ANALYSIS OF ENABLERS AND BARRIERS TO INDUSTRIAL SYMBIOSIS IN THE CHEMICAL INDUSTRY IN TURKEY BY USING MULTI-CRITERIA DECISION-MAKING APPROACHES

(ÇOK KRİTERLİ KARAR VERME YAKLAŞIMLARI KULLANARAK TÜRKİYE'DEKİ KİMYA ENDÜSTRİSİNDE ENDÜSTRİYEL SİMBİYOZUN ÖNÜNDEKİ İTİCİ GÜÇLER VE ENGELLERİN ANALİZİ)

by

Sare Naz ÇİFTÇİ, M.S.

Thesis

Submitted in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

in

LOGISTICS and FINANCIAL MANAGEMENT

in the

GRADUATE SCHOOL OF SCIENCE AND ENGINEERING

of

GALATASARAY UNIVERSITY

November 2023

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my supervisor, İlke Bereketli Zaferiakopoulos, for their guidance, support, and invaluable insights throughout this research journey. Their expertise, patience, and constructive feedback have been instrumental in shaping the direction and quality of this thesis.

I extend my sincere appreciation to my classmates and friends for their unwavering support and encouragement throughout this endeavor. Their love, understanding, and belief in my abilities have provided the motivation to overcome challenges and reach the finish line.

Lastly, I would like to express my deepest gratitude to all the participants who generously gave their time and shared their experiences for the purpose of this research. The role of decision-makers that I reached through my friends is undeniable. Without their willingness to contribute, this study would not have been possible.

September 2023
Sare Naz Çiftçi

TABLE OF CONTENTS

ACKNOWLEDGEMENTS ii
TABLE OF CONTENTS iii
LIST OF SYMBOLS i
LIST OF FIGURES ix
LIST OF TABLES vi
ABSTRACT vii
ÖZET xi
1. INTRODUCTION 1
2 FUNDAMENTAL NOTIONS 5
2.1 Sustainablity 5
2.2 Sustainable Development 6
2.3 Sustainable Developement Goals 8
2.4 Circular Economy 8
2.5 Industrial Ecology 11
2.6 Industrial Symbiosis 13
2.6.1 Industrial Symbiosis Tools 19
2.6.2 Industrial Symbiosis in Chemical Sector 20
2.7 Decision Analysis Methods 22
2.7.1 Multi Criteria Decision Making Methods 23
2.7.2 Application Areas of MCDM Methods 23
3 LITERATURE REVIEW 27
4 APPLICATION 30
4.1 Enablers of Industrial Symbiosis 30
4.2 Barriers of Industrial Symbiosis 33
5 PROPOSED METHODOLOGY 37
6 RESULTS & DISCUSSION 41
7 CONCLUSION 47
REFERENCES 50
BIOGRAPHICAL SKETCH 57

LIST OF SYMBOLS

B	**:** Barrier
DEMATEL	**:** Decision Making Trial and Evaluation Laboratory
DM	**:** Decision Maker
E	**:** Enabler
EIP	**:** Eco-Industrial Park
IE	**:** Industrial Ecology
IM	**:** Industrial Metabolism
IS	**:** Industrial Symbiosis
MCDM	**:** Multi Criteria Decision Making
SD	**:** Sustainable Development
SDG	**:** Sustainable Development Goals

LIST OF FIGURES

Figure 1.1: Cleaner production in factories 2
Figure 2.1: Three pillars of sustainability 7
Figure 2.2: Timeline with main events of sustainable development 8
Figure 2.3: 17 SD goals 8
Figure 2.4: Model of a linear economy 9
Figure 2.5: Circularity and the life cycle of products 10
Figure 2.6: Example of an IS network 15
Figure 2.7: Representation of Kalundborg Symbiosis 17

LIST OF TABLES

Table 2.3: Overall Summary Table of DEMATEL used Studies 27
Table 2.1: Enablers Summary Table.. 31
Table 2.2: Barriers Summary Table... 34
Table 3.1: Linguistic variables for the importance-weight.. 38
Table 6.1: Results compilation of enablers... 41
Table 6.2: Results compilation of barriers.. 44

ABSTRACT

Recent years have seen an increase in greenhouse gas emissions as a result of resource-intensive usage, growing industrialization and urbanization, modern lifestyles, energy-intensive use, and land use patterns. The population and the environment will suffer as a result of this predicament. It is vital to discover solutions that do not impede economic growth but instead offer means of lowering carbon dioxide emissions, which are a major contributor to greenhouse gases, and improving resource utilization. From production and consumption to waste management and the market of secondary raw materials concepts are covered by the circular economy. Industrial ecology and industrial symbiosis focused on industrial processes. These have to do with the production phases that enable organizations and businesses that have often operated separately to collaborate in the sharing of resources. Instead of the size of the economy, the focus is where industrial symbiosis and industrial ecology diverge. But from every economic, environmental, and social perspective, it is equally significant. Industrial symbiosis is described as a group strategy in which one company's waste is utilized by another company as raw material. This application is comparable to biological processes, which are characterized by a mutually advantageous interaction. Companies interact physically through exchanging materials, waste products, energy, and water, giving each participant a competitive edge. Advantages and growth prospects are indicated. Examples show that industrial symbiosis is a relatively new concern for Turkey's industry. Some of the researches are only theoric. Application absence is observed in industrial zones. A questionnaire was prepared to measure the awareness of industrial symbiosis in Turkey, and then this questionnaire was answered by people with different experiences working in different companies and positions in the chemical industry. There are several enablers and barriers are investigated during the literature reviews. The survey results aim to apply multi-criteria decision-making approaches for these enablers and barriers. After the weightings suitable for the criteria are assigned with the help of decision-makers, then necessary calculations are made. Aiming the found the importance of the criteria. These results are aimed to be a pioneer in development by taking appropriate steps by revealing the deficiencies and opportunities in the chemical industry. Considering these results, it is expected that the steps to be taken will have a positive effect by facilitating the processes.

Keywords: industrial symbiosis, multi-criteria decision making, sustainability

ÖZET

Son yıllarda, kaynak tüketen kullanımı, artan sanayileşme ve şehirleşme, modern yaşam tarzları, enerji yoğun kullanımı ve arazi kullanım modelleri, sera gazı emisyonlarının artmasına neden olmuştur. Bu durumun çevre ve toplum için olumsuz sonuçları vardır. Ekonomik gelişmeyi engellemeden sera gazlarının büyük ölçüde sorumlusu olan karbondioksit emisyonlarını azaltmanın ve kaynakları daha verimli kullanmanın yollarını sağlayabilecek çözümlerin bulunması öncelikli amaç olmalıdır. Üretim ve tüketimden atık yönetimine ve ikincil hammadde pazarına kadar tüm kavramlar döngüsel ekonomi kapsamındadır. Endüstriyel ekoloji ve endüstriyel simbiyoz endüstriyel süreçlere odaklanır. Bunlar, geleneksel olarak birbirinden ayrı olan şirketlerin kaynak paylaşımında kendi aralarında işbirliği yapmalarını sağlayan üretim süreçleriyle ilgilidir. Endüstriyel simbiyoz ile endüstriyel ekoloji arasındaki fark, ekonominin ölçeği yerine odak noktasında yatmaktadır. Ancak ekonomik, çevresel ve sosyal tüm açılardan eşit derecede önemlidir. Endüstriyel simbiyoz, bir şirketin atığının başka bir şirket tarafından hammadde olarak kullanıldığı kolektif bir yaklaşım olarak tanımlanır. Bu uygulama, karşılıklı yarar ilişkisi olarak tanımlanan biyolojik süreçlere benzer. Şirketler, tüm katılımcılar için rekabet avantajları sağlayan fiziksel malzeme, yan ürün, enerji ve su alışverişinde bir araya gelir. Bu raporda dünyadaki ve Türkiye'deki endüstriyel simbiyoz uygulamaları örneklendirilmektedir. Avantajlar ve büyüme beklentileri belirtilmiştir. Örnekler, endüstriyel simbiyozun Türkiye sanayisi için nispeten yeni bir araştırma alanı olduğunu göstermektedir. Bazı araştırmalar ise sadece teoriktir. Sanayi bölgelerinde uygulama eksikliği görülmektedir. Bu araştırma kapsamında Türkiye'de endüstriyel simbiyoz farkındalığını ölçmek için bir anket hazırlanmış ve ardından bu anket, kimya endüstrisinde farklı şirketlerde ve pozisyonlarda çalışan, farklı deneyimlere sahip kişiler tarafından yanıtlanmıştır. Literatür incelemeleri sırasında çeşitli itici güçler ve engeller araştırılmaktadır. Anket sonuçları, bu itici güçler ve engeller için çok kriterli karar verme yaklaşımlarını

uygulamayı amaçlamaktadır. Karar vericiler yardımıyla kriterlere uygun ağırlıklandırmalar belirlendikten sonra gerekli hesaplamalar yapılır. Kriterlerin öneminin bulunması çalışmanın amacıdır. Bu sonuçlar neticesinde, kimya sanayisinde endüstriyel simbiyoz uygulamalarında eksiklikleri ve fırsatları ortaya koyarak uygun adımların atılması için yol gösterici olması amaçlanmaktadır.

Anahtar kelimeler : endüstriyel simbiyoz, çok-kriterli karar verme, sürdürülebilirlik

1. INTRODUCTION

Production is defined as actions taken to enhance the quantity or advantages of commodities and services to satisfy human requirements. The insensitive use of resources naturally increases concerns about the future of the world, while a certain level of awareness arises. This wisdom gives rise to "sustainable production". In order to protect their future results, companies that practice sustainable production operate their current manufacturing processes with minimal environmental impact. Because of this, sustainability has grown in importance as a duty shared by society and businesses alike. The main characteristics of sustainable production include being non-polluting, preserving energy and natural resources, economically viable, safe and healthy for worker communities, and consumer processes. (Turhan et al., 2018).

If production is sustainable, then the environment, employees, communities, and organizations—all benefit. These conditions can lead, always in the long term, and often in the short term, to more economically viable and productive enterprises. Two basic application methods for sustainable production are cleaner production and industrial symbiosis. Another approach to environmental management known as clean (or cleaner) production attempts to promote innovative procedures, products, and services that are cleaner and more resource effective. It places a strong emphasis on a preventive approach to environmental management that considers implications over a product's or service's whole life cycle. Cleaner production and industrial ecology have apparent conceptual similarities. Concerns about the growing environmental effects of industrial economic systems motivate both of them. In the development of environmental management, they appeared around the same period, between the late 1980s and the middle of the 1990s. Waste minimization, industrial ecology, life cycle assessment, pollution avoidance, and source reduction are all included in the purview of cleaner production (Jackson, 2002).

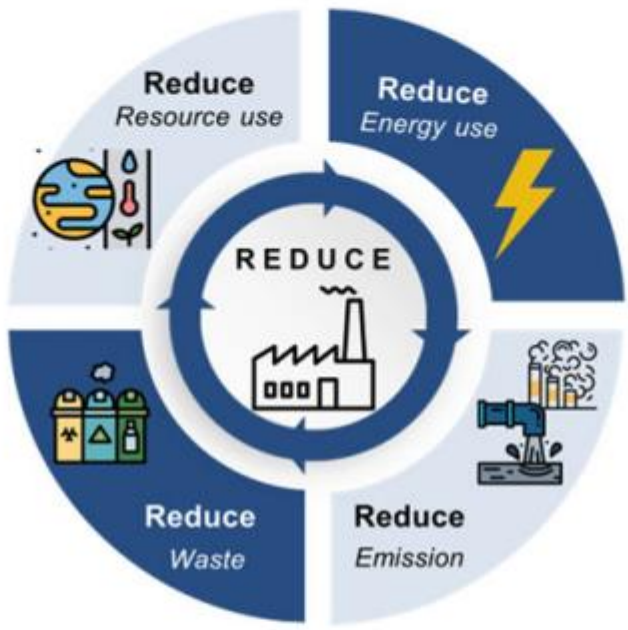

Figure 1.1: Cleaner production in factories

The goal of sustainable development is to achieve long-term prosperity, equity, and well-being for all people. It is a broad concept that encompasses economic, social, and environmental aspects. It strives to satisfy the requirements of the present without sacrificing the ability of future generations to fulfill their own needs by incorporating economic, social, and environmental concerns into the decision-making process. To ensure that development is inclusive, equitable, and environmentally sustainable, sustainable development involves balancing economic expansion with social advancement and environmental protection. One of the systems that promote sustainable development is the circular economy (Diesendorf, 2000).

The circular economy is an economic theory that seeks to minimize waste and maximize resource efficiency by keeping resources and goods in use for as long as feasible through a closed-loop system. To reduce the negative environmental effects associated with production and consumption, this approach includes designing items for reuse and recycling as well as utilizing renewable materials and energy sources. By repurposing waste to produce new products or supplies and by supporting innovative business models that promote environmentally conscious consumption and production, the circular economy also strives to add value to waste (Islam and Kumar, 2021).

A key elements of the circular economy and sustainable development is industrial symbiosis. In order to exchange resources, energy, and byproducts in a closed-loop system that maximizes resource efficiency and reduces waste, it requires cooperation across many industries and stakeholders. Thus, it also promotes sustainable development. Industrial symbiosis can assist with solving some of the major issues that our society is currently confronting in the framework of circular economy and sustainable development. Industrial symbiosis may play a role in lowering greenhouse gas emissions and reducing the effects of climate change by fostering the effective use of resources and energy. Additionally, it can support economic growth, foster employment growth, and lower the environmental and social costs associated with production and consumption. Numerous studies for various nations have outlined facilitators and challenges relating to legislation, management, the environment, social, and financial areas. It's critical to identify the most significant enablers and barriers that will be key to the problem's resolution (Chertow, 2000).

The fundamental elements of industrial symbiosis include analytical tools, which will be utilized to demonstrate the system's current state. The three primary system tools utilized in the operation of industrial symbiosis are "Material Flow Analysis," "Life Cycle Assessment," and "Multiple Criteria Decision Making." In general, recovering industrial waste has significant potential environmental advantages, especially when considering the entire life cycle. The effectiveness of the life cycle assessment (LCA) method for assessing IS has been demonstrated. LCA is a method for assessing the environmental effects of commercial products, processes, or services at any stage of their life cycles. (Özkan et al., 2018)

In the light of all these definitions, industrial symbiosis potentially comes to the fore. Investigating the enablers and barriers to industrial symbiosis in various fields in the chemical industry has been one of the main focuses of this study. In the literature, a gap has been observed in studies on this subject. The feature that distinguishes this study from other studies is the realization that there is no study in this field in the chemical industry in Turkey. The fact that it is highly prone to industrial symbiosis applications, especially in the chemical sector due to the diversity of inputs and outputs, aims to determine the priorities that need to be taken action when this field is directed in the coming years. In addition, as an original contribution, it is aimed to pave the way for future studies based on the opinions of decision makers from different experiences and fields. Especially the existing studies in the field of industrial symbiosis are based on verbal evaluation and qualitative analysis. In this study, quantitative analysis was carried out with the help of a mathematical model by compiling the results of the qualitative analysis in the literature. As a result of the limitations of the studies and the researches made for this study, it has been clearly seen that this concept has not matured yet in Turkey and there is a long way to go. Although companies take actions such as small-scale raw material exchanges, they do not have a complete idea about their larger returns and consequences. Likewise, it has been determined that it is very difficult for decision makers working in different sectors to reach a consensus on the same issue. In order to create a basis for future studies in this area, more decision makers can be worked with or specific researches can be made for each of the fields related to the chemical industry to ensure consensus. Similarly, there are more areas not included in the study. In the future, evaluations will be made for these areas as well.

2 FUNDAMENTAL NOTIONS

2.1 Sustainablity

The Latin term sustinere (tenere, to hold; sus, up) is the derivation of the English word sustainability. The English word "sustainability," which expresses the potential of a specific matter to be supported, provides the foundation for how sustainability is used today. In order to achieve a greater level of living, societal, economic, and environmental issues should all be balanced. This is what sustainability is thought to represent. Some of the overarching ideas that guide its ambitions and guiding principles include intergenerational fairness, gender equity, social tolerance, poverty reduction, environmental preservation and restoration, natural resource preservation, and the building of an equitable and peaceful society. The United Nations' main philosophy is sustainable development. In order to create a more sustainable future, educational systems must be involved globally. To sum up, by saying that while sustainable development refers to the various methods and routes taken to achieve sustainability, sustainability is viewed as a long-term aim (Jeronen, 2013).

Particularly over the past 50 years, there have been unheard-of industrialization and development advancements, as well as significant economic and technological changes. In addition to having favorable effects on the economy, agriculture, energy access, and individual average income, these changes have also had negative ones, including rapid population expansion, excessive consumption, biodiversity loss, greenhouse gas emissions, and climate change. Since Hans Carl von Carlowitz first outlined the concept of sustainability in 1713, a number of significant milestones have been reached to bring about the current state of sustainable development (SD), including Our Common Future, the Rio Conference, the Johannesburg Conference, and the Sustainable Development Goals (SDGs). SD involves integrating economic, social, and environmental considerations in decision-making processes to achieve long-term prosperity, equity, and well-being for all (Lozano, 2022).

2.2 Sustainable Development

In response to increasing concerns about environmental deterioration, social injustice, and economic instability, the idea of sustainable development originated in the 1970s. The United Nations formed the World Commission on Environment and Development (WCED), sometimes known as the Brundtland Commission and named after its chair, Gro Harlem Brundtland, in 1983. The commission's conclusions were published in 1987 under the title Our Common Future. They argued in favor of making sustainable development a priority for corporations and the world economy. Sustainability was defined as growth that meets current demands without jeopardizing the ability of future generations to meet their own needs. (Thomsen, 2013)

Sustainable development is a concept that recognizes the need to meet the needs of the present without compromising the ability of future generations to meet their own needs. It encompasses the integration of economic, social, and environmental considerations in decision-making processes to achieve long-term prosperity, equity, and well-being for all. Sustainable development involves finding ways to balance economic growth and development with the protection of the environment, the promotion of social equity and inclusion, and the preservation of cultural heritage.

The WCED was established to address growing concerns about the effects of the deterioration of the natural environment and human environment on social and economic development. The Brundtland Report, the results of the commission's work, contained two main ideas: (1) the idea that needs, particularly those of the world's poor, should be given priority; and (2) the idea that environmental sustainability is constrained by social and technological pressures. The UN General Assembly decided that it was in the best interests of all countries to create policies for sustainable development when it established the commission, acknowledging the global dimension of environmental challenges.

At the 2005 World Summit, there was broad agreement that achieving sustainability required balancing the "three pillars" of environmental, social, and economic needs. Three overlapping ellipses are used to illustrate this point of view and demonstrate how the three sustainability pillars are not mutually exclusive and can really support one another. (Brundtland et al., 1987)

Figure 2.1: Three pillars of sustainability

It is understood that sustainable development aims to bring an understanding of a solution to a problem in terms of its emergence and development. The core principle of sustainable development is the incorporation of environmental, social, and economic considerations into all decision-making processes. Sustainability differs from other types of a policy due to this firmly entrenched notion of integration. Following the principles of recycling and reuse (circular economy), the use of renewabl e resources or their joint consumption (sharing economy), the reduction of carbon dioxi de emissions, and the utilization of renewable raw materials of plant origin (low carbon economy) makes sustainable development possible. Achieving sustainable development requires collaboration and cooperation among various stakeholders, including governments, businesses, civil society, and individuals. It also involves innovation and the adoption of new technologies and practices to promote more sustainable ways of living and doing business. Overall, sustainable development is essential for ensuring a healthy and prosperous future for people and the planet (Emas, 2015).

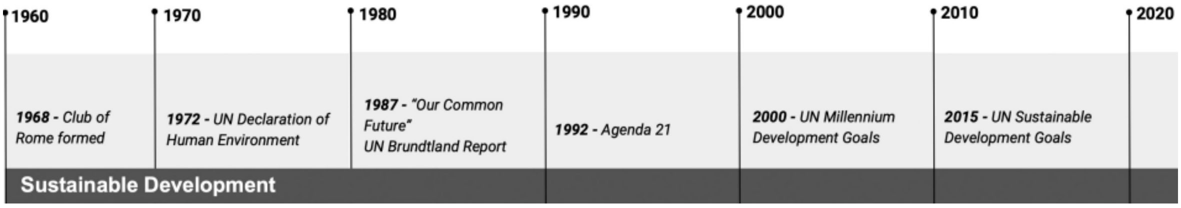

Figure 2.2: Timeline with main events of sustainable development

The main events of sustainable development experienced up to 2020 are shown in the figure (McCowan et al., 2021).

2.3 Sustainable Developement Goals

There are seventeen Sustainable Development Goals (SDGs) in the 2030 Agenda for Sustainable Development, which 193 Heads of State unanimously endorsed. According to UN Secretary-General Ban Ki-moon "The seventeen SDGs are a shared vision of humanity and a social contract between the world's leaders and the people".

Figure 2.3: 17 SD goals

2.4 Circular Economy

Since Kenneth Boulding's distinction between an "open economy" and a "closed economy" in his essay "The Economics of the Coming Spaceship Earth" in 1966, the term "circular economy" has existed for at least a few decades. Since then, various branches in resource management, environmental policy, sustainable development, and other fields have arisen and further developed around the concepts of feedback systems, cradle-to-cradle, closed-loop, and countless more basically equivalent concepts to those in the circular economy. However, the circular economy notion has only just begun to gain momentum on a worldwide and cross-sector level as a comprehensive vision of future economic development (Cui, 2021).

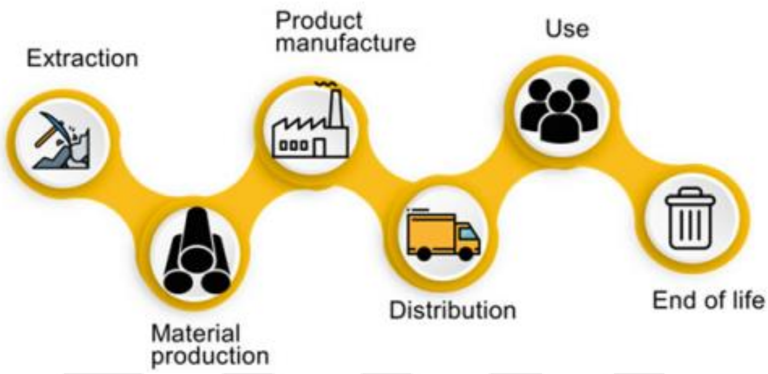

Figure 2.4: Model of a linear economy

As seen in the figure natural resources are extracted, put through industrial processes to create products that serve certain purposes, are consumed, then handled by waste management procedures before being released back into the environment. This "take-make-use-discard" approach has been in use for a long time and continues to be widely used today. The danger of running out of resources has led to a move away from this approach (Gheewala and Silalertruksa, 2021).

The "take-make-use-discard" paradigm of the linear economy is replaced with the circular model at the micro, meso, and macro levels. At the micro level, one particular industry or process can reduce resource use and pollution. At the meso scale, a collection of factories or an entire industrial sector may be integrated, with the waste from one feeding into another in a system resembling an industrial park or an industrial ecosystem. As a result of this, industrial parks often practice industrial symbiosis. This exchange would take place at the level of the entire economy at the macro level.

However, the circular economy encompasses more than just lowering resource consumption and emissions. It focuses more on finding ways to reuse, repair, refurbish, and remanufacture existing products in order to increase their lifespan. The final step in the hierarchy of circularity is likely recycling of materials, which is preferred to discarding things at the end of their useful lives because doing so preserves the value of the materials and energy used to create the product. The circular economy, on the other hand, aims to maximize value at every stage of a product's life, including after usage (Gheewala and Silalertruksa, 2021).

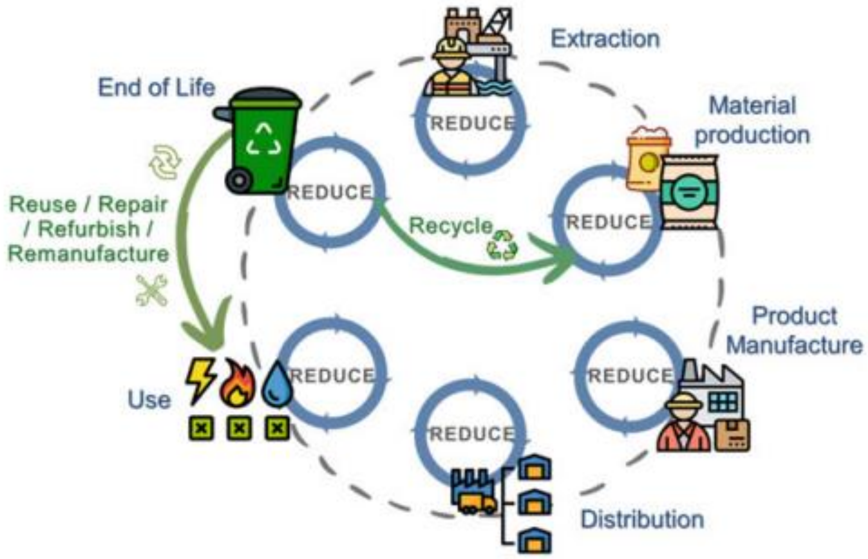

Figure 2.5: Circularity and the life cycle of products

The circular economy is currently influencing talks, especially among the countries that make up the European Union. The circular economy first appeared in the literature in relation to the so-called 3R principles, which stand for reduction, reuse, and recycling. In addition, the essential principles of the circular economy include the following: logical environmental management through stock optimization, mitigating harmful environmental externalities; circulation of natural resources along ecological and technical material flows; non-waste organic production; adaptability to external conditions by using the optimal business model; circular design when developing new products with the improvement of the composition; and circular design when reusing materials. Economic development is strongly related to guaranteeing a sustainable production cycle while taking into account available resources, as economic development in the circular economy model increasingly depends on the consumption of these resources. In addition, the transition to cyclical value chains that can reproduce continuously, boosting production eco-efficiency and creating more environmentally friendly products through technology, and service products through sharing models are the main benefits of CE (La Rosa and Ramakrishna, 2021).

A change from a linear to a circular conception is indispensable. The concept of a comprehensive circular economy (CE) can serve as a representation of it. The idea of "end-of-life" is replaced by the practice of reducing or, alternatively, reusing, recycling, and recovering resources employed in the production, distribution, and consumption processes in an economic system. A change from a linear to a circular conception is necessary. The notion of a comprehensive circular economy (CE) can serve as a representation of it. The idea of "end-of-life" is replaced by the practice of cutting down or, alternatively, reusing, recycling, and recovering resources employed in the production, distribution, and consumption processes in an economic system (Cudečka-Puriņa et al., 2022).

Also, in order to accomplish the Sustainable Development Goals (SDG), the circular economy is a technique that incorporates environmental, social, and governance performance (ESG) into decision-making. Business as usual is incompatible with sustainability, and in recent years it has been clearly apparent that alternative business models, based mostly on technology considerations, must be implemented in order to decrease the harm brought on by the enormous and unpredictable effects of climate change. Policies and company development models must be changed immediately and promptly due to the present situation. The current study focused on industrial symbiosis as one of the circular economy's business models. It evaluated the advantages of symbiosis and the growth of collaboration across industries, and as a result, it significantly affected resource efficiency ratios (Kalmykova et al., 2018).

2.5 Industrial Ecology

The ancient Greek terms "oikos" (which means "household, house, or place to live") and "logos" (which means "speech, word, reason, or science") are where the word "ecology" originates. Focused areas of ecology include ecosystem composition and function, interactions between living things and their surroundings, and the distribution and abundance of species (Jeronen, 2019).

In that it emphasizes product design and production procedures, industrial ecology is industrial. Because they possess the technological know-how required for the successful implementation of environmentally conscious product and process designs, it sees businesses as agents for improving the environment. The industry is the focus because it produces the majority of goods and services and is a substantial source of environmental harm, albeit it is not the only one (Lifset and Graedel, 2002).

According to the book by Frosch and Gallopoulos (1989), industrial ecology uses 'non-human 'natural' ecosystems as models for industrial activity. Many biological ecosystems specialize at resource recycling, and as a result, they are cited as role models for efficient material and energy cycling in business. "Industrial symbiosis" is the name given to the network of contacts in comparison to the symbiotic, mutually beneficial relationships found in nature (Frosch and Gallopoulos, 1989).

Without IE, IS cannot possibly exist because IE is necessary for IS to implement its principles and fulfill its goal. Early definitions of IE occasionally used the terms "method," "approach," or "framework." It has increasingly been clear from the definitions that IE is an interdisciplinary subject of study. Similar to its biological ecology relative, industrial ecology (IE) is a study field that includes many methods, concepts, and frameworks for designing and transforming industrial systems into almost closed-loop industrial ecosystems. Thinking about IE basically as a strategy, framework, or methodology limits its development and uses (Lifset and Graedel, 2002).

A web of knowledge, a network of different organizations, new input sourcing, value-added destinations for non-product outputs (and additional end-life products), efficient business and technical processes, and a collective strategy need to work together for IS to be successful.

The industrial environment, industrial symbiosis, industrial metabolism, and rules and legislation for IE development and implementation are the study topics that Industrial Ecology (IE) focuses on. In order to create industrial ecosystems and change industrial systems into industrial ecosystems, Industrial Ecosystems (IE) adopts and develops a variety of technical and administrative processes and relevant biological ecosystem features. In terms of material exchanges and energy cascading, IE seeks to create diversified, gradually evolving industrial ecosystems. In order to support the growth of networks of synergies both within and between various businesses, the field of industrial symbiosis (IS) investigates how to build knowledge webs of material, energy, and waste exchanges as well as business core operations. In order to construct networks of synergies both within and between different organizations, Industrial Symbiosis (IS) investigates how to create knowledge webs of distinctive material, energy, and waste exchanges as well as business core operations. High levels of essentially closed-loop material exchanges as well as the creation of highly efficient energy cascading within and between industrial ecosystems will be made possible by this. The long-term objective of IM is similar to that of IE, but it focuses on the techniques that may be applied to evaluate and improve eco-efficiency and exchange rates to enable deeper and more beneficial connections (Li and Li, 2018).

2.6 Industrial Symbiosis

The idea of industrial symbiosis should make it possible to utilize resources effectively and collaboratively. It is anticipated that the producers and consumers participating in the system would have a reversible mutual benefit mechanism after this application, which necessitates company synergy. The goal of IS is to improve cooperative sourcing and material movement across facilities.

Industrial symbiosis refers to the development of long-term alliances that will improve the environmental performance and competitiveness of two or more enterprises that now operate separately, typically in close proximity geographically and taking into account the benefit-cost ratio. (Chertow, 2000).

This definition's most prevalent use is when a manufacturing process waste is used as a resource for another manufacturing process. Waste and product are only one aspect of the symbiotic connection; other aspects include energy, water and wastewater, human resources, education, shared facilities, and equipment. Synergies have advantages for the environment as well as the economy, such as lowering waste and emissions and safeguarding raw material supplies. In its broadest definition, resource sharing converts waste and other harmful environmental outcomes into beneficial outcomes including pollution reduction, the use of alternative raw materials, and the preservation of natural raw material supplies (Chertow and Ehrenfeld, 2012).

Over the past twenty years, the circular economy has developed as a theory that provides answers to some of the problems facing sustainable development. Different business models, such industrial symbiosis, have been identified as important tools for sustainable growth as a result (Henriques et al., 2022).

One of the main causes of the significant amount of waste generation can be demonstrated as the emergence of the majority of industrial wastes as a result of conventional manufacturing procedures. Conventional production methods increase production costs while also having an insufficient level of production efficiency. Processes turn non-products like waste and emissions from inputs like water and energy into those. Studies on resource efficiency have recently become necessary due to the conversion of valuable inputs into non-renewable products. As a result of these studies on sustainability, the concepts of clean production and IS have come to the fore in order to ensure efficient resource use and prevent pollution. Today, industrial clean production practices are carried out on systems based on the balance of inputs (consumables and auxiliary materials, water, energy) and outputs (products, wastes, emissions). Studies on these systems generally yield variable results in light of different observations and data. Variable resource costs also negatively affect sustainability efforts (Skorupka, 2008).

(Maletic, 2016). In the light of the researches, it is seen that making a sustainable industry and production system that enables efficient resource use is still a necessity to be achieved. As a key solution method, industrial ecology or industrial symbiosis studies have attracted attention (Maletič et al., 2016).

The circular economy is a strategy that integrates environmental, social, and governance performance into decision-making in order to achieve the Sustainable Development Goals (SDG). Business as usual is incompatible with sustainability, and it has been clearly clear in recent years that alternative business models, primarily based on technological considerations, must be developed in order to reduce the harm caused by the vast and unpredictable effects of climate change. The current situation necessitates urgent and immediate changes to policies and business development methods. In recent years, research has concentrated on industrial symbiosis as one of the business models for the circular economy. Assessments are shown that there are advantages of symbiosis and the promotion of collaboration across industries, and as a result, it significantly affected resource efficiency ratios. Economic advantages come to the fore for industrial organizations. With the advantages, it offers in each of the four key areas of industry, resource protection, environment, and economics, the Industrial Symbiosis network, which shows a solid framework for many phenomena and systems, will be the executor of sustainable development (Cudečka-Puriņa et al., 2022).

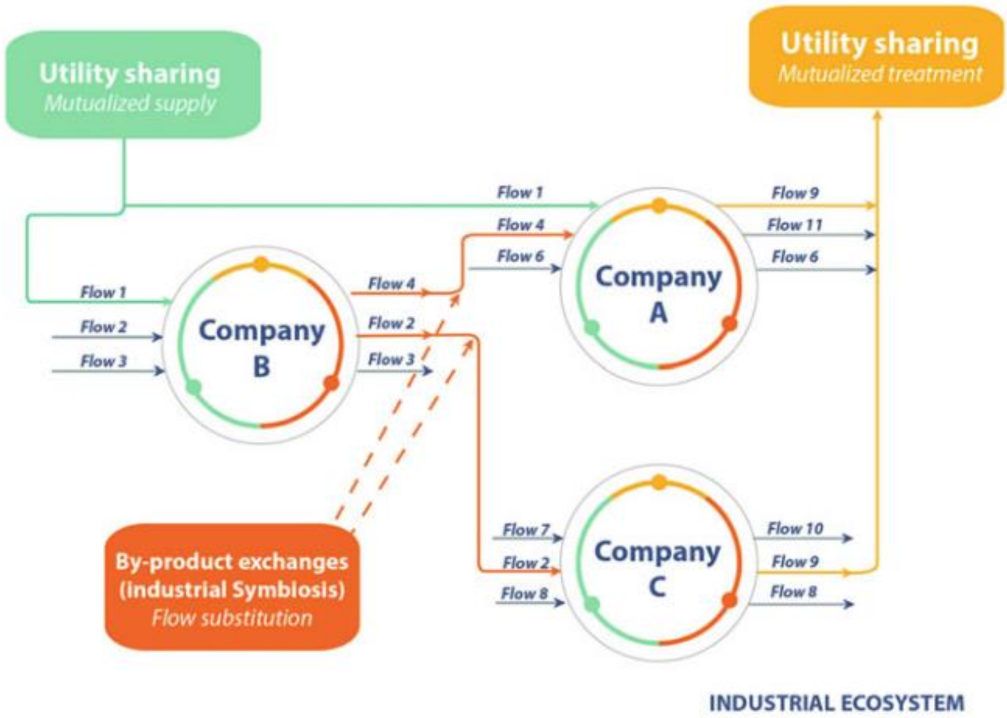

Figure 2.6: Example of an IS network

IS emphasizes collaboration because firms gain a collective advantage bigger than the sum of individual gains that might be realized by acting alone when they collaborate (La Rosa and Ramakrishna, 2021). In addition to fostering social values among the participants, such teamwork may also benefit the areas around it. Despite the widespread use of the term "eco-industrial park" to characterize businesses engaged in exchanges, the symbioses need not take place inside the formal confines of a "park". It is seen that industrial symbiosis models are generally included in the literature in two ways: the "Self-Organized Symbiosis Model" and the "Planned Eco-Industrial Park (EIP) Model." The planned EIP concept includes a deliberate attempt to identify and co-locate businesses from various industries so that they can pool their resources. Creating a stakeholder group of different players to direct the process and involving at least one government or quasi-government entity with some authority to encourage growth, such as land use planning, grant granting, or long-term funding, are typical planning steps for these systems. According to the self-organized symbiosis concept, an industrial ecosystem develops as a result of choices made by private players who are driven to exchange resources in order to accomplish objectives like cost reduction, revenue development, or business expansion. The individual enterprise to initiate resource exchange faces a market test, and these exchanges can increasingly continue if the exchanges are successful and there is continued mutual interest. Consciousness of participants in industrial symbiosis or those involved in the industrial ecosystem can also evolve over time. It has been observed that the self-organizing symbiosis models are more sustainable than the EIP model. The best example of the self-organizing model is the Kalundborg symbiosis (Chertow, 2007).

In addition to its effects on resource consumption and waste reduction from an economic and environmental perspective, it also improves relations between industrial regions and businesses by creating collaborative projects that address businesses that share the same waste and resources. Applications of the concept of Industrial Symbiosis have been the subject of many studies, including eco-industrial parks with rapidly expanding industrial production potential. The symbiotic linkage of two or more businesses is necessary for industrial symbiosis. In this approach, businesses provide advantages, particularly economic and environmental (Wen and Meng, 2015).

The IS at Kalundborg, Denmark, was the first instance of industrial ecology. Since then, industrial symbiosis has successfully changed existing industrial parks, as evidenced by regional synergies in the Australian mineral industries, the National Industrial Symbiosis initiative (NISP) in the UK, and the Circular Economy initiative in Chinese industrial parks, to name just a few instances. Other notable examples are the collaboration between the waste management companies in Chamusca, Portugal, the Tianjin Economic Technological Development Area (TEDA) in China, and the Kymi pulp and paper mill and its linked sectors in Kouvola, Finland (La Rosa and Ramakrishna, 2021).

In the Danish industrial seaside town of Kalundborg, there exists a well-developed industrial symbiosis. The bulk of Kalundborg's industrial symbiosis's tangible components consists of about 18 physical connections. The six main local players in the network that has developed are the Asnaes Power Station, a 1350 megawatt power plant run by SK Power, a sizable oil refinery run by Statoil A/S, Novo Nordisk Novozymes A/S, a Danish pharmaceutical and biotechnology company, Gyproc Nordic East, a plasterboard manufacturer, A-S Bioteknisk Jordrens, a soil remediation company, and the municipality of Kalundborg. Numerous other consumers in the community exchange waste streams, energy resources, and byproducts to create raw materials. Companies from outside the region take part as receivers of swaps of byproducts for raw materials. This partnership has significantly increased environmental and economic efficiency and has also provided benefits such as new employment opportunities, technological improvement, a significant reduction in waste management costs, and significant knowledge accumulation and sharing (Ehrenfeld and Chertow, 2007)

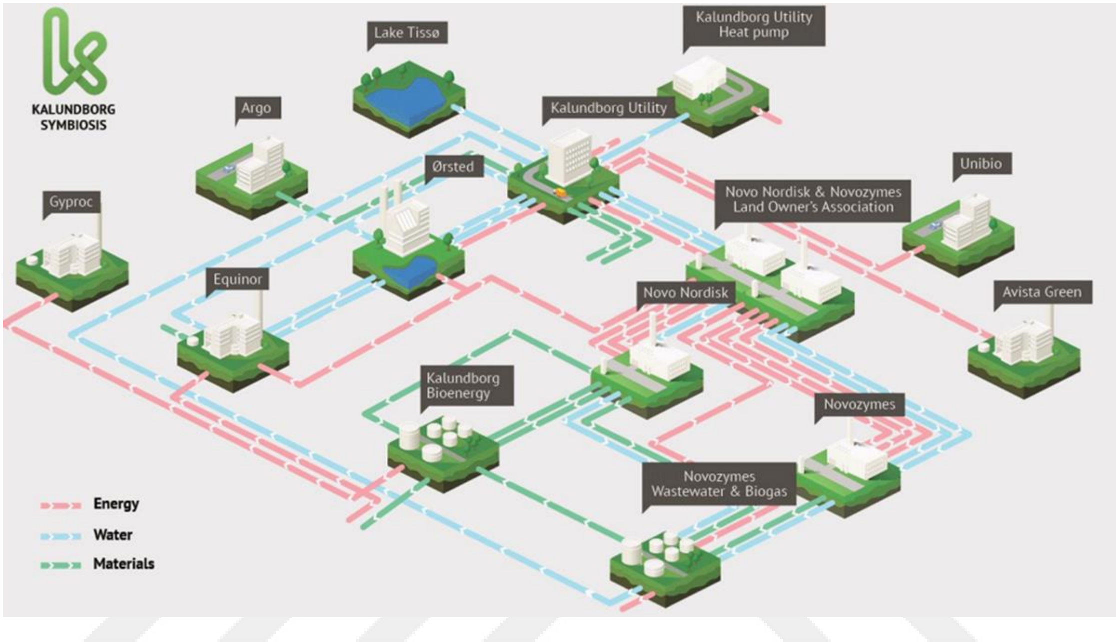

Figure 2.7: Representation of Kalundborg Symbiosis

Even though it started out as pilot programs in several regions, the UK has now taken a national approach to IS practice. In 2003, the BCSD-UK formally unveiled its national IS program (NISP). The three pilot programs for the NISP were located in Scotland, the West Midlands, and Yorkshire and the Humber. It was established in the Humber Estuary Region, located in the east of England, and the Humber River, an oil refinery, large and small businesses manufacturing organic and inorganic chemicals, water and energy facilities, packaging and transportation services and mining, furniture, food, etc. There are various facilities operating in different sectors. NISP was also self-organized IS model (Mirata, 2014).

The European nations with the most confirmed instances of potential industrial symbiosis are Italy, Sweden, and Finland. The fact that these nations support the study of contemporary industrial relations, and their implementation is what unites them. There are several examples of industrial symbiosis that have been documented over time, many self-organizing symbiosis networks, the presence of facilitators through national agencies or local governments, the search for sustainable solutions, and stringent environmental regulations. (Neves et al., 2019).

Although it is a fairly new concept in Turkey, projects on IS are being carried out. Industrial symbiosis in Turkey emerged for the first time with the Iskenderun Project, which was successfully implemented. The Industrial Symbiosis (IS) technique was implemented in Turkey between January 2011 and February 2014 as part of the "Industrial Symbiosis Project in Iskenderun Bay Implementation Phase" project. With help from International Synergies Limited Company (UK) and Middle East Technical University (Turkey), the Technology Development Foundation of Turkey (TTGV) completed the project. Over 500 IS opportunities between institutions were found throughout the project, which resulted in the establishment of a pilot-scale IS network made up of 264 institutions. 10 IS opportunities were chosen, and they were carefully examined (Alkaya et al., 2014).

Bursa Eskişehir Bilecik Industrial Symbiosis Program started with the protocol signed between Bursa Eskişehir Bilecik Development Agency (BEBKA) and Turkey Technology Development Foundation (TTGV) on February 27, 2014. BEBKA also closely followed the industrial symbiosis activities carried out in Turkey, and included this approach in its 2014-2023 regional plan. Accordingly, one of the measures included under the title of "Balanced Spatial Development and Sustainable Environment" has been the "implementation of Industrial Symbiosis practices that provide both environmental and economic benefits by increasing cooperation and solidarity between companies". Thus, in collaboration with BEBKA and TTGV, the "Bursa Eskişehir Bilecik Industrial Symbiosis Program" was launched. The program's main goals are to spread knowledge of industrial symbiosis practices in the area, assess current potential and strategy through sectoral and regional analyses, conduct feasibility studies, conduct communication activities, build the foundation for the sustainability and expansion of industrial symbiosis practices, and carry out the planned studies. (URL-2).

The feasibility study of Gaziantep Industrial Symbiosis Project was completed in 2016, and the general aim of the project is to determine potential industrial symbiosis opportunities in Gaziantep Organized Industrial Zone by carrying out a comprehensive study on industrial symbiosis applications. Nearly 100 Industrial Symbiosis opportunities have been identified, and 13 investment projects that can be implemented in the province have been revealed (URL-3).

2.6.1 Industrial Symbiosis Tools

There are facilitating tools to realize all these mentioned possibilities of industrial symbiosis networking. The first step before deciding to implement industrial symbiosis is to identify the potential symbiotic relations. The most crucial component of industrial symbiosis—the matching of sectors through waste input and output—can be completed manually using the data from the literature research or automatically using software or websites that undertake this matching (Neves et al., 2019). The METU Environmental Engineering Department's "Industrial Symbiosis Opportunity Screening Tool (ESOTA®)" created in Turkey performed manual waste mappings on several OIZs in the context of industrial symbiosis. (Uludag-Demirer and Demirer, 2017)

The Turkey Material Marketplace (TMM) Project is a sub-study of the Business World and Sustainable Development Association (SKD Turkey). It is a digital platform designed to allow raw materials, by-products, production surpluses, and used materials from one company to be used as input for the production of another company. Companies sign up for a membership on this platform and manually add the provided or requested waste to the system. TMM completes its mission as a result of the companies' commitment (URL-4). In addition to all, web-based scanning tools have been developed globally for waste exchange systems and industrial symbiosis. Some of those industrial symbiosis tools are Dansk Symbiosecenter (Symbiosis Center Denmark), CIRCULATOR, Italian Platform for Industrial Symbiosis, EPOS, iNex Circular, SMILE Resource Exchange platform, MAESTRI, SymbioGIS, MarketplaceHUB, Sharebox, SymbioSyS, Synergie Quebec etc. Some of these programs are under development, completed or operational (Álvarez and Ruiz-Puente, 2017).

By capturing the production and consumption data about the flow, process, and product that the consultants get as a consequence of their visit to the firm, using standard office programs or third-party software, the industrial symbiosis potentials of the present region are retrieved (Lens, 2002). Potential symbiotic relationships exist between industrial systems of various sizes. Although the potentials obtained are not detailed, materials and energies that can be reused and evaluated within the company through clean production methods can be seen as Industrial Symbiosis potential. Upon the completion of the pairings, the symbiosis study is initiated, the firms are notified, and any necessary trainings are provided (Lens, 2002).

2.6.2 Industrial Symbiosis in Chemical Sector

The chemical industry contributes significantly to the growth of the world economy and human society. However, it is impossible to disregard the detrimental repercussions of chemical manufacture, which frequently result in significant resource use and environmental contamination. The chemical sector must succeed in achieving sustainable development. One of the important subjects in the fields of industrial ecology and the circular economy, which have been recognized as a pioneering route to sustainability, is industrial symbiosis.

Humans have believed that natural resources are limitless for ages; they neglected the environment and other living things in favor of increased output. Humanity has looked for new production methods since the depletion of the environment and natural resources has an impact on daily life. This inquiry led to the concept of sustainable development, which attempts to satisfy existing demands without endangering the capacity of future generations to satisfy their own. Industrial symbiosis has begun to be applied as a new ecologically conscious production model as a part of this strategy, and it has quickly gained acceptance to the point that it has even become a national program in some nations.

It has been noted that industrial symbiosis practices, which emphasize resource efficiency and environmental responsibility, have an impact on lowering production costs and boosting firm competitiveness. It has been noted that industrial symbiosis practices, which emphasize resource efficiency and environmental responsibility, have an impact on lowering production expenses and increasing firm competitiveness.

When the symbiosis relationships in Australia, Canada, and Sweden are investigated, it becomes clear that the chemical sector is the first to be most conducive to symbiosis transformation. Flue gas is the first of the wastes unique to the chemical industry. The Kwinana Area of Australia's aluminum industry uses gypsum that is produced by desulphurizing flue gas to enhance the soil there since the enterprise's use of aluminum powders has damaged the soil's natural structure (van Beers, 2007).

Numerous studies have demonstrated the value of IS implementation for the chemical industry in achieving a balanced development of the economy and environment. A well-known instance of IS that involves chemical firms like an oil refinery and a sulfuric acid factory is the Kalundborg from Denmark. Researchers looked at the case of Kalundborg and came to the conclusion that creating symbiotic partnerships between businesses can have a significant positive impact on both the economy and the environment. The Rotterdam Harbor area is home to numerous businesses in the fine chemicals and petrochemical industries. It demonstrates how creating symbiotic partnerships helps those chemical businesses save money by reusing waste and byproducts, reducing the amount of water they dump into the environment, and consuming less energy. Surveyors looked into how an IS program in Landskrona performed in terms of the environment and discovered that IS activities support environmental innovation. Examining the effectiveness of the IS set up within Hai Hua Group (HHG), a significant marine chemical industrial area in China, as an example, researchers discovered that IS could create a win-win situation between the economy and the environment by increasing resource utilization rates and fully utilizing wastes and byproducts. Studies have been done on the advantages of the Midong Chemical Industrial Park (MCIP), which is the first circular economy pilot project in the Chinese province of Xinjiang Uygur. In addition, several researchers investigated how IS might help reduce greenhouse gas emissions in light of the growing concern over global climate change. There have been reports on the networks between several chemical industries, Liuzhou Iron and Steel, and Jinan Iron and Steel. They came to the conclusion that by putting IS operations into practice, CO_2 emissions can be efficiently decreased and significant profits may be realized. Research on reducing carbon emissions is being done by the Xinfa Group, and it involves numerous industrial partnerships with a focus on cascading energy and water consumption and by-product reuse. It demonstrated how CO_2 emissions can be successfully decreased within an IS. Researchers contend that IS can offer a novel strategy for carbon reduction because of this (Cui and Liu, 2017).

2.7 Decision Analysis Methods

There are several sub-branches of decision analysis. The three basic types of decision-making processes are single-purpose, multi-criteria, and decision support systems. Single-purpose decision-making methods tend towards only one goal in the solution problem. Decision trees and impact diagrams are the most important tools used in these methods. Decision support systems provide support for the methods and models used and integrate data sources with the necessary support systems. In addition, support systems offer a software system to the decision maker in solving difficult and complex problems (Yeo et al., 2019).

The term "multi-criteria decision making" refers to the process of giving values to alternatives that have undergone multiple levels of evaluation. Two types of multi-criteria decision making are multi-attribute decision making and multi-objective decision making. A finite collection of feasible alternatives are analyzed in multi-attribute decision-making situations in order to choose the best one based on the results of a number of qualities. The multi-objective choice issue involves deciding which alternative is better given a set of competing objectives. There are one or more decision makers in problems involving multi-attribute decision making as well as multi-objective decision making (Phua and Minowa, 2005).

Also, multi attribute decision making can use in classification problems. As a result of the techniques used for selection problems, it is decided which of the many alternatives is the most useful. Classification techniques group alternatives, while ranking techniques sort among alternatives (Dalbudak and Rençber, 2022).

In a decision-making situation, there may be two main types of uncertainty. The initial uncertainty stems from a lack of information regarding the decision circumstance. The second doubt is connected to fuzziness in terms of how events or utterances are described in terms of their semantic meaning. Therefore, probabilistic and fuzzy decision-making problems can be further classified into MODM and MADM problems under uncertainty. The level of ambiguity is a factor in this situation (Singh and Malik, 2014).

Multi-criteria decision problems are encountered when a set of alternatives or candidates must be selected on the basis of a set of criteria or attributes. However, in case of conflicting alternatives, a decision maker must also consider imprecise or uncertain data in such decision problems. Fuzzy set theory is suitable for overcoming this uncertainty in solving multi-criteria decision making problems (Greco et al., 1999).

2.7.1 Multi Criteria Decision Making Methods

Multi-Criteria Decision-Making (MCDM) approaches are used to help decision-making procedures when several criteria or objectives must be taken into account at once. In order to analyze and compare several alternatives based on a set of criteria—some of which may be incompatible or incommensurable—MCDM approaches offer an organized approach.

Decision-making is when the decision maker decides on the alternative that is most suitable for his/her target among a large number of alternatives in a problem consisting of different alternatives. The stages of the decision-making process can be listed as follows:

- Recognizing the problem
- Identifying and defining the problem
- Identification of alternatives
- Evaluation of alternatives
- Identification of the best alternative
- Evaluation of the decision

The decision-making steps listed are the processes used in the methods in general. Of course, these stages may change depending on the structure, size and purpose of the decision problem (Tekeş, 2002).

2.7.2 Application Areas of MCDM Methods

MCDM methods can be applied to a wide range of decision-making problems in various areas, including:

Engineering: MCDM methods can be used in engineering to evaluate and select the best design alternative for a product or system based on multiple criteria, such as performance, cost, safety, and environmental impact.

Business and financial management: MCDM methods can be used in finance to evaluate and compare different investment opportunities based on multiple criteria, such as return on investment, risk, and liquidity.

Environmental management: MCDM methods can be used in environmental management to evaluate and select the best alternative for a project or policy based on multiple criteria, such as environmental impact, social acceptability, and economic feasibility.

Health care: MCDM methods can be used in health care to evaluate and compare different treatment options based on multiple criteria, such as effectiveness, safety, and cost.

Public policy: MCDM methods can be used in public policy to evaluate and select the best policy option based on multiple criteria, such as economic efficiency, social equity, and environmental sustainability.

Transportation and logistics: MCDM methods can be used in transportation to evaluate and compare different transport modes or routes based on multiple criteria, such as travel time, cost, and environmental impact.

In recent years, research has also been conducted in the disciplines of managerial and strategic planning, project management and assessment, manufacturing and assembly, water and energy management, agriculture, and forestry management.

As a result, the application of MCDM techniques can assist decision-makers in reaching better informed and transparent conclusions that are founded on a thorough analysis of the available options. These illustrations can be used to a variety of daily decision-making circumstances (Toloie-Eshlaghy and Homayonfar, 2011).

The use of MCDM methods is particularly relevant in complex decision-making problems where there are multiple stakeholders with different preferences and objectives. MCDM methods can help to facilitate the identification and clarification of these preferences and objectives, and to assess the performance of different alternatives based on them.

The main benefits of using MCDM methods include:

Providing a systematic and transparent approach to decision-making that considers multiple criteria or objectives.

Helping decision-makers to clarify their preferences and objectives, and to assess the performance of different alternatives based on them.

Facilitating stakeholder involvement and participation in the decision-making process.

Supporting the identification and exploration of different scenarios and trade-offs.

Providing a structured approach to dealing with uncertainty and risk.

While MCMD has several advantages, such as taking into account multiple criteria, it also has some disadvantages, including:

Complexity: MCMD involves evaluating multiple criteria, which can make the decision-making process more complex and time-consuming.

Subjectivity: MCMD is highly subjective as it depends on the criteria and their relative importance, which can vary from person to person.

Data quality: MCMD relies on accurate and reliable data for each criterion. If the data used in the evaluation is inaccurate or incomplete, it can lead to wrong conclusions.

Lack of transparency: The decision-making process in MCMD can be complicated, and it may be challenging to explain to stakeholders how the final decision was reached.

Difficulty in weighing criteria: Assigning weights to different criteria can be challenging and may require significant effort and subjectivity.

Interpretation of results: The results of MCDM methods can be difficult to interpret, particularly if the analysis involves multiple criteria or alternatives. It can be challenging to understand the implications of the rankings or choices produced by MCDM methods.

Time and resource-intensive: MCDM methods can be time and resource-intensive, particularly if the decision-making problem is complex or involves multiple stakeholders. The use of MCDM methods may require a significant investment of time and resources to implement effectively.

Overall, the disadvantages of MCDM methods need to be carefully considered against the potential benefits, and the choice of method should be based on the specific decision-making problem and the available data and resources. MCDM methods are useful tools for decision-makers who need to evaluate and compare alternatives based on multiple criteria or objectives, and to make informed and transparent decisions (Bouyssou, 1986).

3 LITERATURE REVIEW

There are several studies related with industrial symbiosis and DEMATEL applications in the literature. As a result of the literature review, it was seen that the number of studies specific to the analysis with the DEMATEL method is quite low. Studies in the form of questionnaires and surveys have been carried out and qualitative results have been obtained. These studies were not evaluated with a mathematical model and took their place in the literature as verbal studies.

Specifically, verbal evaluation and qualitative analysis are the foundations of current studies in the field of industrial symbiosis. By gathering the findings of the qualitative analysis in the literature, the quantitative analysis in this study was carried out with the use of a mathematical model. Thanks to this feature, it is aimed that this study fills the gaps in the literature. In this way, it is desired to obtain results that will be a step in taking more precise results and taking steps for the future.

As seen in the below table, the dating of the works is not based on old times, but rather recent. As such concepts gain importance, the diversity of these studies is also increasing.

Table 3.1: Overall Summary Table of DEMATEL used Studies

Authors	Year	Objective of the Study	Methods Used
Bacudio et al.	2016	Identify and analyzing barriers to the adoption of industrial symbiosis in the industrial park of Laguna, Philippines.	DEMATEL
Castro et al.	2022	Determining the barriers to the implementation of integrated biorefineries in the Philippines.	DEMATEL

Hariharan et al.	2021	Risk assessment of a Indian cement industry to improve risk profile.	DEMATEL
Jayakrishna et al.	2020	Analyzing key variables of manufacturing firms in India that can improve corporate performance in a symbiotic industrial environment.	DEMATEL
Gardas et al.	2018	Modeling the difficulties with sustainability in the Indian textile and apparel (T&A) industry by using the Delphi-DEMATEL technique.	Delphi-DEMATEL
Taqi et al.	2022	Utilizing the DEMATEL approach and examining the causal links to model the IS issues in the context of a growing economies.	DEMATEL
Bhatia and Srivastava	2018	Identifying and evaluating external barriers to remanufacturing in Indian electronic waste (e-waste) sector.	Grey-DEMATEL
Sivakumar et al.	2018	Understanding and analyzing the barriers that hinder the use of sustainable end-of-life approaches.	DEMATEL
Farooque et al.	2019	Seeking to uncover and comprehensively examine the causal effect by using decision-making approaches between supply chain barriers to China's circular food production.	Fuzzy DEMATEL

Kayikci et al.	2021	Introducing the idea of a Smart and Sustainable Circular Economy (SSCE) and looking into an Eco-Cluster for small and medium-sized businesses in the automotive sector.	Fuzzy DEMATEL
Sharma et al.	2023	Proposing a methodology to analyze the major barriers to India’s oil & gas industry existing and offer solutions.	Fuzzy DEMATEL and BWM
Islam and Kumar	2021	Specifying the ten major barriers towards the adoption of circular economy to support developing strategies.	DEMATEL
Xia and Ruan	2020	Specifying critical barriers for the government, farmers, and enterprises to develop circular agriculture to suggest policies in China.	Grey-DEMATEL
Chen et al.	2021	Filling the gaps by analyzing the barriers and relationships to the CE in the textile industry.	Fuzzy Delphi Method-DEMATEL

4 APPLICATION

When the enablers and barriers of industrial symbiosis are investigated in the literature, the results frequently encountered are compiled in the tables below. The studies carried out are for different application areas and are not specific to the chemical sector. In this study, the effects of these criteria in the chemical industry will be examined.

4.1 Enablers of Industrial Symbiosis

The main enablers encountered in applying industrial symbiosis in the literature are summarized in the below.

E1 - Geographic proximity of industries

E2 - Common resource use (energy, water, etc.)

E3 - Regulatory policies/ policy support

E4 - Social responsibility

E5 - Resource constraints

E6 - Access to new markets

E7 - Financial incentives

E8 - Shared environmental goals

E9 - Stakeholder participation

E10 - Presence of successful cases of implemented

E11 - Diversity of nearby industries

E12 - Creating new job opportunities

E13 - Reducing operational costs

The table below represents which publication the criteria are based on.

Table 4.1: Enablers Summary Table

Abbrev.	Enabler	Description	References
E1	Geographic proximity of industries	Geographical proximity is often seen as a prerequisite for companies that plan to cooperate.	Henriques et al., (2021), Taddeo et al. (2017) Farooque et al. (2019)
E2	Common resource use	The use of common resources between companies may be necessary in cases where access to the same resource is required.	Chertow (2007) (La Rosa and Ramakrishna, 2021)
E3	Regulatory policies/ policy support/legislation	Another issue cited as encouraging the adoption of IS is compliance with laws intended to safeguard the environment.	Zhao, Boom-Cárcamo and Peñabaena-Niebles (2022)
E4	Social responsibility	It is possible to uphold social responsibility, company morale, environmental standards, and needs of an environmental management system.	Ji, Boom-Cárcamo and Peñabaena-Niebles (2022)
E5	Resource constraints	In order to overcome the asymmetry between supply and demand, technical measures must be taken, such as the creation of	Yeo et al. (2019), Boom-Cárcamo and Peñabaena-Niebles (2022)

		tools for information sharing and network optimization for the exchange of materials.	
E6	Access to new markets	As the new networks planned to be formed will create new opportunities, access to different markets may occur.	Henriques et al., (2021),
E7	Financial incentives	Since one of the priorities of any business to be established will be to reduce its costs, financial incentives will be necessary.	Bacudio et al. (2016) , Liu and Bae (2018)
E8	Shared environmental goals	It is possible to meet the standards of social responsibility and environmental requirements from the perspective of the company's and employees' high environmental awareness.	Ji et al. (2020)
E9	Stakeholder participation	Stakeholder enthusiasm to join networks is essential for networks to form and develop.	Taddeo et al. (2017), Neves et al., (2019)
E10	Presence of successful cases of implemented	Any successful example of the synergy that exists will create a positive perception among companies increase participation.	Neves et al., (2019)
E11	Diversity of industries	The predominance and diversity of certain types of industry within countries can also be a driving factor for the creation of industrial symbiosis networks.	Neves et al., (2019)

E12	Creating new job opportunities	The inclusion of new revenues through the integration of new products and services with synergy will be advantageous.	Henriques et al., (2021), Fraccascia and Giannoccaro (2020)
E13	Reducing operational costs	Since each new network to be established can cover all partnerships, including logistics and human resources, it provides a reduction in operational costs.	Sellitto et al. (2021), Huang et al. (2020)

4.2 Barriers of Industrial Symbiosis

The main enablers encountered in applying industrial symbiosis in the literature are summarized in the below.

B1 - Lack of companies to provide and receive waste

B2 - Lack of legislation and policies

B3 - Different organizational cultures

B4 - Lack of trust and communication problems

B5 - Conflicts of interest and competition for resources

B6 - Lack of technology availability and integration problems

B7 - Social and economic instabilities of countries

B8 - Complexity of process

B9 - Uncertainty of profitability and risks

B10 - Fear of dependence

B11 - High initial costs of infrastructure and equipmant

B12 - Lack of awareness and knowledge about opportunities

B13 – Lack of participative network and limited willingness to collaborate

The table below indicates which publication the criteria are based on.

Table 4.2: Barriers Summary Table

Abbrev.	Barrier	Description	References
B1	Lack of companies to provide and receive waste	It is a situation that binds companies together as the potential to receive or provide waste will directly affect the production of each company.	Wolf et al. (2005)
B2	Lack of legislation and policies	The fact that legislation and policies do not impose heavy taxes or sanctions on companies constitutes an obstacle to transitioning to an environmentalist order.	Sakr et al. (2011), Bacudio et al. (2016), Ji et al. (2020)
B3	Different organizational cultures	Having different organizational cultures can cause managerial and social problems when cooperation between companies.	Taddeo et al. (2017)
B4	Lack of trust and communication problems	The exchange of waste characteristics across businesses is hindered by a lack of trust and communication, which eliminates any chance of recycling.	Kosmol (2019),Walls and Paquin (2015)

B5	Conflicts of interest and competition for resources	In any synergy that will occur, positive or negative results will affect all parties, so a conflict of interest may occur.	Neves et al., (2019)
B6	Lack of technology availability and integration problems	Existing technological developments may not be sufficient to establish a network and there may be incompatibilities in terms of integration.	Dong et al. (2017), Neves et al., (2019)
B7	Social and economic instabilities of countries	In countries with fluctuating economies, all kinds of investments and initiatives bring about future uncertainty.	Salvia et al. (2019)
B8	Complexity of process	As the number of companies planned to join the symbiosis network increases, the system becomes more complex and the planning part becomes more important.	Gardas et al. (2018)
B9	Uncertainty of profitability and risks	The fact that all kinds of profits and losses of companies depend on the success of their cooperation with each other will be an uncertainty for the company that does not fully understand the operation of other companies.	Domenech et al. (2019), Aid et al. (2017)
B10	Fear of dependence	There is a dependency situation for companies whose production and income depend on waste from another company.	Neves et al., (2019)

B11	High initial costs of infrastructure and equipmant	Sustainable by-product exchange requires a well-built infrastructure such as roads and communication networks.	Boom-Cárcamo and Peñabaena-Niebles (2022), Li et al. (2015)
B12	Lack of awareness and knowledge about opportunities	Companies that do not realize what industrial symbiosis is and the opportunities it will create will be deprived of the advantages that may arise.	Patricio et al. (2018), Golev et al. (2015)
B13	Lack of participative network and limited willingness to collaborate	Lack of alliance, communication, and harmony among the stakeholders can hinder any possibility and development of cooperation.	Herczeg et al. (2018), Henriques et al., (2021)

5 PROPOSED METHODOLOGY

A systematic design approach is needed to facilitate the successful implementation of industrial symbiosis networks. Nonetheless, the first step is to properly identify potential enablers and barriers to success. After a comprehensive literature review, 13 priority barriers to industrial symbiosis are listed. After that, a proper questionnaire was prepared in the form of a matrix was prepared for people with different experiences working in different companies and positions in the chemical industry in Turkey. The prepared matrix is created with a scoring system consisting of dual evaluations of enablers and barriers.

According to the results of the questionnaire, important criterias were purposed to use in multi-criteria decision-making approaches. There are several examples are found in literature that use DEMATEL (Decision Making Trial and Evaluation Laboratory) method. DEMATEL is a method for figuring out how various aspects relate to one another in order to adequately comprehend the issue. This method's advantage is that it evaluates each criterion twice and determines which one is more important than the other. Stakeholders can use the study's findings to develop initiatives that concentrate on solving the core enablers and barriers to developing sustainable IS networks.

A tool for problem structuring called Decision Making Trial and Evaluation Laboratory (DEMATEL) is primarily used to specify the cause-and-effect relationship between the problem criteria. The DEMATEL approach, one of the best methods for visual representation, was created to help people deal with complex issues by creating a diagram between the issues' contributing aspects and appropriately analyzing solutions. (Fontela and Gabus, 1976). There are several steps to follow.

Step1 - Generating the direct-relation matrix by using the linguistic variable table. In the first stage, an answer is sought to the question at what level the criteria affect each other while creating the matrix. Decision makers constitute pairwise comparisons between criteria by using Table 1 shown in belowings.

Table 5.1: Linguistic variables for the importance-weight

Linguistic variable	Values
No influence	0
Very low influence	1
Low influence	2
High influence	3
Very high influence	4

As a result, the direct-relation matrix that is a nxn (dimensional) matrix A_k is obtained. The matrix A_k is obtained from each expert where each element a_{ijk} symbolizes the influence of barrier i over j and n indicates the total number of factors considered. Zero should be noted in the main diagonal elements of matrix A. Which means factors do not have influence on itself.

$$A_k = \begin{bmatrix} 0 & a_{12k} & a_{13k} & \cdots & a_{1(n-1)k} & a_{1nk} \\ a_{21k} & 0 & a_{23k} & \cdots & a_{2(n-1)k} & a_{2nk} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{(n-1)1k} & a_{(n-1)2k} & a_{(n-1)3k} & \cdots & 0 & a_{(n-1)nk} \\ a_{n1k} & a_{n2k} & a_{n3k} & \cdots & a_{n(n-1)k} & 0 \end{bmatrix}$$

Step 2 – The following is how the total direct relationship matrix A is obtained. This action incorporates all experts' opinions.

$$A = \frac{[a_{ij}]}{k}$$

In problems where ‘k’ (number) decision-makers are found, the elements of the direct relations matrix are the average of the results of ' k ' decision makers. In this case, the new matrix A is obtained by using all decision makers' direct relation matrix results average. According to that, some sources in the literature, A matrix is also named an average matrix.

where A is the overall direct relation matrix; a_{ij} the average of a_{ijk} of all experts; and k total number of experts (Sivakumar et al. 2018).

Step 3 – The normalized overall direct-relation matrix is obtained by using required equation.

$$X = [b_{ij}]_{nxn} = \frac{A}{\max\limits_{1\leqslant i\leqslant n} \sum_{j=1}^{n} a_{ij}}, \text{ where } 0 \leqslant b_{ij} \leqslant 1$$

After this step, X is obtained that normalized overall direct relation matrix.

Step 4 – The total relation matrix T is obtained by using normalized overall matrix.

$$T = [t_{ij}]_{n\times n} = X[I - X]^{-1}$$

I is denoted as an identity matrix and T total relation matrix.

Step 5 – Within the total-relation matrix, the sum of the rows and the sum of the columns are calculated as shown below and are designated separately as R and C. (Dikmen and Taş, 2018) :

$$R = [r_{ij}]_{nx1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{nx1}$$

$$C = [c_{ij}]_{1xn} = \left[\sum_{i=1}^{n} t_{ij}\right]_{1xn1}$$

Step 6 - A causal diagram is drawn by mapping the values of $(R_{ij} + C_{ij}, R_{ij} - C_{ij})$, where the horizontal axis implies to the values of $(R_{ij} + C_{ij})$ while the vertical axis implies to the values of $(R_{ij} - C_{ij})$. This is also known prominence–causal relationship diagram. (Wu and Lee, 2007).

In the first step, enablers and barriers are identified and a matrix is prepared for the progress of the research. Matrices containing the prepared binary evaluations are filled by the decision makers. Then, priority criteria are calculated according to the decision makers working in each field. In order to obtain an integrated result of the calculated criteria, the social function choice is applied and the final results are obtained.

In summary, a comprehensive literature review on the subject was made and the necessary criteria were determined. In this regard, a sufficiently detailed matrix questionnaire was created and the decision makers in different positions and expertise in the sector were contacted and the matrices were resolved. The results at this point are quite subjective and results are closely related to the past experiences of the decision makers. Although the results obtained are similar to a point, quite a variety of results have been obtained. 15 decision makers results were compiled then results were interpreted.

After all these theoretical explanations, the framework of the study is summarized as follows.

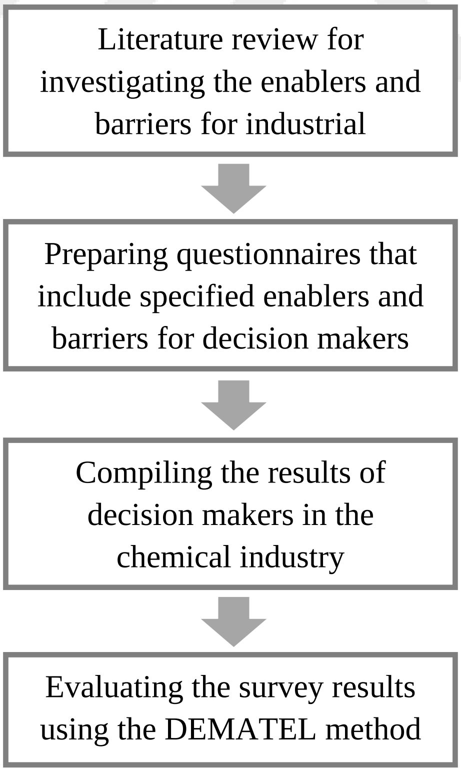

Figure 3.8: Framework of the study

6 RESULTS & DISCUSSION

The matrices answered by the decision makers in a scaled from 0 to 4 are applied using Excel and result tables were obtained. 15 decision makers from chemical production sectors were attended to the survey. After the compiling results main enablers and barriers of industrial symbiosis was emerged.

After calculating and analyzing all these results, the most important ones among 13 enablers and barriers were determined.

Table 6.1: Results compilation of enablers

	D	R	D+R	D-R
E1	6.341903	5.810582	12.15249	0.531321
E2	6.189426	6.266326	12.45575	-0.0769
E3	5.288242	5.412298	10.70054	-0.12406
E4	5.531932	5.712928	11.24486	-0.181
E5	6.143129	6.181716	12.32484	-0.03859
E6	5.12584	5.696936	10.82278	-0.5711
E7	6.752949	5.826477	12.57943	0.926471
E8	6.651578	6.299665	12.95124	0.351913
E9	5.63736	6.070792	11.70815	-0.43343
E10	5.900695	5.607508	11.5082	0.293187
E11	5.719207	5.623445	11.34265	0.095762
E12	5.011101	6.17625	11.18735	-1.16515
E13	6.063495	5.671934	11.73543	0.391561

According to the table, the option with the highest D+R value is the one that has the most impact. E8, E7 and E2 are the most influential enablers that support industrial symbiosis in Turkey respectively.

There are some strategies it can take to advance common environmental goals, which emerge as the most important enablers. Some of these are the use of green technologies, waste management and recycling, sustainable raw material supply, carbon dioxide emissions reduction efforts, sustainability steps in product design, and participation in joint R&D projects. When it comes to the use of green technologies, they can encourage the use of technologies that will leave less environmental impact in production processes by switching to renewable energy sources. Regarding waste management and recycling, encouraging recycling processes to effectively manage plastic waste will enable waste to be minimized and a transition to a sustainable production model. Regarding sustainable raw material Supply, they can encourage the use of environmentally friendly materials by collaborating with sustainable raw material suppliers to increase the use of recycled materials. Companies can use techniques and technologies that minimize greenhouse gas emissions by increasing energy efficiency to reduce carbon dioxide emissions in their production processes. In the design of the products to be produced, it is important to investigate alternatives that facilitate recycling and provide the same function while using less plastic. For this purpose, emphasis can be given to biodegradable or biocompotable alternatives. In terms of developing Joint R&D projects, it is possible for different companies in the chemical industry to come together and develop innovative solutions on sustainability by carrying out joint R&D projects. This will provide the opportunity to establish more solid and open communication-based partnerships. Companies can also document the environmental impacts of their production processes by complying with environmental certifications and standards. This situation can set an example for other manufacturing companies and lead to cooperation possibilities. All of these can be among the strategies that factories operating in the plastics industry can apply to improve their environmental goals.

Companies engaged in chemical production in Turkey can take some steps to benefit from financial incentives, which are the second most important enabler. They can evaluate possibilities such as obtaining an investment incentive certificate, preparing project reports, evaluating regional incentive opportunities, benefiting from employment creation and vocational training incentive opportunities, and recycling projects. It is important to prepare a project report for financial incentives. This report should include details of the investment to be made, its economic and environmental impacts, employment creation potential and other important information. Special R&D incentives may be available for

R&D investments for manufacturing companies. Regions in Turkey offer different incentives depending on their level of development. Regional incentives can be benefited from, especially considering the development needs of the region where the investment will be made. Energy efficiency is becoming more important day by day, and investments to increase energy efficiency both reduce energy costs and minimize environmental impacts. As mentioned about the common environmental objectives, which is the first important enabler, when compliance with environmental standards is documented with some certifications, it may provide the right to various environmental incentives. Investments made in waste management, recycling and environmental sustainability can be evaluated in this context. Similarly, social responsibility projects such as employment creation projects and vocational training programs can help obtain some incentives. Recycling Projects are an important step towards reducing environmental impacts, especially in places where chemical production is carried out. R&D and innovation investments in an area that is very open and suitable for development in our country, such as industrial symbiosis, can be encouraged especially for technological development and competitiveness.

The third enabler that encountered is the use of common resources. There are some steps that can be taken to support the use of common resources such as water and energy, especially by factories producing chemicals in Turkey. Factories operating in the chemical industry can create industrial symbiosis platforms to support and encourage industrial symbiosis. These platforms enable resource exchange and collaboration between different industries. Similarly, by creating collaboration networks, they can collaborate with other industries to optimize the use of shared resources such as water and energy. In the first stage, these networks start with 2 or more companies and if they are successful, they can gradually grow with the participation of other companies in the environment. It is important to promote successful industrial symbiosis projects and encourage other chemical production factories, especially the plastics industry, to adopt this concept. The common resource to be used need not only be raw materials, but also common training and information sharing should be provided. To embrace and implement the concept of industrial symbiosis, it is important to promote the sharing of knowledge and experience between factories. It would be useful to organize joint training programs and share experiences.

Table 6.2: Results compilation of barriers

	D	R	D+R	D-R
B1	11.92462	11.31792	23.24253	0.606701
B2	11.77868	11.00235	22.78103	0.77633
B3	10.26727	9.90138	20.16865	0.365889
B4	12.08043	10.71645	22.79688	1.363974
B5	11.43111	11.82093	23.25204	-0.38981
B6	12.10507	11.64709	23.75217	0.457982
B7	11.32133	12.47149	23.79282	-1.15016
B8	9.194836	10.99404	20.18887	-1.7992
B9	11.59979	12.81719	24.41698	-1.2174
B10	11.61868	11.44221	23.06089	0.176473
B11	10.76254	11.35275	22.11529	-0.59021
B12	12.36788	11.12932	23.49721	1.238561
B13	11.81796	11.65708	23.47504	0.160887

According to the table, the option with the highest D+R value is the one that has the most impact. B9, B7 and B6 are the most remarkable barriers that hinders development of industrial symbiosis in Turkey respectively.

The common concern of all manufacturing companies is to cause less harm to the environment in the face of depleting resources and to gain economic profit. Training that will highlight the environmental and economic benefits and bringing to light both the environmental and economic benefits of industrial symbiosis practices may encourage factories to pay more attention to this concept. Several ways to enhance industrial symbiosis were discussed in light of the first three enablers.

As with the enablers, barriers were also analyzed in order of importance. When the barriers are listed as a result of the analysis, it is seen that the first barrier encountered is the uncertainty of profitability and risks. With risk analysis and management, companies should conduct a detailed risk analysis and manage these risks effectively to reduce profitability and uncertainty of risks. It is important to identify potential financial, operational and environmental risks and take necessary precautions. They can be prepared for economic uncertainties by providing financial management and taking financial measures such as controlling liquidity, budget management and cost reduction strategies. Industrial symbiosis projects often require a long-term perspective. Companies should make long-term planning, try to foresee potential risks and create profitability strategies. Industrial symbiosis networks enable businesses to be more resilient to economic fluctuations. Common source use can increase the financial resilience of businesses by reducing costs. By researching alternative financing sources, factories should investigate different financing sources to finance their projects. Different financing options such as private sector funds, government incentives and grant programs can be evaluated. It is important to ensure a more efficient and competitive production process by following technological developments by investing in technological advances. This can increase profitability and reduce risks. By establishing strategic partnerships and collaborations, it is possible to cooperate with other companies, share risks and manage industrial symbiosis projects together. By receiving training and consultancy support, companies may get training on the concept of industrial symbiosis, especially by contacting people who have played a role in successful examples abroad. Similarly, the coming together of businesses from different sectors encourages the sharing of technological knowledge and experience. This can increase the technological capacity of factories participating in industrial symbiosis networks. In this way, uncertainties and risks can be minimized. In addition, industrial symbiosis networks can diversify the risks of businesses because they bring together companies that produce in different fields. Finally, they can minimize risks by working with legal experts by receiving legal consultancy and risk management services.

The second barrier is the social and economic instability of the countries. The precautions that can be taken and the suggestions that will support participation in industrial symbiosis are similar to the moves that can be made in case of uncertainty of risks and profitability. In addition, businesses from different industries serve different markets and customer groups, which can spread the businesses' risks and create a more balanced portfolio. Another possibility is that they can be more resistant to economic instability by opening up to international markets, engaging in foreign trade, and taking measures against fluctuations in exchange rates. In order to quickly adapt to economic changes, companies need to develop flexibility and quick decision-making abilities.

Third barrier that encountered in industrial symbiosis applications in Turkey is lack of technologic availabilities and integration problems. A comprehensive assessment of existing technologies should be conducted and areas where improvements or investments may be required should be identified. A risk assessment should be conducted to identify potential challenges and develop contingency plans to address technology-related issues. To support this situation, training programs can be provided to employees to improve their technical skills and knowledge in areas related to industrial symbiosis. In order to have up-to-date information about emerging technologies, it is necessary to participate in industry associations, conferences and workshops. The lack of technology can be overcome through international collaborations and technology transfer. They can promote innovation by collaborating with universities and research institutions. Technologies that are compatible and efficient with the goals of industrial symbiosis should be adopted. By taking these precautions, companies can mitigate the challenges associated with a lack of technological opportunities and integration problems, allowing them to participate more effectively in industrial symbiosis networks. It's important to approach technology adoption strategically and consider the specific needs and capabilities of the organization

7 CONCLUSION

Sustainability means meeting our own needs without compromising the ability of future generations to meet their own needs. Sustainability is not just about the environment. Social and economic resources have the same importance as natural resources.

The circular economy has emerged over the past two decades as a concept that offers solutions to some of the sustainable development challenges. Industrial symbiosis is one of the resource efficiency models that incense sustainable development. However, the adoption of a circular economy, sustainable development, and industrial symbiosis requires a systemic change in our economic, social, and political systems. As a result, various business models such as industrial symbiosis have been defined as significant tools for sustainable development.

Wastes or byproducts from one industrial process can become the starting point for another through a process known as industrial symbiosis. Cooperation between the raw material and energy industries benefits firms in terms of the economy, environment, and society. Due to issues with the availability of resources, IS applications have become increasingly common, particularly in the decade preceding. In IS applications, complex network structures appear. To efficiently sustain the industrial symbiosis network in this complex system, several decision difficulties must be solved. Techniques from operations research are at the forefront of approaches to decision-making.

The decision-making process that goes along with real-world situations is just as complicated as the problems themselves. Therefore, certain effective methods that highlight the ideal option are needed. After extensive investigation, it has been found that studies in the IS emphasis on the exchange of matter and energy. However, businesses are unable to focus only on the interchange of materials and energy in the current competitive market and with technological advancements. A company's manufacturing resources, including its financial, logistical, and mechanical equipment, may also alter. As a result, it should be thought about sharing these elements for operational processes throughout the IS network. This highlights the areas that require further attention.

Within the scope of this research, 15 decision makers working in chemical production companies in Turkey were consulted and the enablers and barriers to industrial symbiosis were analyzed. DEMATEL, one of the multi-criteria decision-making methods, was used to analyze the results resulting from differences such as the decision makers' experience and job definitions. The most important reason for choosing this method is that it is a decision-making method based on pairwise comparison.

Considering Turkey's economy, it has been seen that the most important barrier is the uncertainty of profitability and risks. Firms are hesitant to tie the conditions that will enable them to continue their production to another firm. Likewise, the social and economic instability of countries has an impact in such cases. If the companies that provide and receive waste are not sufficient to support each other's production as a resource, this is one of the obstacles to industrial symbiosis. Limited cooperation and lack of a participatory network also have to be resolved for continuous production.

To sum up conducting awareness campaigns and educational programs to inform businesses about the benefits and potential of industrial symbiosis, providing financial incentives, grants, or subsidies for businesses engaging in industrial symbiosis practices, facilitating the transfer of relevant technologies and knowledge between industries to enable effective resource sharing, encouraging research and development activities focused on sustainable and resource-efficient technologies, support pilot projects and demonstration initiatives to showcase successful examples of industrial symbiosis in the chemical production sector is important to achieve goals in industrial symbiosis.The chemical sector can considerably benefit from the application of IS as it is sustainable development. According to the literature, establishing EIPs is crucial for the chemical industry to build and improve IS, and there is a close relationship between IS and chemical industry safety issues. By implementing industrial symbiosis, the chemical industry can gain both economic and environmental benefits.

The main purpose of this entire study was to identify the gaps in the literature and to carry out a study to fill it. It is hoped that it will form the basis for further studies and illuminate the way. Studies in this field can be designed to fill the gaps and exceed the limits of this study. Working with more decision makers and performing analyzes using more criteria may be some of them. Also, MCDM method may be change or create a new method to evaluate results. All can be possible in the future works.

REFERENCES

Aid, G.; Eklund, M.; Anderberg, S.; Baas, L. Expanding roles for the Swedish waste management sector in inter-organizational resource management. Resour. Conserv. Recycl. 2017, 124, 85–97.

Alkaya, E., Böğürcü, M., & Ulutaş, F. (2014). Industrial symbiosis in Iskenderun Bay: A journey from pilot applications to a national Program in Turkey. *Technology Development Foundation of Turkey*, 1-8.

Álvarez, R.; Ruiz-Puente, C. Development of the Tool SymbioSyS to support the transition towards a circular economy based on industrial symbiosis strategies. Waste Biomass Valoriz. 2017, 8, 1521–1530.

Bacudio, L. R., Benjamin, M. F. D., Eusebio, R. C. P., Holaysan, S. A. K., Promentilla, M. A. B., Yu, K. D. S., & Aviso, K. B. (2016). Analyzing barriers to implementing industrial symbiosis networks using DEMATEL. *Sustainable Production and Consumption*, *7*, 57-65.

Bhatia, M. S., & Srivastava, R. K. (2018). Analysis of external barriers to remanufacturing using grey-DEMATEL approach: An Indian perspective. *Resources, Conservation and Recycling*, *136*, 79-87.

Boom-Cárcamo, E., & Peñabaena-Niebles, R. (2022). Analysis of the Development of Industrial Symbiosis in Emerging and Frontier Market Countries: Barriers and Drivers. *Sustainability*, *14*(7), 4223.

Bouyssou, D. (1986). Some remarks on the notion of compensation in MCDM. European journal of operational research, 26(1), 150-160.

Brundtland, G. H., Khalid, M., Agnelli, S., Al-Athel, S. A., Chidzero, B. J. N. Y., Fadika, L. M., ... & Singh, N. (1987). Our common future; by world commission on environment and development.

Castro, Y. K. G., Manalo, B. P., Saunar, N. B., Belmonte, B. A., Andiappan, V., & Benjamin, M. F. (2022). A DEMATEL Approach to Analyzing Barriers t

Implementing Integrated Biorefineries in the Philippines. *Chemical Engineering Transactions*, *97*, 1-6.

Chen, W. K., Nalluri, V., Hung, H. C., Chang, M. C., & Lin, C. T. (2021). Apply DEMATEL to analyzing key barriers to implementing the circular economy: an application for the textile sector. *Applied Sciences*, *11*(8), 3335.

Chertow, M. R. (2007). “Uncovering” industrial symbiosis. *Journal of industrial Ecology*, *11*(1), 11-30.

Cudečka-Puriņa, N., Atstāja, D., Koval, V., Purviņš, M., Nesenenko, P., & Tkach, O. (2022). Achievement of sustainable development goals through the implementation of circular economy and developing regional cooperation. *Energies*, *15*(11), 4072.

Cui, H., & Liu, C. (2017, July). Applying industrial symbiosis to chemical industry: A literature review. In *AIP Conference Proceedings* (Vol. 1864, No. 1, p. 020090). AIP Publishing LLC.

Cui, M. (2021). Key Concepts and Terminology. *An Introduction to Circular Economy*, 17-34.

Dalbudak, E., & Rençber, Ö. F. (2022). Çok Kriterli Karar Verme Yöntemleri Üzerine Literatür İncelemesi. Gaziantep Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi, 4(1), 1-17.

Domenech, T.; Bleischwitz, R.; Doranova, A.; Panayotopoulos, D.; Roman, L. Mapping industrial symbiosis development in Europe_ Typologies of networks, characteristics, performance and contribution to the circular economy. Res. Conserv. Recycl. 2019, 141, 76–98.

Dong, L.; Liang, H.; Zhang, L.; Liu, Z.; Gao, Z.; Hu, M. Highlighting regional eco-industrial development: Life cycle benefits of an urban industrial symbiosis and implications in China. Ecol. Model. 2017, 361, 164–176.

Ehrenfeld, J. R., & Chertow, M. R. (2002).

27. Industrial symbiosis: the legacy of Kalundborg. A handbook of industrial ecology, 334.

Emas, R. (2015). The concept of sustainable development: definition and defining principles. *Brief for GSDR*, *2015*, 10-13140.

Farooque, M., Zhang, A., & Liu, Y. (2019). Barriers to circular food supply chains in China. *Supply Chain Management: An International Journal*, *24*(5), 677-696.

Fraccascia, L., & Giannoccaro, I. (2020). What, where, and how measuring industrial symbiosis: A reasoned taxonomy of relevant indicators. *Resources, conservation and recycling*, *157*, 104799

Frosch, R. A., & Gallopoulos, N. E. (1989). Strategies for manufacturing. *Scientific American*, *261*(3), 144-153.

Gardas, B. B., Raut, R. D., & Narkhede, B. (2018). Modelling the challenges to sustainability in the textile and apparel (T&A) sector: A Delphi-DEMATEL approach. *Sustainable Production and Consumption*, *15*, 96-108.

Gardas, B. B., Raut, R. D., & Narkhede, B. (2018). Modelling the challenges to sustainability in the textile and apparel (T&A) sector: A Delphi-DEMATEL approach. *Sustainable Production and Consumption*, *15*, 96-108.

Golev, A., Corder, G.D., Giurco, D.P., 2015. Barriers to industrial symbiosis: insights from the use of a maturity grid. J. Ind. Ecol. 19 (1), 141–153. https://doi.org/10.1111/jiec.12159.

Greco, S., Matarazzo, B., & Slowinski, R. (1999). The use of rough sets and fuzzy sets in MCDM. Multicriteria decision making: Advances in MCDM models, algorithms, theory, and applications, 397-455.

Hariharan, B., Kathiravan, A., Jambunathan, K., & Bathrinath, S. Analysing of Environmental Issues Of Cement Industries Using DEMATEL (MCDM) Method.

Henriques, J., Azevedo, J., Estrela, M., & Dias, R. (2022). Relating Industrial Symbiosis and Sustainable Development Goals. *Materials Proceedings*, *5*(1), 111.

Henriques, J., Ferrão, P., Castro, R., & Azevedo, J. (2021). Industrial symbiosis: a sectoral analysis on enablers and barriers. *Sustainability*, *13*(4), 1723.

Herczeg, G., Akkerman, R., Hauschild, M.Z., 2018. Supply chain collaboration in industrial symbiosis networks. J. Clean. Prod. 171, 1058–1067. https://doi.org/

Huang, L.; Zhen, L.; Yin, L. Waste material recycling and exchanging decisions for industrial symbiosis network optimization. J. Clean. Prod. 2020, 276, 124073.

Islam, A. U., & Kumar, N. (2021). Analyzing The Barriers For The Shifting Towards Circular Economy In Manufacturing Context: A DEMATEL Approach.

Jackson, T. (2002). Industrial ecology and cleaner production. A handbook of industrial ecology, 36-43.

Jayakrishna, K., KEK, V., Vibha, M., Jain, S., & Kulatunga, A. K. (2020). Fostering systematic eco-innovation in an industrial symbiosis environment using DEMATEL. *International Journal of Industrial and Systems Engineering*, *34*(1), 20-42.

Jeronen, E. (2013). Sustainability and Sustainable Developement. *Encyclopedia of corporate social responsibility*, 2370-2378.

Jeronen, E. (2019). Ecology and Ecosystem: Sustainability. *Encyclopedia of Sustainable Management; Springer Nature: Cham Switzerland*.

Ji, Y.; Liu, Z.; Wu, J.; He, Y.; Xu, H. Which factors promote or inhibit enterprises' participation in industrial symbiosis? An analytical approach and a case study in China. J. Clean. Prod. 2020, 244, 118600.

Ji, Y.; Liu, Z.; Wu, J.; He, Y.; Xu, H. Which factors promote or inhibit enterprises' participation in industrial symbiosis? An analytical approach and a case study in China. J. Clean. Prod. 2020, 244, 118600.

Kalmykova, Y.; Sadagopan, M.; Rosado, L. Circular economy—From review of theories and practices to development of implementation tools. Resour. Conserv. Recycl. 2018, 135, 190–201.

Kayikci, Y., Kazancoglu, Y., Lafci, C., & Gozacan, N. (2021). Exploring barriers to smart and sustainable circular economy: The case of an automotive eco-cluster. *Journal of Cleaner Production*, *314*, 127920.

Klamler, C. (2005). On the closeness aspect of three voting rules: Borda–Copeland–Maximin. Group Decision and Negotiation, 14, 233-240.

Kosmol, L., 2019. Sharing is caring - information and knowledge in industrial symbiosis: a systematic review, 2019. In: IEEE 21st Conference on Business Informatics (CBI), pp. 21–30.

La Rosa, A. D., & Ramakrishna, S. (2021). Industrial symbiosis for circular economy: a possible scenario in Norway. *An Introduction to Circular Economy*, 95-106.

Lens, P. Water Recycling and Resource Recovery in Industry: Analysis, Technologies and Implementation. IWA Publishing. (2002).

Li, J.; Pan, S.Y.; Kim, H.; Linn, J.H.; Chiang, P.C. Building green supply chains in eco-industrial parks towards a green economy: Barriers and strategies. J. Environ. Manag. 2015, 162, 158–170

Li, X., & Li, X. (2018). Industrial Ecology Applications in the Four Areas. *Industrial Ecology and Industry Symbiosis for Environmental Sustainability: Definitions, Frameworks and Applications*, 39-60.

Lifset, R., & Graedel, T. E. (2002). Industrial ecology: goals and definitions. In *A handbook of industrial ecology*. Edward Elgar Publishing.

Liu, X.; Bae, J. Urbanization and industrialization impact of CO2 emissions in China. J. Clean. Prod. 2018, 172, 178–186.

Lozano, R. (2022). Sustainable Development and Sustainability. In *Toward Sustainable Organisations: A Holistic Perspective on Implementation Efforts* (pp. 5-17). Cham: Springer International Publishing.

Maletič M, Maletič D., Gomišček B. (2016). The impact of sustainability exploration and sustainability exploitation practices on the organisational performance: a cross-country comparison. Journal of Cleaner Production.

Maqbool, A. S., Mendez Alva, F., & Van Eetvelde, G. (2018). An assessment of European information technology tools to support industrial symbiosis. *Sustainability*, *11*(1), 131.

McCowan, T., Leal Filho, W., & Brandli, L. (2021). Universities facing climate change and sustainability.

Mirata, M. (2004). Experiences from early stages of a national industrial symbiosis programme in the UK: determinants and coordination challenges. *Journal of Cleaner production*, *12*(8-10), 967-983.

Neves, A., Godina, R., G. Azevedo, S., Pimentel, C., & CO Matias, J. (2019). The potential of industrial symbiosis: Case analysis and main drivers and barriers to its implementation. *Sustainability*, *11*(24), 7095.

Özkan, A., Günkaya, Z., Özdemir, A., & Banar, M. (2018). Sanayide Temiz Üretim Ve Döngüsel Ekonomiye Geçişte Endüstriyel Simbiyoz Yaklaşimi: Bir Değerlendirme. Anadolu University Journal of Science and Technology B-Theoretical Sciences, 6(1), 84-97.

Patricio, J., Axelsson, L., Blom´e, S., Rosado, L., 2018. Enabling industrial symbiosis collaborations between SMEs from a regional perspective. J. Clean. Prod. 202, 1120–1130.

Phua, M. H., & Minowa, M. (2005). A GIS-based multi-criteria decision making approach to forest conservation planning at a landscape scale: a case study in the Kinabalu Area, Sabah, Malaysia. Landscape and urban planning, 71(2-4), 207-222.

Sakr, D.; Baas, L.; El-Haggar, S.; Huisingh, D. Critical success and limiting factors for eco-industrial parks: Global trends and Egyptian context. J. Clean. Prod. 2011, 19, 1158–1169

Salvia, A.L.; Leal Filho, W.; Brandli, L.L.; Griebeler, J.S. Assessing research trends related to sustainable development goals: Local and global issues. J. Clean. Prod. 2019, 208, 841–849.

Sellitto, M.A.; Murakami, F.K.; Butturi, M.A.; Marinelli, S.; Kadel, N.; Rimini, B. Barriers, drivers, and relationships in industrial symbiosis of a network of Brazilian manufacturing companies. Sustain. Prod. Consum. 2021, 26, 443–454.

Sharma, M., Joshi, S., Prasad, M., & Bartwal, S. (2023). Overcoming barriers to circular economy implementation in the oil & gas industry: Environmental and social implications. *Journal of Cleaner Production*, *391*, 136133.

Singh, A., & Malik, S. K. (2014). Major MCDM Techniques and their application-A Review. IOSR Journal of Engineering, 4(5), 15-25.

Sivakumar, K., Jeyapaul, R., Vimal, K. E. K., & Ravi, P. (2018). A DEMATEL approach for evaluating barriers for sustainable end-of-life practices. *Journal of Manufacturing Technology Management*, *29*(6), 1065-1091.

Skorupka, D. (2008). "Identification and Initial Risk Assessment of Construction Projects in Poland." J. Manage. Eng., 120-127

Taddeo, R., Simboli, A., Morgante, A., Erkman, S., 2017. The development of industrial symbiosis in existing contexts. Experiences from three Italian clusters. Ecol. Econ. 139, 55–67.

Taqi, H. M. M., Meem, E. J., Bhattacharjee, P., Salman, S., Ali, S. M., & Sankaranarayanan, B. (2022). What are the challenges that make the journey towards industrial symbiosis complicated?. *Journal of Cleaner Production*, *370*, 133384.

Tekeş, M. (2002). Çok ölçütlü karar verme yöntemleri ve Türk Silahlı Kuvvetleri'nde kullanılan tabancaların bulanık uygunluk indeksli analitik hiyerarşi prosesi ile karşılaştırılması (Doctoral dissertation, Fen Bilimleri Enstitüsü)

Thomsen, C. (2013). Sustainability (world commission on environment and development definition). *Encyclopedia of Corporate Social Responsibility, Heidelberg: Springer*, 2358-2363.

Toloie-Eshlaghy, A., & Homayonfar, M. (2011). MCDM methodologies and applications: a literature review from 1999 to 2009. Research Journal of International Studies, 21, 86-137.

Turhan, E., Kartum, G., & Özdemir, Y. (2018). Sürdürülebilir Üretim ve İşletme Uygulamaları. Bucak İşletme Fakültesi Dergisi, 1(1), 1-15.

Uludag-Demirer, S.; Demirer, G.N. Determination of regional industrial symbiosis opportunities by using relationship mimicking with ESOTA®. Prog. Ind. Ecol. Int. J. 2017, 11, 343–360.

URL-1 https://www.un.org/sustainabledevelopment/development-agenda/

URL-2 https://bebka.org.tr/planlama/bursa-eskisehir-bilecik-bolge-plani-2014-2023/

URL-3 https://gso.org.tr/tr/projeler/gaziantep-endustriyel-simbiyoz-projesi-13.html

URL-4 https://www.skdturkiye.org/turkiye-materials-marketplace

van Beers, D. (2007). Capturing regional synergies in the Kwinana industrial area. *Centre for Sustainable Resource Processing: Kensington, Australia*.

Zhao, X.; Xue, Y.; Ding, L. Implementation of low carbon industrial symbiosis systems under financial constraint and environmental regulations: An evolutionary game approach. J. Clean. Prod. 2020, 277, 124289

BIOGRAPHICAL SKETCH

Sare Naz Çiftçi [illegible] graduated with her bachelor’s degree in Chemical Engineering from Kocaeli University in 2016. One year later, she started Polymer Science and Technology master's degree at İstanbul Technical University. In 2019, she obtained a master's degree. After her graduation, she worked as a purchasing and foreign trade specialist in a rubber factory. She decided to study for a Master of Science Degree in Logistics and Financial Management Program in Industrial Engineering Department at Galatasaray University in 2020. Now she is working as a product registration specialist.