very Low	Low	Low	Very Low	Low	Very Low	Low
D	Average	Low	Low	Average	Low	Very High	Very Low	Average	Very High	Low	Low	Low	Very High	Very High	Very High	Very Low
E	Low	Very Low	Very Low	Average	Very Low	Very High	Very High	Very High	Very High	Average	Average	Average	Very High	Very High	Very High	Average

Expert 3	v1	v2	v3	v4	v5	u1	u2	u3	u4	u5	u6	u7	u8	u9	u10	u11
A	High	High	Very High	Very High	Very High	Low	Very Low	Average	Low	Low	Average	Average	Very Low	Very Low	Very Low	Very Low
B	Very High	Very High	Very High	Very High	High	Low	Average	Low	Very Low	Very Low	Average	Low	Low	Average	Average	Low
C	Very High	Very High	Very High	Very High	Very High	Very Low	Very Low	Low	Average	Very Low	Average	Very Low	Very Low	High	Average	Low
D	Average	Low	Very High	High	Low	High	Low	Low	Low	Very Low	Very High	Very Low	Average	Very High	Very High	Very High
E	Very Low	Very Low	Very Low	Low	Average	High	High	Very High	Very High	Very High	Very High	High	Very High	Very High	Very High	Very High

Expert 4	v1	v2	v3	v4	v5	u1	u2	u3	u4	u5	u6	u7	u8	u9	u10	u11
A	Very High	Very High	Very High	High	Very High	Very Low	Average	Very Low	Very Low	Average	Very Low	Very Low	Low	Low	Low	Low
B	Average	High	Very High	Very High	Very High	Very High	Very High	Average	Low	Average	Average	Average	Low	Average	Average	Low
C	Very High	Very High	High	Very High	Very High	Low	Very Low	Average	Low	Very Low	Low	Very Low	Average	Very Low	Very Low	Very High
D	Very Low	Average	Low	Low	Very High	High	Very Low	Very Low	Very High	Very High	High	High	Very High	Low	Average	Low
E	Average	Very Low	Very Low	Very Low	Low	Very High	High	High	Very High	Very High	Very High	Very High	Very High	Very High	Very High	Very High

Expert 5	v1	v2	v3	v4	v5	u1	u2	u3	u4	u5	u6	u7	u8	u9	u10	u11
A	Very High	Very High	Very High	Very High	High	Low	Low	Low	Low	Average	Average	Low	Low	Very Low	Very Low	Low
B	High	High	Very High	Very High	High	Average	Low	Average	Average	Low	Very Low	Average	Average	Average	Average	Very Low
C	Very High	High	Very High	Very High	Very High	Low	Very Low	Average	Very Low	Very Low	Very Low	Average	Low	Low	Low	Very Low
D	Low	High	Very Low	Very Low	Average	Low	Average	High	High	Very High	Very High	Very Low	Very Low	High	High	Very High
E	Very Low	Average	Very Low	Very Low	Low	High	Very High	Very High	High	Very High	Very High	High	Very High	Very High	Very High	Very High

Expert 6	v1	v2	v3	v4	v5	u1	u2	u3	u4	u5	u6	u7	u8	u9	u10	u11
A	Very High	Average	Very High	Very High	Very High	Low	Low	Very Low	Very Low	Average	Average	Average	Low	Very Low	Low	Low
B	Very High	Average	Very High	Average	Average	Average	Low	Very Low	Very Low	Low	Very Low	Low	Average	Very Low	Average	Very Low
C	Very High	Very High	Very High	Average	Very High	Average	Low	Low	Average	Low	Low	Low	Average	Low	Low	Low
D	Average	Low	Very Low	Low	Average	Low	Very High	Very Low	Very High	Very High	Very High	Average	Low	Low	Low	Average
E	Low	Very Low	Average	Very Low	Very Low	Very High	Low	Very High	Average	Very High	Very High	Very High	Very High	Very High	Very High	Very High

Expert 7	v1	v2	v3	v4	v5	u1	u2	u3	u4	u5	u6	u7	u8	u9	u10	u11
A	High	Very High	Very High	Very High	Very High	Very Low	Average	Low	Low	Very Low	Low	Very Low	Low	Very Low	Low	Low
B	Average	Average	Very High	Very High	High	Average	Very Low	Average	Average	Average	Low	Average	Low	Low	Low	Very Low
C	Very High	Very High	Very High	Very High	High	Low	Very Low	Very Low	Average	Very Low	Low	Average	Low	Very Low	Very Low	Low
D	Very Low	Average	Low	Average	Low	Very Low	High	High	Low	Very High	Very High	Very Low	High	Low	Average	Low
E	Average	Low	Very Low	Very Low	Average	Low	Very High	High	Very High	Very High	Very High	High	Very High	Very High	Very High	Very High

Expert 8	v1	v2	v3	v4	v5	u1	u2	u3	u4	u5	u6	u7	u8	u9	u10	u11
A	Very High	Very High	Very High	Very High	High	Low	Low	Low	Low	Average	Average	Low	Very Low	Very Low	Very Low	Low
B	Average	Average	Very High	Very High	Very High	Very Low	Average	Low	Average	Very Low	Low	Average	Low	Low	Average	Low
C	High	Very High	Very High	Very High	High	Very Low	Average	Low	Very Low	Very Low	Very Low	Low	Low	Low	Low	Very Low
D	Very Low	Average	Low	Low	Average	Very High	Very High	Low	Very Low	Very Low	Very High	Very High	Low	Low	Low	Low
E	Low	Very Low	Very Low	Very Low	Low	Low	Very High	Very High	Very High	Very High	Very High	Very High	High	Very High	Very High	Low

Expert 9	v1	v2	v3	v4	v5	u1	u2	u3	u4	u5	u6	u7	u8	u9	u10	u11
A	High	High	Very High	Very High	Very High	Low	Average	Very Low	Low	Low	Average	Average	Very Low	Very Low	Low	Low
B	Average	Very High	Very High	Very High	Average	Very Low	Very Low	Average	Average	Average	Average	Average	Low	Low	Low	Average
C	Very High	Very High	Very High	Very High	High	Low	Average	Very Low	Average	Low	Low	Average	Very Low	Very Low	Very Low	Average
D	Low	Average	Very Low	Average	Low	Very High	High	Very High	Very High	Very Low	Average	Very High	Low	Low	Low	Very Low
E	Very Low	Low	Very Low	Low	Low	Very High	Very High	Very High	Very High	High	Very High	Very High	Very High	High	High	Very High

Expert 10	v1	v2	v3	v4	v5	u1	u2	u3	u4	u5	u6	u7	u8	u9	u10	u11
A	High	Very High	Very High	Very High	Very High	Low	Low	Average	Very Low	Very Low	Average	Very Low	Low	Low	Low	Very Low
B	Average	Average	Very High	Average	Very High	Average	Very Low	Very Low	Low	Low	Average	Average	Low	Low	Low	Low
C	Very High	Very High	Very High	Very High	High	Very Low	Low	Average	Very Low	Low	Low	Very Low	Low	Very Low	Very Low	Low
D	Average	Low	Very Low	Very Low	Average	Very High	Very High	Very Low	Very Low	Very High	Very High	Very High	Very High	Average	Average	Low
E	Low	Low	Very Low	Very Low	Very Low	High	Very High	Very High	Very High	Very High	Very High	Very High	High	Very High	Very High	Low

Expert 11	v1	v2	v3	v4	v5	u1	u2	u3	u4	u5	u6	u7	u8	u9	u10	u11
A	High	Very High	Very High	Very High	Very High	Very Low	Low	Very Low	Low	Average	Very Low	Low	Low	Low	Low	Average
B	Average	Average	Very High	Average	Average	Average	Average	Very Low	Average	Low	Very Low	Average	Low	Low	Low	Low
C	Very High	Very High	Very High	High	Very High	Very Low	Low	Very Low	Average	Low	Very Low	Low	Average	Very Low	Very Low	Very Low
D	Average	Average	Very Low	Average	Very Low	Average	Very Low	Average	Very Low	Very High	Very High	Low	Low	Very High	Very High	Average
E	Very Low	Low	Very Low	Low	Very Low	Very High	Very High	Very High	Very High	High	Low	Average	Very High	Very High	Very High	Very High

Expert 12	v1	v2	v3	v4	v5	u1	u2	u3	u4	u5	u6	u7	u8	u9	u10	u11
A	Very High	Very High	Very High	Very High	High	Low	Low	Very Low	Very Low	Very Low	Average	Low	Low	Very Low	Very Low	Low
B	Average	High	High	Average	Very High	Low	Average	Average	Very Low	Average	Average	Average	Very Low	Average	Average	Average
C	Very High	Very High	Very High	High	Very High	Very Low	Low	Low	Very Low	Very Low	Very Low	Low	Low	Average	Average	Very Low
D	Average	Low	Low	Very Low	Very High	Very High	Low	Low	Very High	Very High	Very High	Average	High	Very Low	Very Low	High
E	Low	Low	Very Low	Very Low	Low	Very High	Very High	Very High	Very High	Very High	Very High	High	High	Very High	Very High	Very High

Expert 13	v1	v2	v3	v4	v5	u1	u2	u3	u4	u5	u6	u7	u8	u9	u10	u11
A	Very High	Very High	High	Very High	Very High	Low	Low	Low	Very Low	Low	Very Low	Very Low	Very Low	Average	Average	Average
B	Very High	Very High	Average	Average	High	Average	Average	Very Low	Very High	Very Low	Average	Very High	Low	Low	Low	Low
C	Very High	Very High	Very High	Very High	High	Low	Very Low	Average	Low	Very Low	Low	Average	Low	Very Low	Very Low	Low
D	Very High	Very High	Average	Very Low	Average	Average	High	High	Low	Low	Low	Very Low	Very High	Very High	Very High	Very High
E	Average	Average	Very Low	Average	Very Low	Very High	Very High	Very High	High	Very High	High	Very High	Very High	Very High	Very High	Very High

Expert 14	v1	v2	v3	v4	v5	u1	u2	u3	u4	u5	u6	u7	u8	u9	u10	u11
A	High	Very High	Very High	Very High	Very High	Low	Very Low	Very Low	Very Low	Very Low	Low	Low	Average	Average	Average	Low
B	Average	Very High	Very High	Very High	Average	Average	Low	Average	Average	Low	Low	Average	Average	Very Low	Very Low	Very High
C	High	Very High	Very High	Very High	Very High	Very Low	Low	Low	Very Low	Low	Very Low	Average	Very Low	Very Low	Low	Low
D	Low	Low	Low	Average	Very High	Very High	Average	Very Low	Very Low	Very High	Very High	Very High	Average	High	High	Very High
E	Low	Average	Very Low	Low	Very Low	High	Very High	Very High		High	Very High	Very High	Very High	Very High	Very High	Very Low

Expert 15	v1	v2	v3	v4	v5	u1	u2	u3	u4	u5	u6	u7	u8	u9	u10	u11
A	Very High	Very High	Very High	Very High	Very High	Very Low	Very Low	Low	Very Low	Low	Very Low	Low	Very High	Average	Average	Low
B	Average	Very High	Very High	Average	Average	Average	Average	Average	Very High	Average	Very Low	Very Low	Low	Low	Low	Low
C	Very High	Very High	High	Very High	Very High	Average	Very Low	Very Low	Average	Very Low	Average	Very Low	Low	Very Low	Very Low	Low
D	Low	Average	Very Low	Very Low	Average	High	High	Average	Low	Low	Very High	Very High	Very High	Very Low	Very Low	Very Low
E	Very Low	Very Low	Very Low	Very Low	Very Low	Very High	Very High	Very High	Very High	Very High	Very High	Very High	High	High	High	Very High

Expert 16	v1	v2	v3	v4	v5	u1	u2	u3	u4	u5	u6	u7	u8	u9	u10	u11
A	Very High	Very High	Very High	Very High	Average	Low	Low	Average	Very Low	Low	Average	Very Low	Low	Low	Low	Low
B	Average	Average	Very High	Average	Average	Very High	Average	Very Low	Average	Low	Very Low	Very Low	Average	Average	Average	Low
C	Very High	Very High	Very High	Very High	Very High	Very Low	Low	Very Low	Very Low	Average	Very Low	Very Low	Low	Low	Low	Very Low
D	Very High	Very Low	Very Low	Low	Average	High	High	High	Very Low	Average	Average	Very High	Very High	High	High	Low
E	Average	Very Low	Very Low	Low	Low	Very High	Very High	Very High	Very High	High	High	Very High	Very High	Very High	Very High	Very High

Expert 17	v1	v2	v3	v4	v5	u1	u2	u3	u4	u5	u6	u7	u8	u9	u10	u11
A	Very High	Very High	Very High	High	Very High	Low	Low	Low	Average	Low	Low	Average	Low	Very Low	Very Low	Low
B	Average	Very High	High	High	High	Average	Average	Very Low	Average	Very Low	Average	Average	Low	Low	Low	Low
C	High	Very High	Very High	Very High	Very High	Very Low	Very Low	Low	Average	Very Low	Very Low	Average	Low	Very Low	Very Low	Low
D	Very Low	Very Low	Average	Average	Low	Average	Very High	Very High	Very Low	Very High	Very High	Very Low	High	Very High	Very High	High
E	Very Low	Low	Very Low	Very Low	Low	Very High	Very High	Very High	High	Very High	Very High	Very Low	Very High	Very High	Very High	Very High

Expert 18	v1	v2	v3	v4	v5	u1	u2	u3	u4	u5	u6	u7	u8	u9	u10	u11
A	High	Very High	Very High	Very High	Very High	Low	Very Low	Very Low	Low	Low	Low	Low	Average	Very Low	Very Low	Average
B	Average	Very High	Very High	Average	Average	Average	Average	Low	Low	Average	Average	Average	Average	Very Low	Very Low	Average
C	High	Very High	Very High	Very High	Very High	Low	Very Low	Average	Very Low	Very Low	Very Low	Very Low	Low	Low	Low	Very Low
D	Low	Average	Very High	Very Low	Very Low	Low	Low	Very High	Very High	High	Very High	Very High	Very High	Very Low	Very Low	High
E	Low	Very Low	Average	Very Low	Very Low	Very High	Very High	Very High	Average	High	Very High	Very High	Very High	Very High	Very High	Very High

Expert 19	v1	v2	v3	v4	v5	u1	u2	u3	u4	u5	u6	u7	u8	u9	u10	u11
A	High	Very High	Very High	Very High	Very High	Very Low	Average	Average	Very Low	Low	Low	Low	Very Low	Low	Low	Low
B	Average	Very High	Very Low	Very High	Average	Average	Average	Average	Average	Very Low	Very Low	Average	Low	Low	Low	Low
C	Very High	Very High	Very High	Very High	Very High	Very Low	Very Low	Low	Average	Low	Low	Low	Average	Very Low	Very Low	Very Low
D	Average	Very Low	Very Low	Average	Low	Very High	Very High	Very Low	Very Low	Very High	Very High	Very High	High	Average	Average	Low
E	Very Low	Very Low	Very Low	Low	Low	Very High	Very High	Very High	Very High	High	High	Very High	Very High	Very High	Very High	Low

Expert 20	v1	v2	v3	v4	v5	u1	u2	u3	u4	u5	u6	u7	u8	u9	u10	u11
A	Very High	Very High	Very High	Very High	High	Very Low	Very Low	Low	Low	Low	Very Low	Average	Average	Average	Average	Very Low
B	Average	Average	Very High	Very High	Average	Low	Average	Very Low	Very Low	Average	Average	Low	Low	Average	Average	Average
C	High	Very High	Very High	Very High	High	Average	Average	Very Low	Very Low	Average	Average	Low	Low	Very Low	Very Low	Very Low
D	Average	Average	Low	Very Low	Low	Very Low	Very Low	Very High	Very High	High	High	Average	Low	Low	Low	Very High
E	Low	Very Low	Very Low	Low	Average	Very High	Very High	Very High	Average	High	Very High	Very High	Very High	Very High	Very High	Very Low

APPENDIX 2 – DEA Models for Companies B, C, D and E

```
dvar float+ v1; dvar float+ v2; dvar float+ v3;
dvar float+ v4; dvar float+ v5; // inputs

dvar float+ u1; dvar float+ u2; dvar float+ u3; dvar float+ u4; dvar float+ u5;
dvar float+ u6; dvar float+ u7; dvar float+ u8; dvar float+ u9; dvar float+ u10;
dvar float+ u11; // outputs

dvar float g2;

minimize g2 ;

subject to {

(6.45*v1 + 6.79*v2 + 6.65*v3 + 7.17*v4 + 6.71*v5) == g2;

(6.87*v1 + 7.02*v2 + 6.86*v3 + 7.51*v4 + 7.23*v5) - (2.80*u1 + 3.08*u2 + 3.25*u3 + 3.86*u4 + 2.90*u5 + 4.41*u6 + 2.60*u7 + 3.24*u8 + 4.26*u9 + 2.46*u10 + 2.83*u11) >= 0;
(6.45*v1 + 6.79*v2 + 6.65*v3 + 7.17*v4 + 6.71*v5) - (3.89*u1 + 4.60*u2 + 4.19*u3 + 4.92*u4 + 4.26*u5 + 3.96*u6 + 4.52*u7 + 4.17*u8 + 3.74*u9 + 4.37*u10 + 4.39*u11) >= 0;
(7.41*v1 + 6.86*v2 + 7.09*v3 + 8.63*v4 + 7.49*v5) - (2.72*u1 + 3.58*u2 + 3.02*u3 + 3.58*u4 + 2.45*u5 + 2.98*u6 + 2.73*u7 + 2.73*u8 + 2.98*u9 + 2.96*u10 + 3.78*u11) >= 0;
(4.91*v1 + 4.58*v2 + 4.77*v3 + 4.92*v4 + 4.92*v5) - (5.98*u1 + 6.60*u2 + 6.18*u3 + 5.91*u4 + 5.82*u5 + 5.25*u6 + 5.97*u7 + 5.69*u8 + 4.92*u9 + 6.44*u10 + 5.98*u11) >= 0;
(3.98*v1 + 3.27*v2 + 3.74*v3 + 3.56*v4 + 3.93*v5) - (7.00*u1 + 8.24*u2 + 7.93*u3 + 7.77*u4 + 7.58*u5 + 7.03*u6 + 7.76*u7 + 7.84*u8 + 7.42*u9 + 7.64*u10 + 7.14*u11) >= 0;

(3.89*u1 + 4.60*u2 + 4.19*u3 + 4.92*u4 + 4.26*u5 + 3.96*u6 + 4.52*u7 + 4.17*u8 + 3.74*u9 + 4.37*u10 + 4.39*u11) == 1;

}
```

```
dvar float+ v1; dvar float+ v2; dvar float+ v3;
dvar float+ v4; dvar float+ v5; // inputs

dvar float+ u1; dvar float+ u2; dvar float+ u3; dvar float+ u4; dvar float+ u5;
dvar float+ u6; dvar float+ u7; dvar float+ u8; dvar float+ u9; dvar float+ u10;
dvar float+ u11; // outputs

dvar float g4;

minimize g4 ;

subject to {

(4.91*v1 + 4.58*v2 + 4.77*v3 + 4.92*v4 + 4.92*v5) == g4;

(6.87*v1 + 7.02*v2 + 6.86*v3 + 7.51*v4 + 7.23*v5) - (2.80*u1 + 3.08*u2 + 3.25*u3 + 3.86*u4 + 2.90*u5 + 4.41*u6 + 2.60*u7 + 3.24*u8 + 4.26*u9 + 2.46*u10 + 2.83*u11) >= 0;
(6.45*v1 + 6.79*v2 + 6.65*v3 + 7.17*v4 + 6.71*v5) - (3.89*u1 + 4.60*u2 + 4.19*u3 + 4.92*u4 + 4.26*u5 + 3.96*u6 + 4.52*u7 + 4.17*u8 + 3.74*u9 + 4.37*u10 + 4.39*u11) >= 0;
(7.41*v1 + 6.86*v2 + 7.09*v3 + 8.63*v4 + 7.49*v5) - (2.72*u1 + 3.58*u2 + 3.02*u3 + 3.58*u4 + 2.45*u5 + 2.98*u6 + 2.73*u7 + 2.73*u8 + 2.98*u9 + 2.96*u10 + 3.78*u11) >= 0;
(4.91*v1 + 4.58*v2 + 4.77*v3 + 4.92*v4 + 4.92*v5) - (5.98*u1 + 6.60*u2 + 6.18*u3 + 5.91*u4 + 5.82*u5 + 5.25*u6 + 5.97*u7 + 5.69*u8 + 4.92*u9 + 6.44*u10 + 5.98*u11) >= 0;
(3.98*v1 + 3.27*v2 + 3.74*v3 + 3.56*v4 + 3.93*v5) - (7.00*u1 + 8.24*u2 + 7.93*u3 + 7.77*u4 + 7.58*u5 + 7.03*u6 + 7.76*u7 + 7.84*u8 + 7.42*u9 + 7.64*u10 + 7.14*u11) >= 0;

(5.98*u1 + 6.60*u2 + 6.18*u3 + 5.91*u4 + 5.82*u5 + 5.25*u6 + 5.97*u7 + 5.69*u8 + 4.92*u9 + 6.44*u10 + 5.98*u11) == 1;

}
```

```
dvar float+ v1; dvar float+ v2; dvar float+ v3;
dvar float+ v4; dvar float+ v5; // inputs

dvar float+ u1; dvar float+ u2; dvar float+ u3; dvar float+ u4; dvar float+ u5;
dvar float+ u6; dvar float+ u7; dvar float+ u8; dvar float+ u9; dvar float+ u10;
dvar float+ u11; // outputs

dvar float g3;

minimize g3 ;

subject to {

(7.41*v1 + 6.86*v2 + 7.09*v3 + 8.63*v4 + 7.49*v5) == g3;

(6.87*v1 + 7.02*v2 + 6.86*v3 + 7.51*v4 + 7.23*v5) - (2.80*u1 + 3.08*u2 + 3.25*u3 + 3.86*u4 + 2.90*u5 + 4.41*u6 + 2.60*u7 + 3.24*u8 + 4.26*u9 + 2.46*u10 + 2.83*u11) >= 0;
(6.45*v1 + 6.79*v2 + 6.65*v3 + 7.17*v4 + 6.71*v5) - (3.89*u1 + 4.60*u2 + 4.19*u3 + 4.92*u4 + 4.26*u5 + 3.96*u6 + 4.52*u7 + 4.17*u8 + 3.74*u9 + 4.37*u10 + 4.39*u11) >= 0;
(7.41*v1 + 6.86*v2 + 7.09*v3 + 8.63*v4 + 7.49*v5) - (2.72*u1 + 3.58*u2 + 3.02*u3 + 3.58*u4 + 2.45*u5 + 2.98*u6 + 2.73*u7 + 2.73*u8 + 2.98*u9 + 2.96*u10 + 3.78*u11) >= 0;
(4.91*v1 + 4.58*v2 + 4.77*v3 + 4.92*v4 + 4.92*v5) - (5.98*u1 + 6.60*u2 + 6.18*u3 + 5.91*u4 + 5.82*u5 + 5.25*u6 + 5.97*u7 + 5.69*u8 + 4.92*u9 + 6.44*u10 + 5.98*u11) >= 0;
(3.98*v1 + 3.27*v2 + 3.74*v3 + 3.56*v4 + 3.93*v5) - (7.00*u1 + 8.24*u2 + 7.93*u3 + 7.77*u4 + 7.58*u5 + 7.03*u6 + 7.76*u7 + 7.84*u8 + 7.42*u9 + 7.64*u10 + 7.14*u11) >= 0;

(2.72*u1 + 3.58*u2 + 3.02*u3 + 3.58*u4 + 2.45*u5 + 2.98*u6 + 2.73*u7 + 2.73*u8 + 2.98*u9 + 2.96*u10 + 3.78*u11) == 1;

}
```

```
dvar float+ v1; dvar float+ v2; dvar float+ v3;
dvar float+ v4; dvar float+ v5; // inputs

dvar float+ u1; dvar float+ u2; dvar float+ u3; dvar float+ u4; dvar float+ u5;
dvar float+ u6; dvar float+ u7; dvar float+ u8; dvar float+ u9; dvar float+ u10;
dvar float+ u11; // outputs

dvar float g5;

minimize g5 ;

subject to {

(3.98*v1 + 3.27*v2 + 3.74*v3 + 3.56*v4 + 3.93*v5) == g5;

(6.87*v1 + 7.02*v2 + 6.86*v3 + 7.51*v4 + 7.23*v5) - (2.80*u1 + 3.08*u2 + 3.25*u3 + 3.86*u4 + 2.90*u5 + 4.41*u6 + 2.60*u7 + 3.24*u8 + 4.26*u9 + 2.46*u10 + 2.83*u11) >= 0;
(6.45*v1 + 6.79*v2 + 6.65*v3 + 7.17*v4 + 6.71*v5) - (3.89*u1 + 4.60*u2 + 4.19*u3 + 4.92*u4 + 4.26*u5 + 3.96*u6 + 4.52*u7 + 4.17*u8 + 3.74*u9 + 4.37*u10 + 4.39*u11) >= 0;
(7.41*v1 + 6.86*v2 + 7.09*v3 + 8.63*v4 + 7.49*v5) - (2.72*u1 + 3.58*u2 + 3.02*u3 + 3.58*u4 + 2.45*u5 + 2.98*u6 + 2.73*u7 + 2.73*u8 + 2.98*u9 + 2.96*u10 + 3.78*u11) >= 0;
(4.91*v1 + 4.58*v2 + 4.77*v3 + 4.92*v4 + 4.92*v5) - (5.98*u1 + 6.60*u2 + 6.18*u3 + 5.91*u4 + 5.82*u5 + 5.25*u6 + 5.97*u7 + 5.69*u8 + 4.92*u9 + 6.44*u10 + 5.98*u11) >= 0;
(3.98*v1 + 3.27*v2 + 3.74*v3 + 3.56*v4 + 3.93*v5) - (7.00*u1 + 8.24*u2 + 7.93*u3 + 7.77*u4 + 7.58*u5 + 7.03*u6 + 7.76*u7 + 7.84*u8 + 7.42*u9 + 7.64*u10 + 7.14*u11) >= 0;

(7.00*u1 + 8.24*u2 + 7.93*u3 + 7.77*u4 + 7.58*u5 + 7.03*u6 + 7.76*u7 + 7.84*u8 + 7.42*u9 + 7.64*u10 + 7.14*u11) == 1;

}
```