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IMPORTANCE OF INDUSTRIAL SYMBIOSIS STRATEGIES ON ENERGY EFFICIENCY IMPROVEMENT IN ORGANIZED INDUSTRIAL ZONES: KONYA OIZ CASE

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Highlights

- Collecting data to demonstrate the feasibility of industrial symbiosis
- Compiling information about the structure in the region with data visualizations
- Emphasizing the importance of collaborations such as industrial symbiosis and energy efficiency networks on the basis of industrial regions

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ABSTRACT: Industrial symbiosis (IS) refers to the integration and optimization of numerous industrial systems and processes and is inspired by the nature. By allowing the exchange of materials, energy, other resources, byproducts or valuable waste among companies, the goal is to increase resource efficiency and decrease potential waste. In this study, the IS relevant concepts and examples from the literature are briefly discussed, and a survey is conducted in Konya organized industrial zone. The primary obstacle faced during the survey study is the companies' reluctance to communicate and share information. The survey explores the current level of knowledge, existing energy efficiency efforts, and organizations' willingness to address the topic if grants and subsidies are available. Following the survey, exchange opportunities from the literature are compiled, considering the sectoral structure of the selected zone. Sectoral pairings are formed to encourage businesses and to demonstrate applicability and symbiosis opportunities. Hence, outcomes show how industrial symbiosis has an impact on energy and resource efficiency and waste reduction within selected industrial zone. In addition, its connection and relationship with government incentives, investments and energy efficiency networks are also discussed. As a result, it has been found that there is significant symbiosis potential in a growing and developing region like the Konya industrial zone, through sectoral matching of companies. By increasing awareness among companies, providing financial and legal support, and assisting them in setting targets, inter-company symbiosis efforts can be facilitated and expanded.

Keywords: *Industrial Symbiosis*, *Energy Efficiency, Resource Efficiency, Organized Industrial Zones, Waste Reduction*

1. INTRODUCTION

International Energy Agency (IEA) defines energy efficiency (EE) as the primary fuel for a sustainable global energy system [1]. According to Turkish Ministry of Energy and Natural Resources, EE is the process of eliminating energy usage per unit of service or product without affecting production quality, quantity, living standards, or service quality while reducing economic and environmental burdens [2]. EE is one of the key area where we can ensure the essential commitment and effectiveness in resource use, mitigate the effects of climate change-related concerns, generate cost-effective outputs fast, and adopt a circular economy model [1]. It provides continuous development and growth toward the climate goals and shrinks reliance on fuel imports. On top of that, by reducing pressure on fuel markets and the need for expensive and unpredictable investments in additional supply, it offers advantages for energy security, particularly as the world moves toward a decarbonized energy system. It is an undeniable and useful instrument in many policies and strategies to address consumer vulnerability in the face of high and volatile fuel prices and pressure in the energy market [3].

EE efforts in the industrial sector, in particular, create an environment with several potential benefits. EE initiatives in industry, both active and potential, could minimize energy consumption in processes so that cutting energy costs. Concurrently, these activities may assist minimize the environmental impacts and emissions connected with these processes. Furthermore, they can improve energy supply security by reducing energy usage for the same processes and creating an atmosphere that encourages the adoption of new technologies and innovations [4].

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On this basis businesses must review and update their methods of operation to promote not only energy but also other resources. They should also shift to long-term business models that rely on collaborations [5]. Prioritizing issues like boosting resource efficiency, generating value from waste, repurposing corporate operations for social and environmental benefits, and substituting natural processes and renewable resources rather than current ones are all important when developing sustainable business models. As the pressure for sustainability increases, the need for companies and stakeholders to work together, whether compulsory or voluntarily, has become more important for value creation than individual efforts [6]. Therefore, collaborative efforts such as industrial symbiosis (IS) and energy efficiency networks (EEN), which rely on cooperation and collective action, represent methodologies that can be employed to achieve the desired outcomes [7], [8].

Symbiosis can be defined as a biological interaction and mutual benefit that occurs between different organisms that are either close or distant from each other in nature [9]. Industrial symbiosis, on the other hand, can be described as practices where businesses imitate natural life and adapt it to the industrial environment, based on the exchange of information, energy, and resources. Stated differently, industrial symbiosis is the process of rethinking resources, goods, and manufacturing techniques to maximize efficiency while delivering positive effects on the environment, society, and economy. It is also known as an industrial analogy in some sources [10]. In addition, industrial symbiosis is a framework that unites separate enterprises in the context of resource usage, ensuring the sustainability of the modern methods and procedures introduced by the clean production approach [11]. Applications of symbiosis encompass a wide range of issues, including climate change, clean production, environmentally friendly green jobs, energy, water, and raw material efficiency and intensity, and the circular economy. These issues are both directly and indirectly impacted by symbiosis.

Energy efficiency networks are voluntary structures in which companies, organizations, or industries participate to reduce energy consumption and increase energy efficiency [8]. These networks usually seek to accomplish energy-saving objectives by working together, exchanging knowledge, and creating examples of best practices. EEN are a concept that Switzerland created and deployed in the 1980s to encourage energy savings that may help the commercial and industrial sectors to save energy resources [12]. Energy efficiency networks are usually formed by institutions in a specific region, but governments or energy organizations can facilitate the establishment of these networks by providing support, guidance, and technical know-how. Agreements within these networks are typically based on voluntary commitments and may include elements such as targets, criteria, and regular reporting on energy consumption and savings.

These two mechanisms are valuable especially during the design phase of industrial zones, requiring pre-feasibility studies and determination of preliminary investor requirements, creation of a financial model, determination of suitable locations based on the results of pre-feasibility studies, logistics, environmental and social evaluations. Following that, detailed feasibility analyses, market research, and layout planning are need to be carried out. The main government policies, available infrastructure options, natural surrounding and geopolitical conditions should be carefully considered especially when selecting location [13]. These analyses can lead to the development of more beneficial, efficient, and effective industrial systems to meet environmental goals if actions can be taken in accordance with concepts such as clean production, potential collaborations, green organized industrial zone (OIZ), and IS. For instance, eco-industrial parks (EIPs), also known as sustainable, low-carbon, green or circular OIZs, are industrial zones that aim to increase the economic, social and environmental performance of firms operating inside them. These parks are sites designed with specific goals in mind, such as advancing IS, and EEN supporting the green supply chain, encouraging environmentally friendly corporate practices, bringing attention to environmental problems, and boosting the use of green technology that save resources [13].

In parallel to such developments in worldwide, Türkiye has been implementing several policies to encourage sustainability and reduce the industrial sector's negative environmental impacts. For example, in the 11th Development Plan, covering the years 2019 - 2023, it is stated that the supports provided by Regional Development Agencies will be structured to prioritize applications such as clean production, EE and IS [14]. In addition, in the Industrial and Technology Strategy 2023, emphasis is placed on supporting green production, green OIZs and clean production investments in OIZs [15]. Also, the 12th Development Plan states that emphasis will be placed on green and digital transformation in the agriculture, industry, energy, and services sectors, and that investments in energy transformation, green infrastructure, and the circular economy will be increased. The Plan indicates that investments in areas directly related to EE, such as green transformation in industry, sustainable agriculture and transportation, circular economy, and green infrastructure and urban planning, are expected to accelerate. It emphasizes the dissemination of the best available technologies and practices, especially EE and IS, in small and medium-sized enterprises, industrial facilities, and OIZs [16].

Moreover, the National Energy Efficiency Action Plan (UEVEP) for 2017-2023 period was prepared. According to the 2022 progress report of this I. UEVEP, the industrial sector has a total theoretical waste heat potential of 3.82 Mtoe per year. It is projected that this waste heat potential could prevent 10 Mt CO_2 equivalent carbon emissions annually. Through applications such as industrial symbiosis, this potential waste heat can be utilized, and contributions can be made to the green OIZ transformation. As a continuation of these efforts, the Energy Efficiency 2030 Strategy and the II. UEVEP covering the 2024-2030 period have been prepared [17], [18], [19]. In this second plan, horizontal actions (Y) chosen for the energy (E) and industry (S) sectors could promote industrial symbiosis and green and digital industrial transformation. These actions include: Y1-Establishment and Enhancement of Energy Management Systems, S1-Expansion of Cogeneration Systems in Large Industrial Facilities Using Heat, S2-Providing Support to Increase the Diversity and Number of Energy Efficiency Projects in Industry, S3-Dissemination of Energy Efficiency Practices for a Low-Carbon, Green, and Digital Transformation in the Industry Sector, S5-Creating an Energy Savings Potential Map in Industry, S6-Supporting the Reduction of Carbon Intensity and Specific Energy Consumption in Industry, S7-Dissemination of Circular Economy Approaches to Increase Energy Efficiency in the Industry Sector, S8-Strengthening Capacity Building and Sharing Activities for the Dissemination of Successful Energy Efficiency Practices in Industry, S11-Conducting Activities to Address Energy Efficiency and Emissions Trading Together; E1-Establishment of a Functioning Heat Market within the Framework of Energy Transformation Goals. Especially, the activities to be carried out within the scope of actions S3 and S7 include statements aimed at increasing industrial symbiosis, recycling, and the use of secondary raw materials [19].

In line with these efforts, initiatives have been accelerated to reduce the environmental footprint of OIZs and encourage sustainable production practices. As a reflection of these endeavors, the definition of "Green Industrial Zone" has been incorporated into Turkish Organized Industrial Zones Law with Law No. 7451 in the Official Journal No. 32159 dated April 10, 2023. Moreover, a modification to Article 14's third phrase, "Loans," guarantees that Ministry of Industry and Technology loans will give preference to OIZ investments that meet the requirements for Green Industrial Zones. This step is an important one towards encouraging industrial zones to transition to environmentally friendly practices and establishing an optimal balance between ecological harmony and economic sustainability [20], [21].

In addition to these revisions in the Law, a project financed by the World Bank with a total support of 300 million dollars has been launched and signed in February 2021 to support green OIZs and increase environmental sustainability standards. The project will cover various activities carried out by OIZs and will be supported by loans specifically allocated to these activities. The objective is to improve the competitiveness and environmental sustainability of OIZs chosen as a consequence of their operations and to serve as a model for other OIZs. Among the project's initiatives, investing in green solutions for infrastructure stands out. Infrastructure investments such as roads, water, rainwater, sewage and wastewater treatment facilities, investments for the reuse or recycling of waste and innovation center investments are also within the scope of the project. Accepted projects will be loaned for 13 years with a 3% interest rate and a grace period of 3 years [22].

Based on aforementioned explanations, it is evident that initiatives are being made in our nation to promote and increase awareness of industrial symbiosis and green transformation. However, they have not received the required attention or have not been substantially expanded. There are 282 OIZs now in operation in Türkiye as of June 2024. Moreover, 51 OIZs are in the planning stages, 37 have infrastructure under construction, and 32 have finished land acquisition [23]. The evaluation of benefits regarding common infrastructure and collaboration opportunities, especially for the new OIZs are substantial. In this context, potential and opportunities can be identified through regional, environmental, and sectoral analyses, and relevant strategies can be developed. Thus, by adopting such a holistic approach to the system, the conditions for industrial symbiosis and clean production activities can be more easily developed.

Consequently, the objective of this study is to understand the awareness level and applicability of industrial symbiosis in Türkiye through an industrial zone case, considering energy efficiency practices that require comprehensive work and have similar goals under different definitions. By presenting potential solutions based on the findings, we aim to accelerate industrial symbiosis efforts and increase the industry's contribution to sustainable development, like global practices. Through this objective, this study will contribute awareness on energy and resource efficiency in industrial zones, such as industrial symbiosis and energy efficiency networks, using a particular organized industrial zone as an analysis. By highlighting possible resource matching opportunities among companies and demonstrating the connection between IS and government incentives & investments, the study raises attention on the potential advantages of IS. Moreover, the significance of cooperative efforts within industrial zones is emphasized as a means of reducing the environmental impact of Turkish industry, attaining material and energy efficiency, improving competitiveness, and fostering regional development.

For this objective, this paper is organized as follows: Literature review (since the subject is multidimensional this section has been presented as a separate main heading to examine the literature deeply) about the subject is given in Section 2 and methodologies used in the study and the analysis specifications is given in Section 3. Section 4 is the application of the analysis, results and discussion from the output. After that the conclusion is given in Section 5.

2. LITERATURE REVIEW

Main studies in literature about IS are analyzed and summarized in Table 1 below. As evident from the existing literature, IS practices are subject to influence from a countless of factors. The implementation of IS applications is mainly dependent upon the selection of a suitable location. Factors such as geographical features, logistical benefits, and closeness to industries involved are critical in determining the efficacy of such projects. The diversity of industrial sectors engaged in symbiotic relationships further contributes to the complexity of these systems. The variety of products and by-products adds complexity to the mutualistic interactions, prompting specialized integration strategies [24]. Additionally, the strategies used to support IS—whether via cooperative networks, technology platforms, or legal frameworks—have a big influence on the results. The amount and quality of information exchanged between involved parties also become important factors, affecting the transparency, reliability, and overall well-being of the mutually beneficial partnerships [24].

The wide range of applications for industrial symbiosis is highlighted by these considerate perspectives. The literature highlights the diverse range of applications and possible variations in these methods' implementation, emphasizing their multidimensional nature. This variation highlights the necessity for thorough and context-specific techniques in order to fully realize the potential of industrial symbiosis, as well as how adaptable it is to different circumstances. Therefore, Table 2 is designed to show the numerical results obtained from example projects conducted worldwide. The purpose of this table is to demonstrate the potential benefits arising from symbiosis or collaborative efforts. It briefly summarizes the country or countries where the study was conducted, the objectives of the study, and its outcomes.

In addition to the IS examples included in Table 2, cases that are present in Türkiye while taking the concept of symbiosis into consideration are provided below:

- Industrial symbiosis applications carried out in Türkiye include Iskenderun Bay Industrial Symbiosis Project; Bursa, Bilecik, Eskişehir Industrial Symbiosis Program; Gaziantep Industrial Symbiosis Project; Thrace Region Industrial Symbiosis Potential Research; Aksaray OIZ Industrial

Symbiosis Project and Izmir Eco-Industrial Park Transformation projects.

• In the "Ceramine Product Manufacturing from Calcite Wastes Formed as a Result of Sugar Production" in Eskişehir, calcite, can be sold as a raw material from sugar producing facilities to ceramic producing facilities. In this way, 12,000 tons of calcite were saved and an emission reduction of approximately 70% was achieved.

• Another study from Eskişehir named "Production of Building Materials from Waste Silica Sand Originating from the Foundry Industry" focused on the cost incurred in sending waste sand to landfills. Waste sand can be evaluated by sharing it with companies operating in the building products sector in the same region. With this application, 570-670 tons of raw materials can be saved, 20-30% carbon dioxide (CO_2) emission reduction from transportation and 95% reduction in waste transportation costs can be achieved.

• In a different application in Eskişehir, studies were carried out to use foundry furnace slags as aggregate in road construction after certain tests and feasibility studies. In this way, 1,000 tons of raw materials can be saved.

• According to another study also conducted in Eskişehir, 73,000 tons of raw materials can be saved by selling glass shards to companies that make glass wool at a reasonable price because they are directly used to make glass wool.

• Marble sludge shards were used in ceramic and tile production in the ceramic industry, resulting in approximately 1,200 tons of raw material savings and 3% energy savings in the ceramic production process in Eskişehir.

• Fruit pulp resulting from production activities was dried using waste heat in a different facility and converted into animal feed in the industrial symbiosis study conducted in Iskenderun Bay. In this way, 3,500 tons of CO_2 were saved, 12,000 tons of trash were used annually, 115 tons of waste heat equivalent to petcoke was employed, and more than 1,400 tons of feed were saved. The project has a computed payback period of three years.

• In a different application in Iskenderun Bay, the pyrolysis process was used to extract carbon black, scrap steel wire, pyrolytic oil, and pyrolytic gas from end-of-life tires. The oil and gas collected were then used to generate power. The annual output was 20,000 tons of tires, 8,000 tons of carbon black, 2,000 tons of steel wire, 8,000 tons of pyrolytic oil, and 2,000 tons of pyrolytic gas. And with this, an 8 MW installed power generated 40 million kWh of electricity annually. The project has a 15-month payback period.

• In Aksaray Organized Industrial Zone; feasibility studies were conducted on issues such as the evaluation of the possibility of starch recovery from wastewater originating from potato chip production, the use of dust and sludge from waste marble pieces in tile/paving stone production, and the use of iron oxide wastes generated during the production of other metal tanks, reservoirs and containers in biogas production facilities. It was anticipated that these studies would be beneficial in terms of environment and economy.

• The feasibility studies for the Izmir project, which was finished in 2019, revealed potential possibilities for boosted wastewater treatment systems, wastewater recovery, rainwater recovery, engine efficiency, and industrial symbiosis activities. The applications are expected to yield annual savings of 3 million m3 of water and $1 million in net savings. The project has an estimated payback period of 4.8 years [25] – [31].

Table 1. Summary of Literature Review [7], [24], [32] – [46].

Writers	Subject / Objective	Findings
Frosch, R. A., & Gallopoulos, N. E. (1989)	Industrial Ecosystem	Study mention the necessity of creating structures that will most closely resemble the ecosystem in order to maintain living standarts and minimize environmental impacts. It also mentioned the importance of businesses and societies being open to change. Paper emphasized that an investigation of the connections between inputs and outputs is necessary for sustainable ecosystems. Furthermore discussed the challenges involved in developing an industrial ecosystem.
Graedel, T. E. (1996)	Industrial Ecology	Study mentions that the structural framework of biological ecology sheds light on industrial ecology and emphasizes its potential applicability. The paper maintains that even though resource circularization is a key component of the industrial ecology idea, there are other factors that should be taken into account beyond that.
Chertow, M. R. (2000)	Comprehensive review about IS, general explanations, risks and opportunities about the subject.	The study conducted methodological examinations and evaluated symbiosis practices. Furthermore remarked that the interactions between businesses might be occur even if they aren't necessarily called symbiosis. It highlighted the importance of materials, system compatibility, infrastructure, financial constraints, and preliminary analyses.
Soylu, A., Oruç, C., Turkay, M., Fujita, K., & Asakura, T. (2006)	Mathematical Models / Mixed integer lineer program	In order to compare the expenses and environmental emissions that will arise from many enterprises supplying their energy-consuming systems through a shared system, the proposed model was solved in different scenarios involving two and three companies. The study found that cost improvement in a two-company structure is superior to that in a three-company example; additionally, it was noted that the three-company structure had higher environmental impact improvement. Energy losses have been significantly decreased in the developed systems as a result of the efficient use of steam.
Van Beers, D., Bossilkov, A., Corder, G., & Van Berkel, R. (2007)	Case Study / Analysis	A comparative analysis of the motivators, barriers and catalyzing events for regional synergy activities in Kwinana and Gladstone was made, and previous and current regional synergy developments in these two regions were mentioned. The heavy metal and mineral sectors are two examples of sectors in the system where traditionally distinct sectors collaborate. Through the recycling of leftover waste materials, physical exchanges of materials, energy, water, and/or byproducts can function together to obtain a competitive advantage. In terms of IS, the structure developed here highlights the value of collaboration and geographic proximity, as well as the fact that building this type of network involves learning process.
Karlsson, M., & Wolf, A. (2008).	Mathematical Models / Mixed Integer Linear Programming Model	Mixed integer linear programming is utilized to analyze the impacts of IS on energy requirements and costs. This allowed comparation the advantages of IS enterprises with those that operated more conventionally. While system costs decreased in each scenario, there were a few cases where the demand for electricity increased. The sensitivity analysis showed that fuel prices and modifications to structures like green certificates have a significant impact on companies that do not use IS. The analysis also mentions how rising energy and electricity prices will increase IS's benefits. The system's general structure was the primary focus, with less attention paid to how symbiosis affects other entities and resources. Although additional costs may apply to all applications, this structure has generally been considered to be a successful and financially favorable strategy.
Kim, S. H., Yoon, S. G., Chae, S. H., & Park, S. (2010)	Mathematical Models	Eco-industrial parks have been described as a useful innovation for establishing industrial ecology. By applying a model that incorporates the usage of alternative raw materials and the seasonal shutdown of certain equipment to actual operations in the petrochemical complex, a study was conducted to minimize the overall cost. Because of the newly built pipeline between the source and recipient organizations, the model resulted in a minor increase in investment cost, even though the overall cost and waste load dropped. Consequently, it has been noted that by optimizing the service network within an industrial complex, waste load and service costs can be decreased.
Gümüş, T. Ç. (2016)	Using an open source website to simplify decision-making	A platform has been developed that contains data from consultants and companies, evaluates how procedures effect the environment, and allows feedback on possible synergistic pairings. Following data upload, consultants can assess investments based on costs and research to share their opinions regarding companies. Sharing reports on the platform is meant to make it a model for other projects of a similar nature. The website was found to be a helpful resource for consultants and corporations alike after being evaluated using three different case studies. It highlighted how crucial is to decide on demands in a clear and concise manner when the system was being developed.

Daddi, T., Nucci, B., & Iraldo, F. (2017).	Environmental impacts of IS initiatives carried out by SMEs	The comparison's findings showed that numerous values, including the reduction of CO2, the development of photochemical ozone, acidification, the use of water resources, and the eutrophication of fresh and saltwater, were present in the case of symbiotic activities. Furthermore, it was pointed out that policy makers might support the growth of IS research by utilizing the cluster strategy. It has been claimed that by doing these studies in clusters, opportunities to conduct Research & Development (R&D) studies may present themselves, resource restrictions that might prevent the expansion of Small and Medium-Sized Enterprises (SMEs) can be avoided, and life cycle analysis can assist enterprises in projecting their future.
Zhao, H., Zhao, H., & Guo, S. (2017)	Case study / Multi Criteria Desicion Making	The goal of the paper is to assess the advantages of eco-industrial parks using a hybrid multi-criteria decision-making approach from a perspective of the circular economy. The model's advantages are listed in order of priority and is demonstrated using a case study on six representative parks in China. The proposed approach evaluates and ranks benefits and provides a good reference for management. It also suggests policy implications for various improvements.
Özden, S., & Öztürk, A. (2018)	Time series and artificial neural networks / Mathematical Models	The purpose of the article is to estimate the electrical energy needs of the Ankara OSTİM OIZ by utilizing artificial neural networks and time series. Energy consumption data and temperature parameters based on electrically powered heating systems were taken into consideration, with a special focus on small and medium-sized enterprises. Artificial neural networks have been found to yield more effective results than time series.
Özkan, A., Günkaya, Z., Özdemir, A., & Banar, M. (2018)	Mathematical Models	Examples of IS networks created with Material Flow Analysis, Life Cycle Analysis, Multi-Criteria Decision Making methods, method descriptions. They looked at examples of IS networks and highlighted the importance of spreading it.
Eryılmaz, G. D. (2019)	A study wih NACE codes in Mediterranean region	A web-based software that illustrates the dynamic IS networks in the areas of Adana, Mersin, and Hatay as well as their benefits to the local and national economies was established for the study. Waste materials and by-products from different sectors were used as by-products in the iron and steel industry. It has set an example of industrial symbiosis network establishment with low costs and reasonable feasibility study.
Yılgın, Z. G. (2019)	Mathematical Models / Lineer Opt Model	A linear optimization model was developed to minimize costs, the interactions of the materials used as waste were taken into consideration, the waste usage rates of the sectors and the extent to which the products using these wastes were affected were examined, and the study examined the applicability and optimize ability of the IS structure in resource-intensive sectors. By including as much waste as feasible, the model seeks to produce the desired output at the lowest possible cost. The mathematical model was used to calculate resource use, waste utilization, and cost savings, and Matlab software was used for optimization.
Genç, O. (2020)	Mathematical Model / Food Webs and Social Network Analysis	For exploring the possibility of Turkish industrial parks and to design new OIZ to be built in this manner, a study conducted in the construction industry utilizing food webs and social network analysis to create a prototype design. Conclusions were reached that the functions of recycling facilities in OIZ can be increased, new recycling facilities can be added, and if the potential waste level that new companies can use is high, the investment and enterprise potential may be high as well. It has also been concluded that a wider range of businesses having access to the OIZ will make the system less fragile and the symbiotic network stronger. The new facilities will be able to operate not only as facilities that receive and consume waste, but also as facilities that produce new waste types that existing companies can use. Within the scope of the study, strong eco-industrial parks can be supported by the combined use of food webs and social network analysis.
Neves, A., Godina, R., Azevedo, S. G., & Matias, J. C. (2020)	Industrial Symbiosis	Articles and IS studies that have been subject to literature have been classified and detailed according to region, country, sector and method. They mentioned that IS provides environmental, economic, and social benefits and the economic aspect is the most significant driving force. It has been observed that businesses prefer to collaborate by utilizing their waste instead of using infrastructures like water and ventilation, as this method is less risky. It is emphasized that when alternatives are created in the symbiosis network, no problems will arise even if any element exits the network.
Patricio, J., Kalmykova, Y., Rosado, L., Cohen, J., Westin, A., & Gil, J. (2022)	Mathematical Models	Its goal is to give businesses comprehensive answers by breaking down problems into smaller units and applying the top-down strategy to focus on those units. The upper-level steps were chosen as identifying waste, determining the materials needed and matching waste with materials. Industries, input wastes and other materials are classified according to the Eurostat standard. Additionally, it was stated that although the waste numbering system used in the study—which was applied among businesses utilizing wood resources in a region of Sweden—might be helpful in identifying possible partners, the fact that waste is gathered within such a broad framework may limit the number of possible matches. However, with additional data, results regarding more substantial relationships will be attained.

Table 2. Worldwide Good Practices for Collaborations [47] – [62]

Country	Program / Project / Implementation	Activity Area / Description / Objective	Benefit / Gain	Ref.
Australia, Brazil, Bulgaria, Canada, China, Denmark, England, Germany, Hungary, Korea, Mexico, Northern Ireland, Poland, Romania, Scotland, Slovakia, Turkey, USA	NISP - National IS Programme (2003-)	Widespread implementation of IS practices, providing training, consultancy and information infrastructure, and developing capacity planning models.	Between 2005 and 2013 in the UK, annually: 9.4 million tonnes of industrial waste were diverted from landfills, generating €234 million in new sales, reducing carbon emissions by 8.4 million tonnes, achieving €243 million in savings, reusing 0.4 million tonnes of hazardous waste, creating over 10,000 jobs, conserving 12 million tonnes of natural resources, and preserving 15 million tonnes of industrial water.	[47]
EU	SHAREBOX (2015-2017)	The project promotes IS by developing an online platform that provides information about waste resources such as energy, water, and residues. It offers decision-makers waste resources that can be used to replace primary resources.	26 synergy setups, 515.500 tons of waste prevented, 635.500.000 tons of primary resources saved, 1.38 million tons of CO_2 equivalent emissions prevented, 53.85 million EUR in additional sales, 14.12 million EUR in cost savings, 74 new jobs created.	[48]
Belgium	EPDM Rubber Pilot Case (2016-2019)	The process of making window handles from window rubber, involving the reprocessing and reuse of hard-to-recycle waste within the same production facility.	Annual 100 tons of waste 100% recycled, 97.67 tons of CO_2 emissions reduced, 169.77 m^3 of water saved, and 151.16 tons of raw materials saved.	[49]
United Kingdom	A fruitful collaboration case	In a nitrogen-producing company, CO_2 generated during ammonia production is converted into hot water and pumped into a tomato greenhouse, equivalent to 23 football fields, operated by a vegetable producer.	12.500 tons of CO_2 emission has prevented.	[50]
United Kingdom	A Wheel Innovation for Denso Manufacturing	As a result of an agreement between a company producing air conditioning units and engine cooling systems for the automotive industry, and a company producing primary and secondary phase aluminum alloy ingots, the waste Potassium Aluminum Fluoride is converted into aluminum alloy ingots to be used for vehicle rims.	Reduction of 15 tons of hazardous waste going to landfills and savings of £30,000 in costs.	[50]
Finland	FISS - Finland IS System (2017-2018)	Creating new job opportunities, promoting waste reuse and resource efficiency, reducing natural resource consumption, fostering regional development, and increasing circular economy activities.	With the participation of over 700 companies, more than 2,500 synergy opportunities were identified in 2018 through the Synergie database.	[51]
England and Wales	Industrial symbiosis: Innovation for the water sector	Using water industry waste and by-products as inputs for other processes through IS.	In 13 months, by preventing the use of raw materials, there was a reduction of 57,500 tons of CO_2 carbon emissions. Additionally, there was a reduction of 82 tons of CO_2e emissions through warehouse material redirection, leading to a cost saving of £13.5 million.	[52]
Ireland	A Window of Opportunity for Erne Plas	To reduce dependency on imports and increase the use of recycled products, a PVC and aluminum building product manufacturer has collaborated with companies possessing recycling infrastructure and a company capable of grinding PVC for the extrusion process. They have invested 1 million pounds to establish extrusion lines.	The company reduced import dependency and provided a supply of recycled products, resulting in £1.2 million in new product sales and £37,000 in cost savings.	[50]

Spain	Recycled Aggregates (2016-2019)	As a result of the organization focused on the construction sector, waste management was selected as the main topic. An agreement was reached involving 1 excavation and demolition company, 2 waste management companies, and 1 waste transportation company to establish a facility for recycling both rubble and non-rubble waste.	With the participation of 4 companies, 36.000 tons of waste were recycled annually, resulting in an 80% reduction in waste, 35.280 tons of CO_2 emissions reduced, 61.200 m^3 of water saved, and 50.220 tons of raw materials saved.	[49]
Spain	CIRQLAR: Low temperature heat recovery for industrial use by heat pumps (2023-2025)	The project aims to recover waste heat at around 100°C and use heat pumps to raise the temperature to 150 degrees Celsius. The goal is to recover 3 MW of waste heat from a symbiotic production system and produce usable heat in steam form up to 4 MW.	Expected outputs include a reduction of 59.497 tons of CO_2 equivalent emissions. The energy consumption of the process unit is expected to decrease by 24% by electrifying the process using industrial heat pumps and utilizing existing waste heat, thereby reducing natural gas usage and cutting 0.59 million tons of CO_2 equivalent greenhouse gas emissions.	[53]
Italy	SYMBIOSIS PLATFORM (2022)	Providing guidance to organizations and facilitating their connections. Initially designed for Sicily but can be used throughout Italy.	2646 resources and 1946 symbiosis alternatives have been created with 250 companies.	[54]
Italy	Industrial Symbiosis in the Ceramic Sector: Recycling of Thermal Spray Waste in Sintered Products (2019)	Material Reuse, Separation of Waste Production from the Source	Depending on the type of product produced using spent dust, there can be an increase in economic value ranging from 5% to 30%. This increase is attributed to various factors including a 30% reduction in production energy costs, a 20% to 90% reduction in raw material costs depending on the product, and a 10% to 40% reduction in production costs per unit depending on the product.	[55]
Hungary	Platio Solar Paver (2018)	A modular flooring system made from recycled/reused plastic.	1.4 tons of plastic waste from automobile production [lamps, bumpers] has been recycled, with 90% of it originating from acrylonitrile butadiene styrene (ABS) plastic technology waste.	[56]
Hungary	Map Application (2018)	Mapping of construction waste and making it accessible to everyone, entering the quality and quantity of waste into the system.	Real-time sharing of construction and demolition waste with the participation of 30 companies, recycling of over 440.930 tons of waste.	[57]
Portugal	LIFEfoodCycle (2020-2024)	Creating a digital tool to facilitate the trade of food nearing its expiration date and treated as waste among food retailers and stakeholders, with the goal of reducing food waste by at least 10% in the food retail chain.	In 2022, a total of 54 million EUR worth of food waste was prevented, with 31 million EUR coming from the food waste donation program. Plastic recycling reached 80%, and the recycled plastic content in their productions was achieved at a rate of 14.1%.	[58]
Türkiye	Türkiye Materials Marketplace	Creating a platform for material exchange, inter-sectoral cooperation, resource efficiency, and waste reuse. Users enter their relevant waste into the system with all the information, and the waste can reach potential buyers interested in it. Various communication channels are available within the platform for buyers and sellers to contact each other.		[59,60]
Greece	Municipality of Kozani district heating eco-system (1993-2005-2006)	Heating Systems	The cost is approximately 75 million EUR for the construction of the heating network and an average of 4000 EUR per building for internal heating systems. This project involves the employment of 45 engineers, technicians, and workers, resulting in a savings equivalent to 380.000 tons of oil, a 40% reduction in individual costs, and approximately a 70% decrease in gas and particulate emissions.	[61,62]

According to the literature review, IS can be defined as an approach that aims enhancing resource efficiency and sustainability by facilitating the sharing and reuse of waste and by-products among diverse industries. This concept has been extensively analyzed in the literature, with research addressing a variety of themes including the various aspects of IS, its environmental benefits, economic feasibility, waste reduction, regional development, and practical applications. In these researches, various techniques like artificial neural networks, linear programming, material flow analysis, life cycle analysis, multi criteria decision making, input-output matching, stakeholder processes, materials budgeting, material flow mapping [7], [32], [34], [37], [40], [41], [42], [43], [46] have been utilized. Additionally, there are studies focusing on classifying IS initiatives globally. When examining the distribution of IS applications and case analyses, a significant number of studies focus on the Asia region, with the majority conducted in China. The policies and incentives implemented by China are considered the primary reasons for its leadership in industrial symbiosis applications. Following China, Europe ranks second in research on this topic. The EU and the European Commission emphasize the importance of symbiosis for waste reduction and resource efficiency, which has increased IS studies in Europe [39].

IS researches have different focal points. While some studies concentrate on economic gains, others focus on environmental impacts or social benefits. Some research addresses IS in general terms, while others focus on specific sectors or geographical regions. Similarly, some studies assess the overall environmental impact of symbiosis, while others evaluate it within a specific region or sector. There are also studies focusing on feasibility and cost-effectiveness. Additionally, some research proposes policy recommendations to promote the widespread adoption of IS practices or demonstrates how existing policies can support this topic.

Symbiosis techniques cover a wide range of themes, including cleaner production, energy, water, and raw material efficiency and intensity, climate mitigation, environmentally friendly green jobs, and the circular economy. Even symbiosis can be developed through techniques like sharing office space and information, as well as using transportation networks together. It seeks to decrease waste and bring continuity to the energy and material cycles by constructing an integrated grid structure. As a result, industries are able to lessen their environmental impact. Sites for disposing of garbage and raw materials are becoming less necessary. Furthermore, materials that were previously worthless commercially can gain value. By these ways, continuous improvements can be possible considering energy, economic and environmental management [7], [39].

The support of policymakers and the presence of relevant legal regulations are crucial for the widespread adoption of IS. As seen in various countries, government support plays a significant role in the development and proliferation of these systems, even contributing to the creation of eco-cities. This facilitates mutual benefits for both industries and cities, helping to mitigate issues experienced in both sectors. Some experts refer to the use of waste produced by neighboring industries in cities as alternative raw materials for industrial activities or as an energy source facilitated by their geographical proximity, using the term "Urban Symbiosis" [63], [64]. For an example, the integration of industrial and urban symbiosis has been advocated to maximize the economic and environmental benefits obtained from close geographical proximity with Japan's Eco-Town Program. This program has facilitated the reuse of commercial, municipal, and industrial materials that were previously considered waste in industrial applications. The Japanese government has provided a 36% grant to support the 26 Eco-Towns established across the country. Additionally, at least 107 recycling facilities have been constructed without government support. Some of these Eco-Towns focus on improving industrial efficiency, while others aim to enhance the environmental living space. In 16 of the Eco-Towns, local governments play a supportive role, whereas in 9 others, non-governmental organizations have significant involvement. The presence of investment supports, enacted legal regulations, and the widely accepted need for urgent intervention in environmental issues have been crucial factors in the project's success [65]. With the decisions of policymakers and the presence of various incentives, collaborative systems like IS can become as widespread and well-known as renewable energies.

Based on this literature review discussion, this study targets to show the relationship and connection between IS and structures like energy efficiency. The potential contributions of policy tools and incentives used by policymakers to initiate, maintain, and sustain IS applications are also discussed. For this purpose, this study seeks to determine the applicability of IS in an existing OIZ as a case and to observe its prevalence in Türkiye through a survey conducted in this industrial region. Besides, it focuses on understanding the sectoral structure and highlighting aspects that would encourage companies and ensure the sustainability of these applications. Additionally, a list of examples from the literature related to the NACE (Nomenclature of Economic Activities - Nomenclature des Activités Économiques dans la Communauté Européenne) codes of the region is compiled, and a region-specific study is conducted. This allows companies to gain insights by matching their own NACE codes and potentially become interested in the topic.

The last but not the least, this study highlights that strategic decisions made during the planning phase in potential growth areas of OIZs can create an infrastructure conducive to forming networks that use energy efficiently and effectively. Therefore, shared use and collaborative elements should be considered from the inception and planning stages in newly developed OIZs. It is also noted that various companies might already be engaging in symbiotic interactions without explicitly labeling them as such.

3. MATERIAL AND METHODS

In the scope of literature review, a case analysis was conducted with a selected organized industrial zone in Konya, Türkiye. Various aspects of Konya OIZ, such as its structure, sectoral distribution, and areas of activity, have been investigated. The objective is to gather diverse information by reaching out to the Konya OIZ management and Energy Efficiency Consultancy Companies (in Türkiye EVD) performing consulting, auditing and energy efficiency implementations in the region. Additionally, a survey with targeted questions related to the topic have been administered to the firms in the region for data gathering. The survey is designed to collect data regarding the sectoral organization of the companies inside the chosen structured industrial zone, their degree of familiarity with industrial symbiosis, and their existing waste-sharing procedures. The companies are asked to fill out sections of the survey with information about their field of business, waste, and by-products. The objective is to identify which industries react and to understand the waste management practices of the companies involved in these sectors. Questions are also made about whether the businesses presently share waste or byproducts in the same or different regions. The questions are meant to find out if the businesses are in symbiotic partnerships with other businesses in the area. Questions about the existence of waste heat, energy efficiency efforts, and the presence of existing renewable energy sources are also included in the survey. It also gives a chance to discuss whether incentives for renewable energy encourage businesses in the OIZ to invest in renewables. The questions are carefully designed to be easy to read, comprehend, and provide a clear response. Both multiple-choice and open-ended questions are preferred, depending on the content of the question. To ensure high response rates, the survey is distributed both online and via telephone calls. The gathered information is numerically categorized and expressed as a percentage. These answers and questions are then visualized using stacked bar chart. The total length of the bars corresponds to 100%, and different colors within each bar indicate the proportions of different answer options. The chart also increased readability by indicating the relevant percentage values on each bar. The answers given in the survey have been abbreviated in order to facilitate visuality in the graph.

Parameters such as the level of knowledge and the existence of symbiosis have been assessed through this survey. The communication with the management of the region, companies and EVDs coupled with the survey responses from the local firms, is intended to provide a comprehensive understanding of the region's characteristics and the potential for IS. Below is a process flow chart that provides a brief summary of the methodology employed and the previously described processes:

Figure 1. Methodology of the Study

3.1. Konya OIZ

To begin with, information about Konya OIZ was collected. The selected OIZ was initially established in 1976, and over time, it has expanded steadily with the addition of growth zones. Currently, it spans approximately 2,300 hectares and consists of 785 industrial parcels. Furthermore, it continues to grow progressively [66].

One of the reasons for selecting this region is the perceived usefulness of the growth potential and existing expansion in the region as a beneficial example for implementing collaborative structures such as industrial symbiosis. Apart from the potential for growth, the focus lies on the significance of teamwork in obtaining resource and energy efficiency, promoting regional development, and mitigating the ecological consequences of wide-ranging industrial zones. The establishment of infrastructure for collaborations, such as IS, could also contribute to issues like carbon taxes and carbon trading.

The 763 enterprises in the OIZ operate in 32 distinct categories, according to an analysis of their NACE codes. The numbers of firms in these sectors are shown in Table 3. The predominant sectors in the region include metal, automotive, and machinery, with a notable presence of iron and non-ferrous metal industries. Specifically, there are 448 companies in the metal, automotive, and machinery sectors; 84 in the giftware, education, printing, photography, and various goods sectors; 66 in the food and agriculture sector; 40 in construction arts; 23 in woodworking industry; and 14 in the electrical, electronic, and computer sector.

It is noticeable after examining at the Konya OIZ's sectoral structure that metal-based industries are dominant in this area. Focusing on these sectors and companies as the starting point could be beneficial for the adoption of an IS structure in the region, given the potential for significant interactions. Initial emphasis on companies providing production and services related to metal and ores, along with an analysis of the structure, operations, product details, and production processes of these companies, can form the basis for a potential symbiotic structure.

As each industrial zone has unique economic, social, and environmental conditions, they possess distinct structures, conditions, parameters, and requirements. However, as evident from examples and research in the literature, there are numerous industrial symbiosis alternatives and potential product exchanges that are common both within sectors and across sectors.

Table 3. The sector distributions of companies operating in Konya OIZ

Sector Definition	Number of Businesses
Metal, Automotive, Machinery	448
Gifts, Education, Printing, Photography, Various Goods	84
Food, Agriculture	66
Construction Arts	40
Wood Industry	23
Hairdresser, Barber, Cleaning, Sports, Cosmetics, Health	17
Electrical, Electronic, Computer	14
Clothing, Leather Products, Home Textiles, Weaving	9
Machinery and Equipment	7
Motor Vehicle Sales and Service	6
Repair of Motor Vehicles and Motorcycles	6
Transportation Services	6
Pharmaceuticals and Medical Devices	5
Architecture and Engineering	4
Non-Ferrous Metals	4
Electrical Equipment	3
Financial Institutions	3
Iron and Steel	3
Technical Hardware	2
Chemical Substance	1
Construction	1
Construction Contracting	1
Construction Materials	1
Cosmetics and Chemical Substance	1
Infrastructure Construction	1
Land Vehicles, Spare Parts, and Equipment	1
LPG, Liquefied and Compressed Gases	1
Machine Tools and Automation	1
Motor Vehicle Repair, Maintenance, and Manufacturing	1
Plastic and Rubber	1
Real Estate Services	1
Retail Trade	1

When examining the studies conducted exclusively in the Konya OIZ, based on measurements conducted by the Konya Chamber of Industry Energy Efficiency Study Center for 11 businesses, forecast an annual total energy saving of 1,692.08 TEP (tonnes of oil equivalent) and a reduction of 5,853.65 tons of CO_2 emissions. The identified monetary equivalent of energy savings with the current situation amounts to a total of 1.229.762 EUR. The investment cost required for efficiency studies is determined to be a total of 728.119 EUR. *(The Euro exchange rate has been taken as 32,97 TRY)* (Shown in Table 4.) This measurement info taken by one-on-one meeting with a member of Konya Chamber of Industry Energy Efficiency Study Center. Despite being just a few company examples, these studies indicate a significant potential for energy efficiency, emission reduction, and cost savings. It is evident from these studies that there is considerable potential to leverage energy efficiency and implement industrial symbiosis practices with a clean production perspective in the region.

Table 4. Potential Gains Discovered by Audits Carried Out in the Konya OIZ

Sector	Measurement Type	Saved Energy (TEP/Year)	CO_2 Reduction Amount (Ton CO_2/Year)	Monetary Equivalent of Energy Savings (EUR)	Projected Investment Cost (EUR)	Amortization Period (Days)
Molding	Audit	63,67	229,96	42.426,60	9.093,78	78
Household Goods	Audit	16,49	48,77	9.074,42	7.173,26	289
Food	Audit	552,30	1.630,60	452.779,97	156.451,92	126
Food	Audit	72,20	397,20	102.078,36	354.926,47	1269
Food	Local Audit	44,80	306,00	1.061,57	1.286,02	442
Food	Audit	691,59	2.332,70	459.345,42	121.399,37	96
Food	Audit	127,60	327,50	63.057,78	14.605,70	85
Construction Materials	Audit	24,28	141,99	20.633,58	4.488,93	79
Medical	Audit	12,23	57,83	9.282,71	7.220,26	284
Metal	Audit	44,50	136,60	23.191,77	24.537,46	386
Defense	Audit	42,42	244,50	46.830,08	26.936,61	210
	Total	1.692,08	5.853,65	1.229.762	728.119,78	

In the light of the current situation and analysis in the region, a survey was planned to measure the level of knowledge on the subject and analyze the feasibility of industrial symbiosis.

3.2. Survey Study

For the analysis, after collecting and interpreting information such as the sectoral structure and identified energy efficiency potentials in the region, various questions were formulated into a survey and conveyed to companies in the Konya OIZ. It was meant to bring up questions regarding firms' waste and byproducts, energy efficiency, and industrial symbiosis studies. As a result, a survey with 19 questions was prepared, including questions about companies' wastes, waste exchanges, whether industrial symbiosis is implemented or not, whether energy efficiency studies are carried out, whether there is waste heat, whether there is an energy manager, whether energy efficiency studies are conducted or planned, solar energy information systems are installed or planned, industrial symbiosis awareness, and so on. The aim was to gain a more profound understanding of the cultural makeup of firms, their energy consumption patterns, waste management practices, the utilization of waste, and their awareness of industrial symbiosis. These questions were delivered to firms through various channels, and discussions with companies were facilitated for feedback. To avoid long-lasting survey responses, clear and concise questions were formed. After constructing the survey, the companies' contact information was gathered by contacting the Organized Industrial Zone Directorate, and the survey was e-mailed to a total of 754 companies. In addition, the organized industry regional directorate management was contacted, and the goal and content of the study were explained. The survey was then sent to the businesses via the regional directorate communication unit. Moreover, 196 businesses were contacted by phone, given information about the questionnaire and the issue, and urged to share their responses. As a follow up to these studies, one-on-one contact was made with people working at OIZ, whom we met both through internships and other studies. The described process took place over a period of approximately 5 months in total.

The intention of the questionnaires was to learn more about how companies handle waste and byproducts as well as how they use or share trash and byproducts within the same or different industrial zones. The objective of the study was to gather information on several subjects, such as the evaluation of waste and by-products, possible practices for sharing within or beyond the industrial zone, and the implementation of energy efficiency initiatives. Based on the insights acquired, the information gathered was meant to evaluate the tendency of businesses to embrace and apply industrial symbiosis techniques. Furthermore, the evaluation aimed to consider whether there were existing practices of sharing or trading, without necessarily being classified as industrial symbiosis, within the same region. The study also attempted to determine whether there were any possible chances for collaboration inside the industrial zone and how prepared businesses were to adopt applications of industrial symbiosis.

4. RESULTS AND DISCUSSION

This section of the study offers a thorough examination of the data and a comprehensive summary of the outcomes. A total of 29 responses were obtained out of 754 companies who received the surveys. It is indicated that steel shavings, scrap, metal shavings, industrial oil, paper, plastic, wood, contaminated metal, sand furnace slag, grinding mud, rubber, chemical paint powder, and grinding materials are among the wastes produced by OIZ firms who took the survey. Based on information collected, several enterprises exchange waste and by-products with other local businesses. Generally, industrial waste from sectors such as agricultural machinery, machinery, aluminum casting, metal industry, automotive, and manufacturing is observed to be shared as scrap or disposed of at recycling facilities. However, before considering such materials as scrap, there might be an option to sell them to various firms without undergoing additional processing or requiring reprocessing.

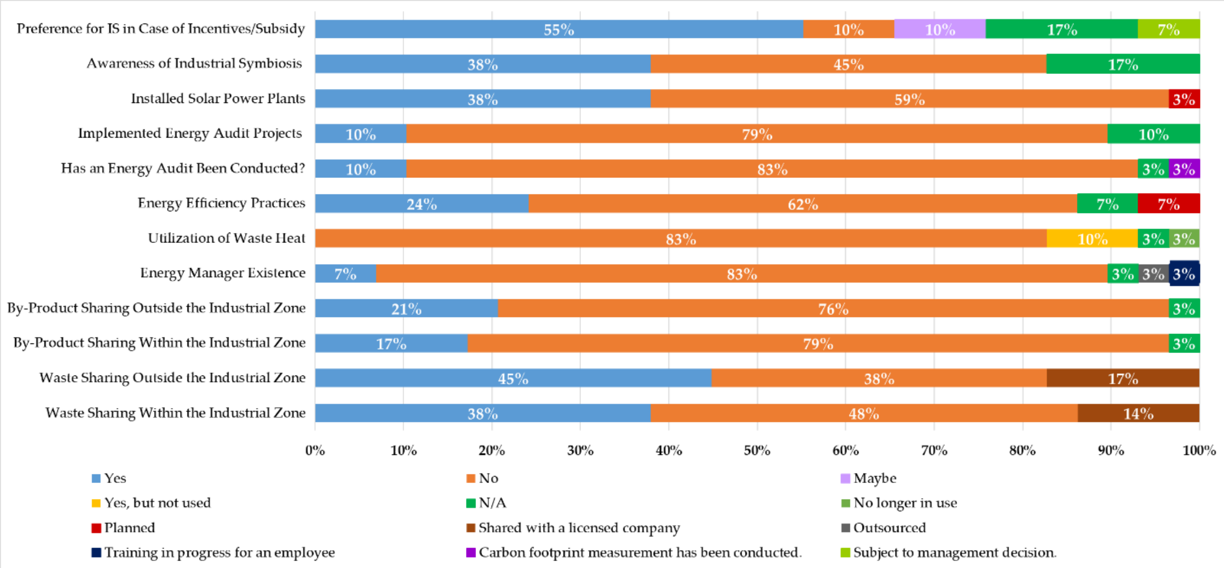
A noteworthy example within the Konya OIZ involves a company in the soil industry purchasing refractory bricks and mortars obtained from dismantling furnaces in sectors like glass, lime, and ceramics. The acquired materials, especially the usable ones, are either sold, or the remaining portion is cleaned and utilized as auxiliary raw materials for various productions. This process could serve as an example of symbiotic networks that could be established in the region.

Regarding waste heat related information obtained from the survey, it is observed that some companies in the region generate waste heat but do not utilize it in any way. Through IS applications, waste heat could be cyclically integrated into the system by sharing it with other companies within the same region or by internal utilization within the same company, if required for any process.

Moreover, Table 5 presents the summary of the findings related IS discussion. Upon reviewing the answers, it is seen that firms have limited knowledge about the concept of industrial symbiosis. Among the 29 firms that responded to the survey, only 9 claimed to have heard about the term industrial symbiosis which is the %38 of the total. The ratio suggests an insufficient level of awareness. When asked about their willingness to engage in agreements and resource sharing with other firms within the same region in cases of investments or state incentives related to industrial symbiosis and waste sharing, a majority of firm, which is %55 of total, expressed a preference for such practices as seen from the first row of Table 5. While %10 of total remaining undecided, %7 of them indicating that the decision might be subject to management evaluation.

It is also noticeable that there is a lack of interest in energy-saving initiatives and energy audit studies. 83% of businesses do not have an energy manager but the widespread knowledge of solar energy systems and the availability of financial incentives suggest an increasing affection among the firms to adopt renewable energies to reduce electricity consumption. However, considering the potential savings values from the energy audit works conducted in the region as mentioned in the previous section, it is unfortunately noticeable that the expected returns from firms that have undertaken energy audit or energy efficiency applications in the OIZ are not realized.

Table 5. Responds of the survey considering IS



Although the number of surveyed firms is limited, the results from the conducted studies and responses suggest a high potential for energy efficiency in the OIZ. The utilization of this potential and the enhancement of energy efficiency initiatives can be facilitated through structures such as industrial symbiosis and energy efficiency networks, supported and promoted by policy measures and obligations introduced by policymakers.

In the initial phase, the NACE codes of every business located within the Konya OIZ are found and sorted. Subsequently, considering that businesses with NACE codes in the same or similar areas may have high waste exchange rates, resource matching of companies in Konya OIZ is made and summarized in Table 6 to serve as an example for businesses in the region. The table is created using information from the MAESTRI open-source library [67]. NACE code of each firm in the OIZ is tracked through the open source file. The corresponding NACE codes and descriptions of the raw materials are then combined to put together the table. This table only includes a portion of the symbiotic exchanges held by companies that operates close or identical sectors with the firms in the Konya OIZ. In the literature, there are wider examples in these areas of activity. Table 6 lists the sharing company's sector and NACE code, together with the definition of the shared waste, the company sector and NACE code of the company receiving the waste, and the shared waste's purpose of use. For instance, a company that manufactures animal feed may use the fruit pulp waste generated by a fruit juice producer as a raw material. Meanwhile, blast furnace slag, which is waste from a steel processing company, might be used as raw material in a cement manufacturing company. Oil mill wastewater from olive oil production can be used as fertilizer in agriculture. Boilers and fly ashes from paper manufacture can be used for soil amendment in agriculture. These and similar examples can be uncovered through future research, and waste materials or outputs can be upcycled into manufacturing, benefiting businesses economically, socially, and environmentally.

In the scope of the findings shown in Table 6 and other examples through literature such as previous IS applications conducted in Türkiye, open source library findings and matchings that encountered in literature reviews, potential exchanges on sectoral basis is shown on the following chart (Table 7 and 8) [25]-[31], [44], [68], [69], [70], [71].

This table which we generated for Konya OIZ, shows the current waste-sharing processes or the ways in which waste is used by firms with these NACE codes based on the mentioned sources. The sectors that are included in the table are those which serve as a component of the Konya industry. The sectors represented in the Table 7 and 8 can interact with at least one other sector and share waste or byproducts. According to the examples provided, only the sector generating photovoltaic modules may share within itself; nevertheless, further sectoral research may disclose the interactions it can have with other industries. To give an example from the table, a company in the wood sector can exchange waste and byproducts with the wood, biogas, cement, agriculture, and greenhouse sectors. Additionally, the cement and construction sector can conduct trade with the wood, glass/ceramic, cement, iron-steel, non-ferrous metals, food, animal feed, chemical products, fertilizer, automotive, refinery, paper, and agriculture industries. The pairings in the table include a wide variety of material changes such as waste heat, waste plastic, waste food, slags, glass shards, fly ashes, cane pulp, steam, hydrogen, mud, organic waste, fruit pulp.

Table 6. Sharing opportunities among businesses in the region with the same or similar NACE codes.

NACE Code of the Company Providing the Waste	Main Business Line of the Company Providing the Waste	Definition of Waste	Main Business Line of the Company Receiving the Waste	NACE Code of the Company Receiving the Waste	Usage of the Waste in the Receiving Company
11.01	Distillery	Isopropyl alcohol	Dairy industry	10.51	Sterilizer
11.01	Distillery	Rice peel	Paper manufacturer	17.12	Process heat
11.07	Fruit juice producer	Fruit pulp waste	Animal feed producer	10.91	Raw Material
21.10	Pharmaceuticals	Yeast sludge and residue	Local farms	150	Animal feed
24.10	Iron and steel production	Ammonium sulfate	Fertiliser company	20.15	Raw Material
24.10	Steelworks	Demineralized water	Energy Plant	35.11	Water
24.10	Steelworks	Exhaust gas	Energy Plant	35.11	Process heat
24.10	Steelworks	Blast Furnace Slag	Cement industry	23.51	Raw Material
24.10	Steelworks	Refractories	Road construction	42.11	Raw Material
24.10	Steelworks	Basic oxygen steelmaking furnace slag	Road construction	42.11	Road Base
24.10	Steelworks	Blast Furnace Slag	Brick production	23.61	Raw Material
24.10	Steelworks	Blast Furnace Slag	Rock wool production	23.99	Raw Material
24.10	Steelworks	Blast Furnace Slag	Glass and glass ceramic production	23.10	Raw Material
24.10	Iron and steel production	Blast Furnace Gas	Ammonia production	20.13	Process energy
24.10	Iron and steel production	Steel slag	Carbonate production	20.14	Ferrous metal refining
29.10	Automotive Industry	Industrial Waste	Energy production	35.11	Fuel
17.11	Paper Pulp Production	Ash	Fertilizer company	20.15	Raw Material
17.12	Paper production	Boiler and fly ashes	Agriculture	011/012	Soil amendment
10.41	Olive oil production	Oil mill waste water	Agroindustry	011/012	Fertilizer
10.81	Sugar refinery	Bagasse	Compound fertilizer production	20.15	Raw Material
10.81	Sugar refinery	Bagasse	Cement mill	23.51	Raw Material
10.81	Sugar production	Stones separated during sugar beet washing	Building trade	41.20	Raw Material
10.81	Sugar production	CO_2	Tomato growing	119	Supports the growth of plants
10.81	Sugar production	Waste Gas	Block production	23.61	Coal Ash Boiler Burning Material

19.20	Organic basic chemicals production	Ethylene	Inorganic basic chemicals production	20.14	Raw Material
19.20	Organic basic chemicals production	Fuel Gas	Inorganic basic chemicals production	20.13	Fuel
20.13	Micronized Silica	Silica	Galvanizing Processes	25.61	Raw Material
20.13	Basic Chemicals	Sodium Hydroxide	Galvanizing Processes	25.61	Raw Material
20.15	Nitrogen production	Steam	Greenhouse	113	Process heat
23.51	Cement production	Coal fly ash	Construction materials production	23.61	Raw Material
23.51	Cement and Lime producer	Lime kiln dust	Cast Iron Facility	24.10	Raw Material
23.61	Construction materials production	Construction and demolition waste	Road construction	42.11	Raw Material
24.42	Metal casting	Spent cell linings	Cement production	23.51	Alternative fuel and raw material (in clinker production)
24.42	Casting	Metallurgical coke dust and fines	Steelworks	24.10	Fuel
27.90	Photovoltaic modules production	End of life semiconductors	Photovoltaic modules production	27.90	Raw Material
35.11	Powet Plant	Fly Ash	Brick production	23.61	Raw Material
36.00	Wastewater treatment	Sludge	Fertilizer company	20.15	Raw Material

Table 7: Potential Sectoral Pairings in Konya OIZ.

	Wood	Treatment	Biogas	Glass / Ceramic	Farm / Animal Husbandry	Cement / Construction	Distillation / Fruit Juice	Gemstone	Iron Steel / Steel / Smelting / Aluminum / Nickel / Chrome	Power Plant / Electricity - Methane Production	Photovoltaic Module Production	Galvanizing Processes	Food / Confectionery / Animal Feed	Service	Pharmaceutical	Urban Asset / Public	Chemical / Paint /	Plastic / Packaging	Logistics	Metallurgical Operations	Automotive	Refinery / Petroleum Processing / Oil Extraction	Cellulose / Paper /	Agriculture / Greenhouse Farming	Transportation / Road Construction
Service									x				x	x	x										
Pharmaceutical					x					x				x	x		x								
Urban Asset / Public Buildings									x							x		x				x			
Chemical / Paint / Fertilizer / Cosmetic		x			x	x			x			x	x		x		x	x				x	x	x	
Plastic / Packaging								x				x	x			x	x	x						x	x
Logistics																			x			x			
Metallurgical Operations																				x	x				
Automotive						x				x										x	x				
Refinery / Petroleum Processing / Oil Extraction			x			x				x			x			x	x		x			x			
Pulp / Paper / Printing						x	x						x				x						x	x	
Agriculture / Greenhouse Farming	x		x			x							x				x	x					x	x	
Transportation / Road Construction									x									x							x
Wood	x		x			x																		x	
Treatment		x							x								x								
Biogas	x		x		x								x									x		x	
Glass / Ceramic				x		x			x				x								x				
Farm / Animal Husbandry			x		x								x		x		x								

Table 8: Potential Sectoral Pairings in Konya OIZ.

	Wood	Treatment	Biogas	Glass / Ceramic	Farm / Animal Husbandry	Cement / Construction	Distillation / Fruit Juice	Gemstone	Iron Steel / Steel / Smelting / Aluminum / Nickel / Chrome	Power Plant / Electricity - Methane Production	Photovoltaic Module Production	Galvanizing Processes	Food / Confectionery / Animal Feed	Service	Pharmaceutical	Urban Asset / Public	Chemical / Paint /	Plastic / Packaging	Logistics	Metallurgical Operations	Automotive	Refinery / Petroleum Processing / Oil Extraction	Cellulose / Paper /	Agriculture / Greenhouse Farming	Transportation / Road Construction
Cement / Construction	x			x		x			x				x				x				x	x	x	x	
Distillation / Fruit Juice							x						x										x		
Gemstone								x										x							
Iron Steel / Steel / Smelting / Aluminum / Nickel / Chrome		x		x		x			x	x				x		x	x								x
Power Plant / Electricity - Methane Production									x	x			x		x						x	x			
Photovoltaic Module Production											x														
Galvanizing Processes												x					x	x							
Food / Confectionery / Animal Feed			x	x	x	x	x			x			x	x			x	x				x	x	x	

As seen in the analysis, there are numerous exchange alternatives between different sectors. By evaluating exemplary practices and case studies for potential matches and industrial symbiosis opportunities, companies can develop roadmaps with the support of conducted study works and policy tools. Businesses operating in sectors for which examples are provided, as well as those for which examples could not be given due to data insufficiency, can identify unique methods through field visits and study works. They can also identify waste and by-products that they can offer to or receive from different companies based on their product and material structures.

While the analysis focuses solely on waste, by-product, and energy exchanges, information and service sharing are also essential components of industrial symbiosis applications. Umbrella structures such as energy efficiency networks within the region can facilitate the sharing of best practices conducted within companies, serving as examples to other businesses within the network. Brainstorming sessions can be organized to generate alternative energy efficiency solutions, and independent efforts by businesses can be supported.

Although industrial symbiosis applications may be challenging to implement and sustain independently, their integration into the establishment and planning phases of industrial zones, especially organized industrial zones, can contribute to the creation of more effective and efficient industrial zones from economic, social, and environmental perspectives. It can also serve as a guiding force for the preference of energy-efficient solutions.

Policy tools such as carbon pricing and energy efficiency obligation systems play a significant role in transitioning to energy-efficient solutions. Therefore, regulations, incentives, investments, and awareness campaigns brought by policymakers at all stages of industrial zone establishment, expansion, and planning will play a crucial role in the adoption and implementation of the industrial symbiosis concept.

Taking into consideration all these results, unlike the cases examined in the literature, collecting required information from companies through websites or platforms and match them accordingly, in this study, it is conducted with NACE codes and a region-specific study. Thus, companies can gain insights through matching their own NACE codes and may become interested in the topic. Furthermore, not only IS related awareness, applications and willingness to do issues but also energy efficiency related requirements such as energy manager presence, energy audit studies and energy efficiency applications as well as renewable energy utilizations together with waste heat were examined by the applied survey study.

Additionally, in the literature, there are numerous studies at the scale of countries, cities, sectors, regions, and specific collaborated firms. In this study, an industrial zone was selected as the scale, and the impacts of the potential within a specific region were examined in detail. This approach aimed to emphasize the benefits of regional development, local collaborations, and environmental and cost-related advantages. In other words, while many studies on IS are generally framed within a broad context, this study specifically examines the applicability in OIZs and the impact of these applications on symbiotic relationships between enterprises. The roles of legal regulations and the importance of collaborative structures are highlighted, as well.

Under the supervision of the European Union, it has been observed that many symbiotic and collaborative projects and applications operate and are receiving financial supporting. Most of these projects have dedicated websites, promotional activities or resources reporting the project outcomes. In Türkiye, however, there are fewer resources and less information available on this topic, which slows down its awareness and dissemination. The relative scarcity of studies specific to Türkiye, compared to the global context, underscores the need to demonstrate the potential through a selected region.

As awareness of the topic increases, symbiosis and cooperation-based practices should proliferate in our country. For the most effective and efficient use of energy, which is indispensable in our lives, collective action and collaborations should be established in areas with high energy consumption, in addition to individual efforts. This way, desired outcomes can be achieved more quickly, the effects of energy dependency can be mitigated, the impacts of climate change can be reduced, and maximum efficiency in resource utilization can be achieved.

5. CONCLUSIONS

Industrial symbiosis can help cut carbon emissions by making the best use of materials and energy. Through resource efficiency, it can lessen the impact of industries on the environment. Using a circular economy to combat climate change can also result in sustainable consumption and production practices. Because of all these advantages, industrial symbiosis is directly related to several United Nations Sustainable Development Goals including; Affordable and Clean Energy (SDG-7); Decent Work and Economic Growth (SDG-8); Industry, Innovation, and Infrastructure (SDG-9); Responsible Consumption and Production (SDG-12); and Climate Action (SDG-13).

This study targets to analyze the role, importance, and potential benefits of industrial symbiosis in energy efficiency initiatives. Additionally, it evaluates its connection and relationship with structures like energy efficiency networks. The study delves into the opportunities that policy tools and incentives can provide for initiating, sustaining, and ensuring the permanence of industrial symbiosis applications.

To assess the applicability of industrial symbiosis in organized industrial zones, a data gathering from selected OIZ and parallel survey study was conducted in the selected region. The objectives include measuring the knowledge and awareness levels about the subject, covering the industrial symbiosis potential, and demonstrating the contributions that can be made to energy efficiency through potential applications. The survey was distributed to companies via phone calls and emails, conducted by researchers and the regional top organization. However, only a small fraction of the firms in the region responded. Various interpretations were made based on these responses. Additionally, energy audit reports conducted by an audit center operating in the region were obtained. These audit reports revealed significant opportunities for energy efficiency, emission reduction, and cost savings. Therefore, it is concluded that there is substantial symbiosis potential in the region based on both survey and audit report results.

Within the scope of this study, it is observed that the sectoral distribution in the Konya OIZ region is predominantly oriented towards iron, steel, and non-ferrous metals, with significant presence in the metal, automotive, and machinery sectors. Although the initial goal of the study was to analyze companies involved in the production and services of metals and ores, focusing on their structure, operations, products, and production details to form a basis for potential symbiotic structures, the low response rate to the survey led to the compilation of examples from all sectors in the region.

From the survey responses, it can be inferred that firms are more knowledgeable and inclined towards renewable energy rather than energy efficiency. The knowledge of solar energy systems appears to be more widespread than energy efficiency. It is believed that financial supports similar to renewable energy incentives could increase interest in industrial symbiosis. The survey responses related to this topic also indicate this trend.

The industrial waste generated by firms, generally treated as scrap or disposed of in recycling facilities, could be kept within a circular system through agreements with different firms in the region. The energy and cost savings realized through such reutilization would benefit all stakeholders involved. Some firms' transactions with nearby firms were found to fit the symbiotic model, even if not explicitly labeled as such.

Regarding waste heat, it is noted that some firms are aware of their waste heat but have not taken action to utilize it. Considering the sectoral structure in the region, it is believed that waste heat potential could be harnessed through further audit studies.

Based on these outcomes, uncovering the existing potential and fostering inter-sectoral collaborations among companies require firms to possess the willingness and vision to achieve these objectives. Companies need to have an understanding of the subject and the ability to foresee the potential benefits to embrace this perspective willingly and engage in industrial symbiosis activities. Additionally, the presence of necessary incentives is crucial for companies to prioritize and invest in systems like industrial symbiosis. The availability of incentives and the emphasis on the subject through incentives and other policy tools provided by governments may serve as a motivating factor for companies to prefer industrial symbiosis applications. While they could consider a different investment alternative with their own capital and resources, they may prefer to implement industrial symbiosis applications with government incentives.

Steps that are specified with the information obtained from the 12th Development Plan, II. UEVEP and survey results to promote industrial symbiosis and encourage more investment in symbiosis include:

- Increasing awareness: Awareness-raising activities can be conducted on the benefits of industrial symbiosis, such as cost savings, resource efficiency, and environmental impacts.
- Setting targets: Policymakers or OIZ management can set targets for resource consumption or waste reduction, encourage firms to participate in symbiosis projects, and track success through monitoring and measuring.
- Providing legal support: Legal regulations and policies can help foster industrial symbiosis activities. Regulatory rules may also include guidance on business models for implementing symbiotic practices.
- Using market-based mechanisms: Businesses can be encouraged to engage in industrial symbiosis projects and offer resources through policies and regulations tools such as tax breaks, obligation systems, and subsidies. Regulations such as energy efficiency obligations generally target the industrial sector with high energy consumption, along with energy distribution and supply companies worldwide. Within these practices, white certificates are also supported. For Türkiye examples, there are three direct actions related to market-based policy mechanisms supporting energy efficiency in the II. UEVEP. The action with code Y2, "Development of National Energy Efficiency Financing Mechanism," is a comprehensive action plan. The use of policy mechanism tools in energy efficiency is also supported by actions Y4, "Supporting Energy Efficiency Projects with Energy Efficiency Competitions," and Y8, "Development of Energy Efficiency Obligation Program.". Taking these action plans into consideration can expedite activities on the issue.
- Developing case studies: Successful examples and case studies can be released as open sources to highlight the potential benefits of industrial symbiosis initiatives, promote the development of potential new projects, and urge companies to follow up on completed projects.
- Facilitating connections: Online platforms or energy efficiency networks can help firms connect with possible partners and resources for industrial symbiosis projects. Best practices among businesses can be shared, creating environments that promote regional development.
- Providing financing: Grants, loans, or other financial support options can be offered to help businesses invest in industrial symbiosis projects.

Implementing these methods will encourage more enterprises, OIZs, and particularly areas in the planning and expansion stages of OIZs, to invest in industrial symbiosis, resulting in a more sustainable and efficient industrial ecosystem. These structures are critical for the region's transition to a green OIZ. The proportion of enterprises participating in symbiosis compared to the total number of businesses is one of the performance indicators required for green OIZ certification. Other performance measures include the OIZ's ratio of water, electricity, and natural gas usage to annual revenue, as well as its renewable energy generation to energy consumption. Given that green OIZ certificates will become essential for new or expanding areas in the next years, the significance of these activities becomes clearer.

Each firm has its own structure, with distinct aims and visions. Potential collaborations and partnerships can be formed even between businesses with diverse goals and focuses by showcasing each firm's resources and potential. Promoting the benefits of structures like industrial symbiosis and energy efficiency networks through training and awareness campaigns may grab the attention of businesses and industries in the subject.

Such frameworks may accelerate regional growth, increase employment, reduce industrial-related environmental problems, and improve product and service quality through competition and incentives.

Each industrial zone has its own structure and characteristics in terms of the environment, society, and economy. As a result, while each application created acts as a model for future applications, it will preserve its distinct characteristics. In this context, with the help of local governments, awareness and expertise of regional enterprises can be raised, making it easier to develop these structures.

DECLARATION OF ETHICAL STANDARDS

The authors declare that all ethical guidelines including authorship, citation, data reporting, and publishing original research.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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DATA AVAILABILITY

Some data used during the analysis was obtained from the MAESTRI open book library. Other additional data will be available upon reasonable request.

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