INDUSTRIAL SYMBIOSIS MODEL AS A TOOL OF CIRCULAR ECONOMY SUPPORTED BY LCA: A CASE STUDY OF ADANA ORGANIZED INDUSTRIAL ZONE

A Thesis Submitted to
the Graduate School of Engineering and Science of
İzmir Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

in Environmental Engineering

by
Berat Batuhan KAPLANGI

JULY 2024
İZMİR

We approve the thesis of **Berat Batuhan KAPLANGI**

Examining Committee Members:

Prof. Dr. Fehmi Görkem ÜÇTUĞ
Mechanical Engineering, Izmir University of Economics

Prof. Dr. Nilgün Ayma ÖZ
Environmental Engineering, Çanakkale Onsekiz Mart University

Assoc. Prof. Hatice Eser ÖKTEN
Environmental Engineering, İzmir Institute of Technology

Assoc. Prof. İstemi BERK
Business Administration, Dokuz Eylül University.

Dr. Ing-. Mehmet Ali KÜÇÜKER
Environmental Engineering, İzmir Institute of Technology

05 July 2024

Dr. Ing-. Mehmet Ali Küçüker
Supervisor,
Environmental Engineering
İzmir Institute of Technology

Prof. Dr. Fehmi Görkem Üçtuğ
Co-Supervisor,
Mechanical Engineering
Izmir University of Economics

Prof. Dr. Sait C. SOFUOĞLU
Head of the Department of
Environmental Engineering

Prof. Dr. Mehtap EANES
Dean of the Graduate School of
Engineering and Sciences

ACKNOWLEDGMENTS

I would like to express my deepest gratitude to my advisor, Dr. Ing-. Mehmet Ali Küçüker, for creating an environment where I could develop myself in a disciplined and happy manner. His guidance and support have been crucial to the successful completion of this thesis. I look forward to achieving many more successes together in the future.

I would also like to thank TÜBİTAK (The Scientific and Technological Research Council of Türkiye) for its support of project no. 122M210 entitled “Developing Circular Economy and Industrial Symbiosis for Transforming Adana Hacı Sabancı Organized Industrial Zone into an Eco-Industrial Park to Comply with the European Green Deal," coordinated by Prof. Dr. Volkan Ediger.

Additionally, I extend my deepest gratitude to Prof. Dr. Fehmi Görkem Üçtuğ, Prof. Dr. Nilgün Ayman Öz, Assoc. Prof. Dr. Hatice Eser Ökten and Assoc. Prof. Dr. İstemi Berk for their presence and valuable feedback during my thesis defence at our institute. I extend my gratitude to Ersin Akpınar, Director of AOIZ, Özkan Özbek, Esin Sevgi and Assoc. Prof. Ali İnan for their endless support in our work at AOSB.

I am eternally grateful to my dear mother, NESRİN OKAN, and my dear father, HAKAN KAPLANGI, for always being by my side. I also extend my love and gratitude to my beloved maternal grandmother, aunt, uncle, and paternal grandmother. Lastly, I would like to express my heartfelt thanks to Sevgi, who has introduced love and peace into my life.

I would like to thank my companions at the institute, Bora and Gizem, and all my friends at İYTE with whom I have shared respect and camaraderie at our large tables. Special thanks go to Çiğdem, Tahir, Yiğithan, Hasan Bey, and Muhammed, with whom I have fought in the same war in our office. I am also grateful to all the Faculty Members and Research Assistants in the Department of Environmental Engineering for their unwavering support.

A heartfelt thanks to my best friend Dr. Ahmet Onur Çakıryılmaz and all my friends from Germany to Bangladesh. I also extend my appreciation to everyone who has been by my side and guided my life, from my primary school teacher to my last boss.

Lastly, I dedicate this thesis to the memory of my grandfather, YAVUZ OKAN

ABSTRACT

INDUSTRIAL SYMBIOSIS MODEL AS A TOOL OF CIRCULAR ECONOMY SUPPORTED BY LCA: A CASE STUDY OF ADANA ORGANIZED INDUSTRIAL ZONE

This thesis aims to develop an industrial symbiosis model for 24 facilities located in the Adana Organized Industrial Zone (AOSB). Within the framework of the European Union Green Deal (EU Green Deal) and the United Nations (UN) Sustainable Development Goals, which emphasize the global importance of the circular economy (CE) model, this thesis focuses on all aspects of industrial symbiosis to transform organized industrial zones into eco-industrial parks and promote greener and more sustainable production. All facilities have been coded with NACE codes, and potential symbiosis alternatives between them and within in-factory processes have been examined. Potential matches have been identified and evaluated based on criteria such as environmental gains, emission reductions, and decreases in electricity, natural gas, and waste production that could be achieved through symbiosis. Value stream maps have been prepared for all facilities, and tables summarizing production and consumption processes have been created. Potential matches with other facilities have been identified, and a visual network was created through network analysis. Life cycle analyses (LCA) were conducted for two facilities, assessing the potential benefits of symbiosis through LCA. Subsequently, environmental benefits of symbiosis were calculated using emission factors. This study reveals that, as a result of possible industrial symbiosis scenarios, an industrial symbiosis system formed by the companies subject to the thesis could potentially achieve approximately 120,000 tCO_2 emission savings and 15,000 MWh electricity savings annually. This study will contribute to future industrial symbiosis efforts in the transformation process of an organized industrial zone into an eco-industrial park.

Key Words: Circular economy, Industrial symbiosis, Life cycle assessment, Eco-industrial park

ÖZET

YDA DESTEKLİ BİR DÖNGÜSEL EKONOMİ ARACI OLARAK ENDÜSTRİYEL SİMBİYOZ MODELİ: ADANA ORGANİZE SANAYİ BÖLGESİ ÖRNEĞİ

Bu tez, Adana Organize Sanayi Bölgesi (AOSB)' de yer alan 22 firmaya ait 24 tesis için bir endüstriyel simbiyoz modeli oluşturmayı amaçlamaktadır. Avrupa Birliği Yeşil Mutabakatı (AYM) ve Birleşmiş Milletler (BM) Sürdürülebilir Kalkınma Hedefleri kapsamında dünya çapında önemi vurgulanan döngüsel ekonomi (DE) modeli ile organize sanayi bölgelerinin eko-endüstriyel parka dönüşmesi ve daha çevreci ve sürdürülebilir üretimin benimsenmesi amacıyla endüstriyel simbiyoza tüm yönleri ile odaklanmaya çalışan bu tezde tüm tesisler NACE kodları ile kodlanmış ve birbirleri arasında, fabrika içi prosesler arasında olası simbiyoz alternatifleri incelenmiştir. Olası eşleşmeler belirlenmiş ve simbiyoz sayesinde elde edilebilecek çevresel kazanımlar, emisyon azaltımı, elektrik, doğal gaz ve atık üretiminin azalması gibi kriterlerle değerlendirilmiştir. Tüm tesisler için değer akış haritaları hazırlanmış, üretim ve tüketim süreçlerini özetleyen tablolar oluşturulmuştur. Diğer tesislerle olası eşleşmeler belirlenmiş ve ağ analizi yapılarak görsel bir ağ oluşturulmuştur. İki tesis için yaşam döngüsü analizi (LCA) yapılarak, simbiyozun olası kazanımları LCA ile değerlendirilmiştir. Daha sonra, simbiyozun çevresel kazanımları emisyon faktörleri kullanılarak hesaplanmıştır. Olası endüstriyel simbiyoz senaryoları sonucunda bu teze konu olan firmaların oluşturacağı bir endüstriyel simbiyoz sistemi ile yılda yaklaşık 120.000 tCO_2 emisyonu ve 15.000 mWs elektrik tasarrufu elde edilebileceğinin olası olduğunu ortaya koyan bu çalışma, bir organize sanayi bölgesinin eko-endüstriyel parka dönüşüm sürecinde bundan sonra gerçekleştirilecek diğer endüstriyel simbiyoz çalışmalarına katkıda bulunacaktır.

Anahtar Kelimeler: Döngüsel ekonomi, Endüstriyel simbiyoz, Yaşam döngüsü analizi, Eko-endüstriyel park

TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

The purpose of this thesis is to develop and evaluate an industrial symbiosis (IS) model supported by life cycle assessment (LCA) as a tool for advancing the circular economy (CE), using the Adana Organized Industrial Zone (AOIZ) as a case study. This research aims to analyze the current production processes of pilot firms in the AOIZ in terms of CE and its tools, including IS practices within the scope of the significant European policies containing the European Green Deal (EGD), the Fit for 55 packages, and the Circular Economy Action Plan (CEAP), drawing a framework for the governments and industries. Furthermore, the study will develop IS scenarios and assess the possible environmental benefits of these scenarios through LCA analyses. Finally, the IS potential in Türkiye and possible improvements will be discussed through the studies carried out for AOIZ.

From the beginning of the Industrial Revolution, industrial activities further the pressure on the climate and global resources day by day. The CE concept is believed to be a promising approach for the sustainable use of resources by maintaining the value of products, materials, and resources in the economy for as long as possible, thereby minimizing waste (Bocken et al., 2015; Harfeldt-Berg et al., 2023). Being a crucial component of the CE, IS facilitates the exchange of by-products, energy, and materials between companies, transforming waste from one organization into valuable inputs for another to decrease adverse pressure on the environment (Harfeldt-Berg et al., 2023; Dolgova & Nikitaeva, 2023).

This research is designed to address the belief that implementation of IS strategies can reduce the environmental impacts of manufacturing processes within the AOIZ, echoing conclusions drawn from prior studies that underline the significance of understanding the material and energy flows of the firms (Chertow, 2007; Geng et al., 2012). In order to achieve this understanding, VSMs for each pilot firm are prepared as a key tool within the lean manufacturing philosophy that helps visualize and analyze processes in terms of waste and inefficiencies (EPA, 2013; Steven et al., 2022). Using VSMs, energy, water, or materials losses can be identified to highlight the potential opportunities for IS (Holgado et al., 2018). Afterward, this study tests the measurability of environmental enhancements resulting from the implementation of IS strategies and determines whether the environmental impacts arising from alterations in resource consumption and waste generation can be effectively demonstrated through LCA studies (Ehrenfeld and Gertler, 1997; Finnveden et al., 2009).

Strict and organized policies are able to create a supportive framework for the IS, which is a system that depends on the collaboration of the various facilities and organizations. It is anticipated that European policies, specifically EGD, Fit for 55, and CEAP, will promote sustainable industrial practices and reduce carbon emissions, thereby easing the adoption of IS practices (European Commission, 2019; European Commission, 2021). The impact of European policies on ' 'Türkiye's industrial practices is clearly observable, and it is believed that there are significant opportunities for extending IS initiatives in the country (Mısır and Arıkan, 2022; Sonel et al., 2023).

This thesis aims to test the stated hypotheses above and provide strategies for enhancing IS in Türkiye. Focusing on the data collected from 22 firms within the AOIZ through interviews and site visits, IS opportunities are proposed for all firms, and LCA will be conducted for two selected firms both before and after the implementation of IS scenarios to evaluate the environmental impacts following the standards outlined in ISO 14040:2006 (Zhang et al., 2017). The uncertainties will be quantified through sensitivity analyses to assess the reliability and robustness of the LCA results (Cellura et. Al., 2011). Consequently, the thesis will offer insights into the implementation of the policies and IS strategies in AOIZ to convert this organized industrial zone (OIZ) into an eco-industrial park (EIP), which is a concept emphasizing industrial synergetic relations aligns with the goals of the United Nations (UN) Sustainable Development Goals and EGD (Geng et al., 2009).

The thesis is divided into five main chapters.

The first chapter introduces the purpose and scope of the thesis, providing a clear understanding of the research objectives. The chapter defines the research hypotheses, outlining the specific hypothesis that will be tested throughout the study.

The second chapter, Literature Review, provides information on existing literature on key concepts relevant to the thesis, including CE, IS, LCA, the relationship between CE and IS, lean manufacturing and VSM, and an examination of significant policies such as the EGD, the Fit for 55 packages, and the CEAP. Additionally, it explores the implementation of the policies of the UN, the reflections of these global acts in Türkiye, and the potential for IS within OIZs by providing examples from the literature, showcasing successful case studies, and identifying opportunities and challenges.

The third chapter, Materials and Methods, explains the data collection processes used in the study and details the characteristics of the 22 pilot firms. It describes the VSM and LCA methodologies. The chapter also introduces the LCA software program, including the formulas used during the calculations of the environmental impacts, and gives information on emission factor calculation.

In the Results and Discussions part, the current situation analysis supported by the VSM of the pilot firms is presented, followed by a detailed LCA for two selected firms among 22 pilot firms. The results are evaluated to define the current environmental impacts and identify potential areas for improvement. The chapter then introduces the proposed IS scenarios and discusses their potential gains by considering energy, carbon, water, and raw material savings. In addition, the IS system is interpreted by achieving network analysis. Following the implementation of the scenarios, the renewed LCAs for the two firms are presented. The results are compared with the initial assessments to evaluate the effectiveness of the symbiosis scenarios in reducing environmental impacts.

The conclusion chapter summarizes the main findings of the research. The chapter concludes with a discussion of the findings, an evaluation of the results in the context of CE and IS, and an examination of the further IS potential in the other firms in AOIZ. It examines the status of IS in Türkiye and its alignment with EU policies; as well as providing recommendations for implementing CE and IS practices and suggests areas for future research.

CHAPTER 2

LITERATURE REVIEW

2.1. Circular Economy

CE is an economical model which is based on closed-loop systems that focus on the sustainable flow of production and consumption. CE preserves materials and resources in the manufacturing cycle as long as possible by emphasizing the principles of reducing, reusing, and recycling raw materials and products as well as energy to reduce the environmental impacts (Ongondo et al., 2021; Yang et al., 2023; Nunez and Perez-Castillo, 2023).

Unlike the traditional linear economy, which follows a 'take, make, 'dispose' model, the CE emphasizes the continuous use of resources by replacing "'disposal' with sustainable waste management techniques, including recycling and reusing (Yang et al., 2023). For instance, replacing fossil fuels with biogas and other renewable energy sources derived from waste as an example of CE application has decreased carbon emissions (Yang et al., 2023). This example covers collaborations where waste or by-products from one process are used as inputs for another, which is an application within the scope of circularity.

CE brings about benefits across economic and social dimensions, in addition to environmental gains. Economically, CE can lead to cost savings and new revenue streams through material recovery and reuse, fostering innovation in product design and business models. This allows companies to reduce material costs and tap into new markets for refurbished and remanufactured products. Socially, CE practices can create job opportunities in recycling, remanufacturing, and product design, promoting societal well-being through a more sustainable lifestyle (Geissdoerfer et al., 2017).

Despite the numerous benefits of the circular economy, its implementation poses several challenges. These include high initial investment costs, lack of consumer awareness and acceptance, difficulties coordinating across various stakeholders, and regulatory barriers. Initial setup costs for circular practices can be substantial, deterring many businesses. Additionally, consumer behaviors and attitudes towards consumption and waste are often deeply accepted, making it challenging to shift to more sustainable practices. The success of the circular economy also relies heavily on collaboration between various sectors, which can be difficult to achieve due to competing interests. Lastly, existing regulations may not be conducive to circular practices, requiring significant and continuous policy changes (Ghisellini et al., 2016).

CE is dependent on various tools. Fundamental mechanisms include LCA for evaluating environmental impacts; tracking material usage and energy consumption by using maps (VSM etc.); Extended Producer Responsibility (EPR) policies to hold manufacturers accountable for their products' lifecycle; design capability to create environmentally friendly products and digital technologies like IoT, big data analytics, artificial intelligence for enhancing efficiency and IS to utilize by-products and waste materials (Yang et al., 2023; Geissdoerfer et al., 2017).

2.2. Industrial Symbiosis

IS is a concept that has gained attention in terms of sustainability and resource efficiency. It can be defined as an organization where industries participate in the exchange of materials, energy, water, and by-products (Baldassarre et al., 2019). This exchange aims to reduce emission by decreasing the consumption of raw materials, energy, and waste generation (Schlüter et al., 2022). Symbiotic relationships between economically independent industries, especially in close geographical proximity, create a more sustainable industrial ecosystem (Herczeg et al., 2018).

IS was first proposed with the claim of using the waste produced in an industrial production process as raw material in order to reduce the negative effects of the processes on the environment (Frosch and Gallopoulos, 1989). One of the earliest and most influential examples of IS is the Kalundborg Eco-Industrial Park in Denmark, which began in the 1970s and has been extensively cited in literature for its successful implementation. This concept has since gained global traction, with the number of related publications growing exponentially, particularly in the last 20 years (Neves et al., 2020).

The most extensive IS research and case studies come from China, with 163 articles, followed by the United States, with 46 articles. Initial studies were focused on North America and Northern Europe, but by 2018, IS research expanded to 54 countries (Chertow et al., 2021). With these studies, it has been well understood that IS is one of the most significant strategies for the transition to CE.

The IS can be implemented in different ways. Input-output matching, which is based on the material exchange amoung companies, refers to a business's waste or by-product being used as raw material by another business and is the most frequently used IS implementation method. This involves identifying potential matches between IS systems by examining the attributes of output streams generated by industries and the corresponding material inputs they require (Patricio et al., 2022). Facilities are grouped – as well as the products, by-products, and wastes- in accordance with their codes, and potential matches can be identified, and potential matches are identified. This reduces both the amount of waste and the cost of raw materials. Secondly, energy exchange covers the use of one process's excess energy by another method. For instance, the steam produced by a power plant can be used in the production processes of a nearby facility. Such collaborations increase energy efficiency and reduce energy costs. In a study conducted in China, it has been stated that an energy-based IS could save up to 6% of energy in the iron and steel sector alone (Fraccascia et al., 2020). Another IS method is water exchange, which involves using a business's wastewater, either by treating it or directly by another business or process. This is especially important in areas where water resources are limited. Water exchange reduces water consumption and reduces businesses' wastewater treatment costs (Lawal et al., 2021). Logistics and transportation cooperation is another field of IS. Businesses located close to each other are very suitable for such partnerships. This mainly contributes to reducing the carbon footprint from transportation (Jacobsen, 2006; Henriques et al., 2021). In an IS system, facilities such as steam boilers and waste processing facilities should be strategically located at the center of the symbiosis network and collaborate with many facilities (Park et al., 2018). Finally, Information and Communication Technology (ICT) tools for sharing information and technology are essential to enhance the effectiveness of IS. These tools need to be designed with user-friendly, facilitating communication and collaboration, managing and analyzing data, supporting the transfer of documentation and knowledge, and identifying and assessing potential opportunities for IS. Moreover, LCA-based analysis, as being a software technology is a useful method to highlight the benefits of shared resources, thereby allowing policymakers to justify their decisions towards sustainable development (Daddi et al., 2017).

The IS applications in the literature are studied in Table 2-1.

Table 2.1. Notable Industrial Symbiosis Cases

Industrial Symbiosis Case	Explanation	Resource
Nanjing Jiangbei New Materials High-Tech Park (NJNMHTP)	NJNMHTP involves several facilities such as chemical manufacturing, recycling, power generation, pesticides and pharmaceuticals, synthetic materials, and sewage treatment enterprises. Recycling enterprises-with peripheral chemical manufacturing enterprises- are the most involved, playing a core role in the industrial symbiosis network by managing and utilizing waste products from various other enterprises.	(Liu et al., 2022)
Hai Hua Industrial Symbiosis (HHIS)	HHIS includes waste heat utilization in thermal power plants in other processes like soda plants and off-gas carbon black in thermal power plants. In addition, flare gas from petrochemical processes and hydrogen by-products from chemical processes are also utilized in the thermal plant. Fly ash generated in thermal plants is used as a raw material in the cement plant. In terms of water, the symbiosis practices include reusing treated wastewater, converting waste ammonia liquid into raw material, and utilizing bittern brine as a resource. Benefits in terms of resource consumption, waste generation and economic are assessed in the study.	(Cui et al., 2018)
Dunkirk Urban Area	The Dunkirk industrial symbiosis network includes 14 firms that exchange scrap, steel slag, refractory bricks, steel mill dust, acid waste, tires, solvents, animal feed, and used oil for the valorization of the industrial by-products. In addition, the study emphasizes the application of pooling services, including sharing logistics and transport operations.	(Morales and Diamer, 2019)
A Large UK Distributor	In the study, IS principles to develop an environmentally supply chain for a timber and building materials distribution industry- a large UK distributor- are explored. Resources exchange implementation, including pallet-return scheme, the remanufacturing of damaged stock involves direct exchanges of resources between the company and its partners, and working with waste management providers to convert non-recyclable waste into energy is one of the main parts of the IS system. Implementing and certifying ISO 14001 and integrating key performance indicators from ISO 50001 are the primary operations for institutionalizing the IS system.	(Leigh and Li, 2015)
Cluster West, Germany	Granulated Blast Furnace Slag (GBFS) from the steel industry is used as a clinker substitute in cement manufacturing, and by-products like fly ash and steel slag are used to replace a portion of the limestone in clinker production. Utilizing waste heat from cement production for electricity generation and district heating is the other leg of the symbiosis. Different cement products in the three cement factories are assessed by using LCA studies to compare CO_2-eq emissions.	(Ammenberg et al., 2015)

(cont. on next page)

Table 2.1. (cont.)

SINP In Columbia	Sustainable Industrial Network Program (SINP) covers 36 companies of different sizes in Columbia. These companies are working in various sectors including food production and processing, construction, waste management, packaging- container, chemical production, furniture, and agriculture. Food residues such as coffee and fruit syrup, wood waste and sawdust, cardboard boxes and plastic foams, plastic materials and wastes, and wastewater and sludges are the main productions that are subjected to the material exchange in the IS system. Environmental benefits of this study include prevention of 7207 tons of waste disposal, reduction of 1126 tons of greenhouse gas emissions, 619,500 kWh energy saving, and 146,000 m^3 water saving per year.	(Park et al., 2018)
Stakeholder Value Network Approach, A Case in France	In France, an incineration plant and the companies that provide waste to this plant and receive steam as energy sources are analyzed in terms of stakeholder relations within the framework of IS. In the study, the stakeholder value network approach is used to identify the value flows and utility degrees (importance, urgency of the relation) and compares the Degree of the symbiotic relations with each other. Due to their control over resources and main facilities, the incineration plant and industrial zone management are identified as the most critical stakeholders in this IS case. Besides, the local population in the industrial zone is essential for the sustainability of the IS	(Hein et al., 2016)
Relationship Between IS and Urban Symbiosis (UrS) in Slovenia	In the context of Slovenia, there is a rising awareness and legislative backing for the concepts of Industrial and Urban Symbiosis. These concepts, which are centered on promoting sustainable development through optimizing resource use and reducing waste, are yet to be fully integrated into urban strategies. Future integration of IS and UrS is anticipated, particularly in the regeneration of brownfield sites, which can enhance both industrial and urban sustainability efforts. Predominant challenges include limited waste conversion into energy and minimal reuse of by-products.	(Azman Momirski et al., 2021)
Industrial Symbiosis in a Subarctic Region	The study uses a multi-faceted methodology combining qualitative and quantitative approaches to explore the industrial symbiosis between data centers and greenhouse farming in a subarctic region. Workshops and interviews gather socio-economic data and stakeholder perspectives, while simulations and optimizations assess the technical potential of using data centers' excess heat to warm greenhouses. The technical model includes dynamic simulations of temperature and humidity control, optimizing for the maximum greenhouse area that a data center can heat. Scenarios are developed to illustrate the material and energy exchange, showcasing the potential for job creation and CO_2 emission reductions through the utilization of low-grade excess heat from data centers for sustainable food production	(Caceres et al., 2022)
Digital Twins to Support IS: the Norwegian Wood Supply Chain	Enhancing supply chain management can achieve industrial symbiosis by improving the transportation and exchange of by-products and waste among industries. This process optimizes resource efficiency, reduces costs, and minimizes environmental impacts. For example, implementing digital twins (visual representations of a system) in the supply chain can lead to significant carbon emission reductions, as seen in the study where direct emissions from fossil energy and indirect emissions from electricity were closely monitored and controlled. Small companies can reduce equipment and labor costs through cloud storage solutions, while large companies benefit from comprehensive digital twins that offer high data integration and long-term economic gains. These improvements facilitate the efficient exchange of materials, leading to more sustainable industrial practices.	(Liu et al., 2023)

2.3. Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is defined as a process to analyze and assess the environmental impacts of a product, process, or activity over its entire life cycle from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling (Cheah, 2014; Hämäläinen & Miettinen, 1997). In addition, LCA looks at product alternatives while carrying out the mass and energy balances from the extraction to the end-of-life issues (Hunkeler, 2016).

LCA objectives include a holistic environmental assessment of a product or process, considering the stages of a production or process by defining system boundaries. LCA quantifies environmental impacts and enables the estimation of cumulative environmental impacts concerning operation or material. In addition, LCA identifies and evaluates the potential environmental trade-offs and impacts shifts between different life cycle stages and different environmental media, such as air, water, and land (Curran, 2019). Furthermore, LCA can influence environmental policies and priorities, with governments using it to guide environmental and energy development priorities effectively. By encompassing all stages of a product's lifecycle and ability of linking environmental, social, and economic performance assessments, LCA serves as a crucial tool in promoting sustainable development and improving environmental management practices (Ashby, 2023; Jolliet et al., 2015).

The Eco Design Directive is a framework directive that requires manufacturers to meet environmental parameters for their products to bear the CE marking (European Commission, 2009). This directive aims to minimize material usage and eliminate toxic substances, carbon footprints, water usage, and waste generation. LCA helps in identifying opportunities for improving the environmental performance of the manufacturing processes, and this can lead to enhance Eco-Design concept (Jolliet et al., 2015; Pallakonda, 2023)

In addition to calculating the environmental impacts of production processes, LCA also helps determine the effects of parameters changing as a result of industrial symbiosis. In Table 2-2, LCA applications for IS in the literature are studied.

Table 2.2. Notable LCA Applications in Industrial Symbiosis Cases

Industrial Symbiosis Case	Explanation	Resource
Relation between fruit and vegetable production in a greenhouse and an anaerobic digestion plant	This study uses material flow analysis (MFA) and life cycle assessment (LCA) to evaluate the environmental impact of integrating greenhouse operations with anaerobic digestion (AD). The MFA accounts for inputs and outputs in mass units. At the same time, the LCA assesses the environmental impact of the entire system, including the production of biogas and digestate from tomato waste. The LCA model is created in SimaPro (software similar to CCalC-2) using the EcoInvent 3.6 database, evaluating impacts such as global warming potential, eutrophication, and acidification. The study shares insights that show the integrated system reduces environmental impacts compared to a conventional greenhouse system.	(Danevad and Carlos-Pinedo 2021)
Symbiotic relation in a chemical industry	LCA is used to assess the environmental impacts of the chemical industry including soda, ammonia, fertilizer plants and, co-generation power plants, and wastewater treatment plants. The environmental improvement due to the steam exchange between the facilities was analyzed by LCA studies in a framework of ISO 14040:2006 and 14044:2006. In this standard, analysis steps are goal and scope definition, inventory list, calculation of the effects, and showing the results.	(Zhang et al., 2022)
Industrial symbiosis for waste electrical and electronic equipment (WEEE)	The LCA methodology was used to quantify environmental impacts, particularly the Global Warming Potential. Environmental benefits were calculated by comparing the new symbiosis model with the baseline scenario without collaboration, highlighting significant reductions in CO_2 emissions due to improved material recovery and reuse.	(Marconi et al., 2018)
Lifecycle approach to map and characterize resource consumption and environmental impacts of manufacturing plants	This study presented the PLANTLCA methodology, focusing on mapping resource consumption and environmental impacts within manufacturing plants. Although manufacturing-specific, the principles and methodologies discussed can be applied to industrial symbiosis scenarios, offering insights into optimizing resource use and minimizing environmental impacts. In the study, human metabolism and industrial metabolism are compared, and similarities are underlined. The LCA analysis are achieved by SimaPro and Ecoinvent database (3.1).	(Favi et al., 2016)
Colloaborative approach for WEEE	In this study, LCA is not used, however, the importance of the construction of a common database for information and waste material sharing is emphasized. The stakeholders, including producers, end users, recyclers, and maintenance services, are involved in this system to share information related to the materials. This kind of system is essential and creates a baseline for symbiotic relations and related analysis such as LCA.	(Marconi et al., 2017)

2.4. Lean Manufacturing and Value Stream Mapping

Lean manufacturing is a comprehensive set of strategies for making products that focuses on eliminating waste and making it more valuable for the customer (Gupta et al., 2013). It uses a set of principles and methods that aim to simplify operations by eliminating activities that don't add value and improving the processes (Ghaithan et al., 2021). Using lean manufacturing can help businesses work more efficiently, lower costs, and make better products, which can give them an advantage over their competitors (Goshime et al., 2019). Lean manufacturing encourages continuous improvement and lets employees help make processes more efficient (Ghaithan et al., 2023). Many different industries use lean manufacturing principles (Genç, 2021). These principles are not limited to traditional manufacturing settings but can also be applied in service contexts to enhance productivity and service quality (Carlborg et al., 2013).

Value stream mapping (VSM) is a fundamental tool in lean manufacturing that allows organizations to visualize and analyze the flow of materials and information required to bring a product or service to the customer (Steven et al., 2022). By visualizing the production process as a whole, including value-added and non-value-added activities, VSM helps identify inefficiencies, bottlenecks, and waste within the system (Suhardi et al., 2019). This mapping technique enables companies to streamline operations, reduce lead times, and enhance overall process efficiency (Jocson & Tinio, 2021).

When incorporating environmental considerations, VSM can be adapted to include green metrics and sustainability practices to enhance both productivity and environmental performance (Gholami et al. (2019). Research has demonstrated that the integration of VSM with environmental concerns can lead to improved productivity and environmental performance (Muñoz-Villamizar et al., 2019). This approach, known as Green Value Stream Mapping, allows organizations to combine lean and environmental-friendly practices to enhance productivity and environmental sustainability (Muñoz-Villamizar et al., 2019).

The other practical approach is to utilize tools like Sustainable Value Stream Mapping (Sus-VSM) to visualize and evaluate manufacturing sustainability performance (Faulkner & Badurdeen (2014). Sus-VSM offers a structured methodology to identify and analyze sustainability aspects within value stream maps, enabling organizations to prioritize improvements aligned with environmental objectives. Furthermore, the adoption of Environmental Value Stream Mapping (E-VSM) can assist organizations in pinpointing and reducing the adverse environmental impacts of industrial operations (Garza-Reyes et al., 2018). By following the E-VSM methodology, companies can discover opportunities to minimize waste, energy consumption, and emissions, enhancing environmental sustainability. Moreover, integrating hot spot analyses in value stream maps with tools such as Sustainable Setup Stream Mapping (3SM) can further bolster sustainability efforts (Ebrahimi et al., 2021). 3SM provides a systematic approach to enhancing setup sustainability by analyzing activities within a value stream map and considering environmental, social, and economic factors.

Industrial symbiosis involves the exchange of waste streams and the sharing of resources among independent industries to reduce environmental impacts and enhance overall sustainability (Park et al. 2018). By incorporating value stream mapping into industrial symbiosis initiatives, companies can identify opportunities for waste exchange, resource sharing, and process optimization to create mutually beneficial relationships within industrial networks (Schoeman et al., 2020).

By mapping out the flow of materials and resources, companies can identify potential synergies and opportunities for collaboration to optimize resource utilization and minimize environmental impacts (Gunduz & Naser, 2017).

2.5. Regulatory Framework and IS Applications in Türkiye

In this thesis section, the relationship between the European regulations, United Nations (UN) Sustainable Development Goals and the application of the CE, IS, LCA and lean manufacturing practices will be explained. In recent years, compliance with the legal regulations determined by the EU in the environmental context in Türkiye has been reflected in the national laws. As a result, it is essential to examine the EU Directives when determining the framework of IS activities in Türkiye and AOIZ.

2.5.1. European Green Deal

The European Union's (EU) roadmap for the green transformation process required by the Paris Climate Agreement has been laid out in the European Green Deal (EGD). Announced on December 11, 2019, the EGD is the EU's growth strategy aiming to make Europe the world's first climate-neutral continent by 2050, where greenhouse gas emissions are net-zero. The EGD, which aims to make the EU resource-efficient, competitive, and modern, is a comprehensive transformation plan covering various areas from production to trade, energy to transportation, and agriculture to taxation. Under the EGD, it is anticipated that all sectors of the EU economy will be restructured to contribute to the EU's goal of being climate-neutral by 2050. To achieve the goals of the EGD, it is planned to implement approximately 1 trillion euros of sustainable investment over the first 10-year period.

"Fit for 55" is a legislative package aimed at reducing greenhouse gas emissions by 55% by 2030 as part of the European Green Deal. This package includes comprehensive regulations in sectors such as energy, transportation, buildings, and land use in accordance with the intermediate goals set to achieve the EU's goal of climate neutrality by 2050 (European Commission, 2021).

The Circular Economy Action Plan is a strategy presented by the European Commission in 2020 to accelerate the transition to a circular economy. This plan includes various measures to extend product life cycles, reduce waste, and use resources more efficiently. The circular economy aims to provide environmental and economic benefits by promoting innovation in areas such as waste management and resource efficiency (European Commission, 2020).

Chronologically, the European Green Deal was introduced in December 2019 as the main policy framework. The Fit for 55 packages followed in July 2021, outlining specific legislative measures to meet the EGD targets by 2030. The Circular Economy Action Plan was launched in March 2020, reinforcing the goals of the EGD by promoting sustainable resource management practices (European Commission, 2023; Marmo, 2021).

These three concepts—the European Green Deal, Fit for 55, and the Circular Economy Action Plan—are interconnected in their pursuit of sustainability and climate neutrality. The European Green Deal sets the overarching vision and targets, while Fit for 55 translates these targets into actionable legislative measures, and the Circular Economy Action Plan provides a specific strategy for resource efficiency and waste reduction. The integration of these initiatives ensures a comprehensive approach to environmental sustainability, addressing both climate change and resource use (Spani, 2020).

2.5.2. UN Sustainable Development Goals

The 2030 Agenda for Sustainable Development, adopted by all UN Member States in 2015, outlines 17 Sustainable Development Goals (SDGs) aimed at eradicating poverty, improving health and education, reducing inequality, promoting economic growth, combating climate change, and preserving oceans and forests. These goals build on previous initiatives such as the 1992 Earth Summit's Agenda 21, the 2000 Millennium Declaration, and the 2012 Rio+20 conference, which laid the groundwork for the SDGs and established the UN High-level Political Forum on Sustainable Development (UN, 2024).

United Nations Industrial Development Organization (UNIDO) supports the Sustainable Development Goals by facilitating eco-industrial parks, where businesses collaborate to manage environmental and resource issues, a practice known as industrial symbiosis. This collaboration enhances environmental, economic, and social performance through the exchange of materials, energy, water, and by-products, promoting sustainable development. Eco-industrial parks drive resource efficiency and circular economy practices, bridging the gap between cities and industries for more sustainable urban development (UNIDO, 2024).

2.5.3. Adaptation of EU and UN Policies in Türkiye

In 2021, Türkiye developed its Green Deal Action Plan, led by the Ministry of Commerce, to guide the country's transition to a green economy. This plan outlines strategic objectives and actions across various sectors, including energy, industry, and waste management, to ensure alignment with the EGD. The plan emphasizes increasing the use of renewable energy sources, improving energy efficiency, and adopting circular economy principles to reduce waste and enhance resource efficiency (Yılmaz, 2022).

Türkiye's goals in the circular economy focus on waste management and energy efficiency. The country aims to recover 60% of municipal waste by 2035 and achieve a recycling rate of 65% for packaging waste by 2026, increasing to 70% by 2031 (Mısır & Arıkan, 2022). The Zero Waste Project, initiated in 2017, plays a crucial role in these efforts by promoting waste reduction, segregation, and recycling at the source. This project has already yielded significant results, including saving 356 million kWh of energy, 437 million m^3 of water and preventing 3 million tons of greenhouse gas emissions by 2021 (Mısır & Arıkan, 2022).

In terms of carbon emissions, Türkiye has committed to reducing its greenhouse gas emissions by 21% from the business-as-usual scenario by 2030, as outlined in its Nationally Determined Contribution under the Paris Agreement. This commitment reduces projected emissions from 1,175 $MtCO_2e$ to 929 $MtCO_2e$ by 2030 (Yeldan et al., 2021). Türkiye's strategies involve increasing the share of renewable energy in its energy mix and enhancing energy efficiency across various sectors to meet these targets (Mirici & Berberoğlu, 2022).

The Ministry of Industry and Technology has put forward a program that includes regulations for Organized Industrial Zones and has established the Green Organized Industrial Zone and Green Industrial Zone Certification System in cooperation with the World Bank. The main aim of the Green Organized Industrial Zone and Green Industrial Zone Certification System Project is to elevate industrial zones in our country to international standards by adopting the principle of "Continuous Improvement" in line with Sustainable Development Goals. Within the framework of this work carried out with the Turkish Standards Institute (TSE), studies were conducted on 6 preliminary criteria and 40 performance criteria to become a Green Organized Industrial Zone. One of the performance criteria is the Ratio of the Number of Companies Participating in Industrial Symbiosis in an Organized Industrial Zone to the Total Number of Companies. If this ratio is between 0% and 5%, 1 point is given; if it is between 5% and 10%, 2 points are given; and if it is 10% or more, 3 points are given. Facilities with 40 points and above are gradually certified with the Green Organized Industrial Zone certificate. This is an essential step towards the transformation of the Organized Industrial Zones in our country into Eco-Industrial Parks.

2.5.4. IS Examples in Türkiye

There are various IS implementation projects for OIZs in Türkiye. Table 2.4 shows IS cases in some OIZs in Türkiye are assessed. In that table, IS applications are identified, and potential environmental achievements are underlined. This thesis evaluates the IS system developed for AOIZ according to the same key indicators.

Industrial symbiosis in Türkiye, an essential aspect of the circular economy, involves the collaboration between industries to use each other's by-products and waste materials. This practice not only reduces waste but also enhances resource efficiency and competitiveness. In addition, this practice is defined by the Ministry of Environment, Urbanization and Climate Change (Mısır & Arıkan, 2022).

In the following Figure 2.1, the symbiotic relationship between the concepts mentioned at the entrance is visualized.

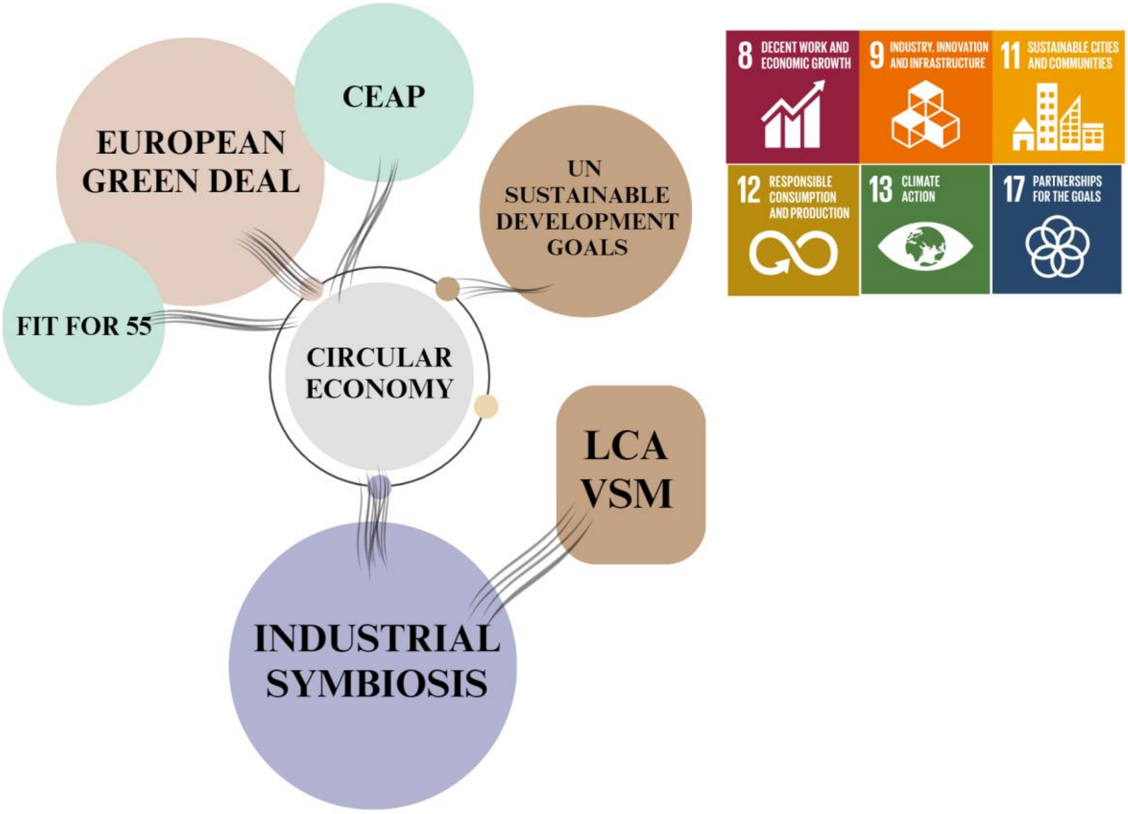


Figure 2.1. Conceptual Symbiosis Outlining the Studies

Table 2.3. IS Cases in Organized Industrial Zones (OIZ) in Türkiye

OIZ Subjected to IS Projet	Key Features	CO2 Emission Save (tCO$_2$/year)	Energy Save	Raw Material Save (tons/year)	Water Save (m^3/year)
Industrial Symbiosis in Iskenderun Bay (2010-2014)	In this study the IS network included 264 institutions. Over 500 IS opportunities were found between these institutions. Ten of these opportunities include Utilizing cottonseed waste to create a product for soil remediation, Using orange juice waste from juice producers for animal feed production, using slag from iron and steel companies for road construction, generating biogas from agricultural and animal waste in the Çukurova region, recycling waste accumulators to recover lead, creating fertilizer from slag produced by iron and steel companies and using soda process waste as an additive in cement production are examined in detailed (Alkaya et.al., 2014; Dolgen and Alpaslan et.al., 2020).	38,680	33,581,155 kWh	276,253	6500
Eskisehir Industrial Symbiosis (IS) Possibilities Research Project (2020)	Green cell (full time staff) in the OIZ has been established for the transformation to EIP (World Bank, 2021). Involving 50 companies and five institutions, the project identified 217 potential symbiosis opportunities. Five high-potential symbiosis projects were prioritized for pilot implementation (GTE, 2024; International Synergies Ltd., 2019)	118,505	3-30% /year	129,312	-
Konya OIZ (2018)	Ground-mounted solar farms with a capacity of 4.5 megawatts were constructed on three plots of nonoperational land within the industrial park, covering a total area of approximately 65,000 m^2. The energy produced by these solar farms is then distributed to the tenant firms within the park. This OIZ managed to obtain a Green OIZ Certificate. (World Bank, 2021; OSBÜK, 2024)	4,420	$804,000 energy cost saving	-	-
Industrial Symbiosis and Eco-efficiency Project in Antalya Organized Industrial Zone (2015-2017)	In this project, some symbiosis alternatives, including the utilization of the wastewater treatment sludge in fertilizer manufacturing, and concrete production for the civil engineering sector by using waste ash and dust generated from various sectors were examined. Interconnections between the paper, textile, poultry, food, cement, and metal industries were analyzed, and potential symbiosis scenarios have been discussed (Antalya OSB, 2015; Dolgen and Alpaslan et.al., 2020).	3,800	-	91,600	75,000
Industrial Symbiosis Project in İzmir Region	170 firms have been visited, and 8 sectors have been determined to study. Then, 57 facilities were investigated and analyzed. During the studies, food manufacturing, textile, chemical, plastic, machinery, and trailer manufacturing sectors were deeply analyzed to convert the İzmir OIZ into an Eco-Industrial Park (GTE, 2024; Dolgen and Alpaslan et.al., 2020).	63,892	151,840,000 kWh/year	16,000	1,152,032

Industrial symbiosis, one of the internationally recognized activities centered on the circular economy, and some of the main equipment- the LCA and VSM tools- used to realize this symbiosis are included in the visual. In addition to these, this study aims to achieve the sustainability goals set by the UN, namely "8-Decent Work and Economic Growth; 9-Industry Innovation and Infrastructure; 11-Sustainable Cities and Communities; 12- Responsible Consumption and Production; 13-Climate Action and 17-Partnership for the Goals".

CHAPTER 3

MATERIALS AND METHODS

The Circular Economy (CE) is an economic model focused on sustainability in production and consumption. CE emphasizes the principles of reducing, reusing, and recycling raw materials, products, and energy, aiming to keep materials and resources within a closed production loop for as long as possible and to minimize environmental impacts (Ongondo et al., 2021; Yang et al., 2023; Nunez and Perez-Castillo, 2023).

Parallel to the CE concept, another definition that emphasizes the elimination of waste in production processes and the optimization of production processes to achieve resource efficiency and increase product value is the lean manufacturing approach (Gupta et al., 2021). The lean manufacturing model, which includes a series of management principles and techniques aimed at eliminating non-value-adding activities in production processes and minimizing raw material/energy consumption, is a beneficial production approach for ensuring circularity and sustainability in the industry due to these characteristics (Ghaitan et al., 2021; Cilliberto et al., 2021).

Today, CE applications are implemented using various tools and mechanisms. The main tools and mechanisms include (i) LCA applications for assessing environmental impacts, (ii) tracking material use and energy consumption through lean manufacturing methods such as Value Stream Mapping (VSM), (iii) implementing producer responsibility policies where producers are held accountable for the lifecycle of their products, (iv) employing Industrial Symbiosis (IS) methods to develop eco-friendly production capabilities and properly utilize by-products and waste materials, and (v) utilizing digital technologies such as the Internet of Things (IoT), large databases, and artificial intelligence to increase efficiency (Yang et al., 2023; Geissdoerfer et al., 2017)

3.1. Data Collection

The first step involved gathering information related to the facilities to implement a significant portion of the applications described above and to establish a potential industrial symbiosis system through pilot companies. For this purpose, 24 facilities belonging to 22 companies located in AOIZ were visited. During these visits, a blank Excel file was provided to the company representatives. This file included information on (i) general information about the facilities (including NACE codes for production), (ii) raw material consumption and quantities of products/by-products (with PRODCOM codes), (iii) machinery used during operations, (iv) a list of chemicals consumed during production, (v) types and quantities of waste (including waste codes), and (vi) water and energy consumption data.

The NACE codes and working areas of the 24 visited facilities are presented in Table 3.1. In the subsequent sections of the study, companies will be referred to by their NACE codes and not by their names. The pilot companies were categorized according to the "Statistical Classification of Economic Activities in the European Community (NACE)" codes used for classifying production activities (Patricio et al., 2022). NACE simplifies the manufacturing types of the various facilities by giving them some order of numbers. Data derived from NACE are comparable at the European level and, in many cases, at the global level (Eurostat/EC, 2018). The first digit of the NACE code represents the section, indicating a broad sector category such as agriculture or manufacturing. The second digit specifies the division within the section, providing more detail about the specific industry, like food products or beverages. The third digit indicates the group within the division, offering even more specificity, such as processing meat or processing fish. Finally, the fourth digit represents the class, providing the most detailed level of economic activity classification, like processing poultry meat.

3.2. Value Stream Mapping (VSM)

After conducting the necessary field observations and collecting datasets from the companies, the identification of ES opportunities for the pilot companies began by creating VSMs for each facility. VSM is a crucial tool within the lean manufacturing concept that enables businesses to visualize and analyze their processes, identifying wastes, inefficiencies, and improvement opportunities (EPA, 2013). VSM maps the flow of materials and information from the beginning to the end of a process, allowing for a clear understanding of value-adding and non-value-adding activities within the processes (Zahraee et al., 2014). By using VSM visuals, all losses, including those of time, energy, water, or raw materials, can be identified, and potential improvement measures related to ES activities can be highlighted (Holgado et al., 2018).

Within the scope of the thesis, environmentally focused VSMs were used instead of traditional VSM tools to better understand the process flows of the facilities. These focus on the annual environmental performance of the processes rather than operational times (Garza-Reyes et al., 2018). Through environmentally focused VSMs, strategies for sustainable raw material usage, energy efficiency, and waste reduction were emphasized (Muñoz-Villamizar et al., 2019; Budihardjo and Hadipuro, 2022). In this way, the aim was to increase the efficiency of production and energy consumption and reduce waste generation for the companies within the context of environmental and economic sustainability (Dadashnejad and Valmohammadi, 2018; Muñoz-Villamizar et al., 2019).

Using VSM tools, areas of high energy and water consumption and significant waste generation—referred to as "hot spots"—were identified in the facilities. ES opportunities were then explored for these hot spots.

3.3. Identification of IS Opportunities

In the global applications of IS, which is the most crucial tool for implementing CE in industrial areas, the exchange of raw materials, energy, by-products, and water is typically considered (Chertow, 2008). The primary goal of IS analyses within organized industrial zones (OIZs) is to facilitate by-product exchange, by-product synergy, or waste exchange among companies (Chertow, 2004). Activities such as the reuse of by-products, the shared use of infrastructure facilities, and joint service procurement among companies are fundamental symbiosis scenarios documented in the literature (Chertow, 2007). Global IS applications encompass not only physical exchanges (materials, energy, by-products, and water) but also include the exchange of information (Ismail, 2020; Lombardi and Laybourn, 2012).

Table 3.1. Manufacturing Sectors and NACE Codes of the Pilot Firms

Label	Manufacturing Sectors	NACE Codes
1	Manufacture of concentrated vegetable and fruit juices	10.32.02
2	Manufacture of tea products (black tea, green tea and tea bag and tea extracts, preparations, and concentrations)	10.83.01
3	Twisting and spinning of artificial or synthetic fibers (except manufacturing of filament yarns and rayon fibers)	13.10.15
4	Manufacture of woven fabrics from synthetic or artificial filament yarns and discontinuous fibers (including veil fabric woven from synthetic and artificial filament yarns) (except fabrics such as towel, plush, etc., and velvet and tufting fab	13.20.22
5	Manufacture of woven fabrics from synthetic or artificial filament yarns and discontinuous fibers (including veil fabric woven from synthetic and artificial filament yarns) (except fabrics such as towel, plush etc., and velvet and tufting	13.20.22
6	Bleaching and dyeing services of fabrics and textile products (including wearing apparel)	13.30.01
7	Bleaching and dyeing services of textile fibers and yarns (including bleaching)	13.30.02
8	Manufacture of textile sacks, bags, pouches, and similar products (those used for packing goods)	13.92.06
9	Manufacture of plywood, MDF, wallboard, etc., made of compressed fiber, wood, and plates	16.21.02
10	Manufacture of paper and paperboard (as roll or layer for further industrial procedures) (including bituminous, laminated, coated, and impregnated ones, as well as crepe and wrinkled papers)	17.12.07
11	Manufacture of basic organic chemicals (hydrocarbons, alcohols, acids, aldehydes, ketones, synthetic glycerol, nitrogen functionalized compounds, etc.) (including ethyl alcohol, citric acid)	20.14.01
12	Manufacture of basic organic chemicals (hydrocarbons, alcohols, acids, aldehydes, ketones, synthetic glycerol, nitrogen functionalized compounds, etc.) (including ethyl alcohol, citric acid)	20.14.01
13	Manufacture of shampoo, hair cream, hair spray, hair conditioner, hair straightening and perming products, hair lotions, hair dyes, etc	20.42.04
14	Manufacture of ware plastic tubes, pipes, hoses, and fittings (including artificial intestines	22.21.03

(cont. on next page)

Table 3.1. (cont.)

Label	Manufacturing Sectors	NACE Codes
15	Manufacture of semi-manufacture plastics profiles, rods, plates, sheets, blocks, film, foil, tape, etc., and monofilament manufacturing (including nylon tarpaulins)	22.21.04
16	Manufacture of semi-manufacture plastics profiles, rods, plates, sheets, blocks, film, foil, tape, etc., and monofilament manufacturing (including nylon tarpaulins)	22.21.04
17	Manufacture of tube, pipe, hollow profiles, and related fittings from steel/iron (cold-drawn or cold-rolled)	24.20.10
18	Activities of metal heat treatment and anodizing, hardening, varnishing, etc., surface treatments, electrolysis, sherardizing or metallic coating with chemical treatment (except tin and nickel coating), and coating activities with plastic,	25.61.01
19	Manufacture of electric motors, generators, and transformers (except parts and components)	27.11.01
20	Manufacture of another lifting, handling, loading, or unloading machinery (traction mechanisms for cable cars, chairlifts, etc., loading machines and others for agricultural use, smart shelf systems, and others)	28.22.13
21	Manufacture of parts of boring, drilling, earthmoving, and excavation machines, cranes and mobile lifting frames, and machine parts used in sorting, grinding, and mixing of Earth, stone, and similar materials or other works (including bulldozer)	28.92.11
22	Manufacture of machinery for textile yarn and fabric washing, bleaching, dyeing, finishing, cleaning, wringing, winding, impregnation, cutting, serging, and the like and machines used in felt manufacturing and finishing	28.94.05
23	Manufacture of trailers, semi-trailers, and other vehicles not having mechanically propelled components (bodywork, frames, axles, and other parts of these vehicles)	29.20.01
24	Recycle of classified nonmetallic waste, scraps, and other components, usually by means of mechanical or chemical replacement	38.32.02

Within the scope of IS research, this study initially focused on the Input-Output Matching application, which is based on material exchange between businesses. These types of applications emphasize using one company's waste or by-product as raw material for another company. This method allows for the identification of potential matches by examining the codes of raw materials, materials, products, by-products, and waste generated by industries (Patricio et al., 2022). It is an effective and easy-to-implement method based on grouping according to product-waste codes, reducing both waste amounts and raw material costs.

In parallel with NACE codes, PRODCOM refers to the system of mining and production statistics for tangible goods within the European Union (data.europa.eu, 2023). An essential component of production statistics is the PRODCOM list, which classifies products. However, instead of being included in regulation, this list is compiled annually by the PRODCOM Committee. The coding is done using an 8-digit code, where the first six digits are aligned with CPA codes. CPA product categories are linked to the activities defined by NACE. Each CPA product is assigned to a specific NACE activity, whether a movable or immovable good or service. This provides a structure that parallels NACE at all levels (Eurostat/EC, 2023).

The European Waste Code (EWC) is a categorized list of waste definitions established by the European Commission Decision 2000/532/EC2. It consists of twenty main sections, which are primarily organized by industry but also by material and processes. Each section is assigned a two-digit code ranging from 01 to 20. These sections contain subsections identified by four-digit codes that match the first two digits of the section code. Within the subsections, individual wastes are assigned six-digit codes. Wastes considered hazardous are indicated by an asterisk at the end of their code. These product and waste codes and definitions were used to identify ES scenarios in the Input-Output Matching application.

The second IS method predominantly investigated during the studies is energy exchange, which involves using excess energy from one process in another process. An example of such an application is the use of steam produced by a power plant in the production processes of a nearby facility. In the literature, such collaborations have been shown to increase energy efficiency and reduce energy costs. A study conducted in China indicated that an energy-based ES application alone could achieve up to 6% energy savings in the iron and steel sector (Fraccascia et al., 2020).

Another ES method considered, based on the data obtained from the companies, is the potential use of wastewater from one facility, either treated or directly used by another facility or process. Such activities reduce water consumption and lower wastewater treatment costs for businesses (Lawal et al., 2021).

Logistics and transportation collaboration is another aspect considered when establishing an IS system. Businesses located in close proximity are well-suited for such partnerships. This significantly contributes to reducing the carbon footprint associated with transportation (Jacobsen, 2006; Henriques et al., 2021). In an IS system, facilities such as steam boilers and waste processing plants should be strategically positioned at the center of the symbiosis network and collaborate with multiple facilities (Park et al., 2018).

Finally, Information and Communication Technology (ICT) tools are essential for enhancing the effectiveness of information and technology sharing within an IS system. These tools should be designed to be user-friendly, facilitate communication and collaboration, support data management and analysis, and identify and evaluate potential IS opportunities. Additionally, LCA-based analysis as software technology is a useful method to highlight the benefits of shared resources, thereby enabling policymakers to justify their decisions toward sustainable development (Daddi et al., 2017). This aspect was also considered during the evaluation of IS scenarios.

3.4. LCA Analysis of the Results

3.4.1. LCA Technique and Software

Life Cycle Assessment (LCA) is a quantitative method used to assess the overall environmental impact of a product, service, or technology throughout its entire life cycle, from raw material extraction to disposal. This study followed the LCA framework outlined in ISO 14040:2006 (CML-2001), which includes defining the goal and scope, conducting inventory analysis, impact assessment, and interpretation (Zhang et al., 2017).

CML is a technique employed to assess the extent of environmental impact resulting from a product. This approach utilizes different impact categories, including eutrophication, ionizing radiation, aquatic ecotoxicity, and acidification (Mohan, 2018).

During LCA analysis, CCalC-2 Software, which has ECOINVENT Database, will be used. CCaLC2 is a software tool used for life cycle assessment (LCA) to estimate the environmental impacts of products and processes. The methodological approach of the software follows the internationally accepted life cycle methodology as defined by ISO 14040 and 14044 (Bor et.al., 2021).

3.4.2. Functional Unit

The functional unit refers to the unit of measurement used to define the system being analyzed and to which the environmental impacts are attributed. It is a crucial aspect of LCA as it determines the scope and boundaries of the study and allows for the comparison of different systems. The functional unit can be defined in various ways, such as mass, volume, energy, or economic value, depending on the goal and scope of the study (Arzoumanidis et al., 2020).

In this study, the functional unit is determined as the annual production amount (kg product/year). LCA analyses results interpret the environmental impacts as a result of the production in the facility in a year (2022). However, CO_2eq/kg of values of two selected firms will be determined to compare the values in the literature.

3.4.3. System Boundaries and Impact Calculations

The CCaLC2 tool enables calculations of carbon footprints from 'cradle to gate' (business to business) or 'cradle to grave' (business to consumer). It also helps to identify carbon 'hot spots' and carbon reduction opportunities. The analysis will consider the activities within the 'facilities' boundaries. The shipment for import and export is not considered during the analyses. Therefore, the LCA of the two pilot firms will adopt a gate-to-gate approach. However, since there will be efforts to reduce raw material usage and waste generation in industrial symbiosis studies, the management of raw materials and waste in the facilities will also be taken into account during the calculations and analyses.

CCaLC2 also calculates other environmental impacts to show how they may be affected by any changes in the carbon footprint. These include acidification, eutrophication, ozone layer depletion, photochemical (summer) smog, and human toxicity.

Acidification potential is the contaminant deposition, including SO_2, NO_x, and NHx acidifying chemicals, on soil, surface/ groundwater, and ecosystems. Those pollutants have negative impacts on the environment, and the acidification potential is the indicator of the pollution impact level of a source on the environment. (Farinha et.al., 2021). Acidification level will be determined using CCalC2 as kg SO_2 eq./f.u. Eutrophication is the term that defines the adverse environmental impact where the excessive increase in the number of algae and plants occurs due to polluting emissions, wastewater discharges, etc. Pollutants create a nutrient-rich environment for the algae and plants where they can be easily reproduced. Fauna and water resources in a region where eutrophication occurs are faced with contamination risk. (Farinha et.al., 2021) The unit of the eutrophication potential level will be kg PO_4 eq./f.u. during the CCalC2 processes.

Ozone layer depletion is another detrimental environmental impact that increases the radiation reaching the Earth's surface. Ozone layer depletion is one of the most important reasons for climate change. The main reason for the depletion of the ozone layer is industrial emissions, including halocarbons. (Farinha et.al., 2021) The ozone layer depletion unit will be kg R11 eq./f.u., which indicates the halocarbon amount in a functional unit.

Photochemical (summer) smog, on the other hand, represents the artificial production of a layer in the atmosphere due to the emission of VOC and CO. This layer behaves as an ozone layer and has toxic impacts on human health, which leads to irritation to the eye, respiratory diseases, etc. C_2H_4 (in kg) eq. /f.u. will be the unit of photochemical smog potential during the LCA analyses (Farinha et.al., 2021). In addition to photochemical smog, human toxicity levels will be analyzed by using CCalC2. This level will indicate the toxicity levels generated from a facility in terms of kg dichlorobenzene (DCB) eq. /f.u.; that causes adverse human health effects (Diner and Biçer, 2018). In this thesis, other environmental impacts are calculated however the alterations due to IS studies are not assessed.

3.5. Interpretation of the Results

Interpreting LCA results is essential for understanding the environmental impacts of products or processes. When analyzing LCA results, it is essential to identify the specific context of the study, the chosen functional unit, the system boundaries, and the impact categories assessed. In the case study related to the LCA of olive pomace utilization, all the environmental impacts associated with the different utilization scenarios of this by-product have been calculated (Duman et.al., 2020). In this way, the environmental sustainability of the scenarios can be assessed.

In addition, the robustness and reliability of the results should be evaluated by completing the sensitivity analysis. Sensitivity analyses determine the extent to which specific parameters affect the outcome. This way, it can be determined how much changes in each process affect environmental impacts, primarily carbon emissions. The one-at-a-time method will be followed during the sensitivity analysis, and sensitive parameters of the two sample companies will be identified in these analyses (Groen et al., 2015; Wei et al., 2015).

After completing the LCA studies of two sample facilities and observing the effects of symbiosis, the potential gains that can be achieved in a year as a result of all symbiosis scenarios will be presented as shown in Table 2-3 by calculating the relevant savings amounts using the emission factors of the savings topics (energy, raw materials, waste, water, etc.).

At the end, the IS system will be visualized by using network analysis methodology. Industrial symbiosis systems can be analyzed using network analysis methods. Network analysis is performed using nodes and edges. In this study, nodes will be facilities, and edges will be concepts such as resource, energy, and information flow subject to symbiosis. Potential relationships of companies coded with NACE codes will be visualized using this method. Companies defined by their codes will be expressed as source and target, and once it is determined whether the symbiosis is within the facility or outside, a visual will be obtained (Zhang et al., 2014; Lee et al., 2016). For this purpose, Gephi software is used. This software is an open-source network analysis and visualization software. It allows users to visualize complex relationships within data sets through a network structure, making invisible relationships visible (Ersöz et al., 2021).

CHAPTER 4

RESULTS AND DISCUSSION

The NACE codes for the 24 facilities involved in the project were identified. These facilities were categorized according to their NACE codes and listed in Table 3-1 in the previous section. This section evaluated all processes based on raw material and chemical consumption, product and by-product production, energy consumption, and machine and equipment content. Value stream maps were also utilized in the assessment processes of the facilities, clearly identifying the production processes and potential environmental impact points.

Following this, industrial symbiosis opportunities were proposed for these facilities. These opportunities include inter-process input-output sharing and optimization processes within their facilities, product and raw material matching, joint use of energy sources, and facilities with other companies. The facilities involved in the project were coded and listed according to their NACE codes. However, some symbiosis opportunities include facilities and sectors beyond the pilot firms and additional manufacturing sectors. Therefore, these opportunities were also evaluated within symbiosis alternatives and coded according to their appropriate NACE codes.

The symbiotic relationships were visualized through network analysis after identifying all activities and facilities involved in symbiosis. Following the presentation of this visual, the effects of industrial symbiosis were evaluated using LCA analysis for two pilot firms. Finally, the potential benefits that could be achieved if all industrial symbiosis opportunities were evaluated were calculated.

4.1. Manufacturing Processes, VSMs of the Facilities, and Identification of the IS Opportunities

In this section, the processes of all facilities are examined according to their NACE codes, their Value Stream Maps (VSM) are drawn, and Industrial Symbiosis (IS) scenarios are provided. Potential matches and relations with the other NACE codes are identified.

4.1.1. NACE: 10.32.02, Manufacture of concentrated vegetable and fruit juices

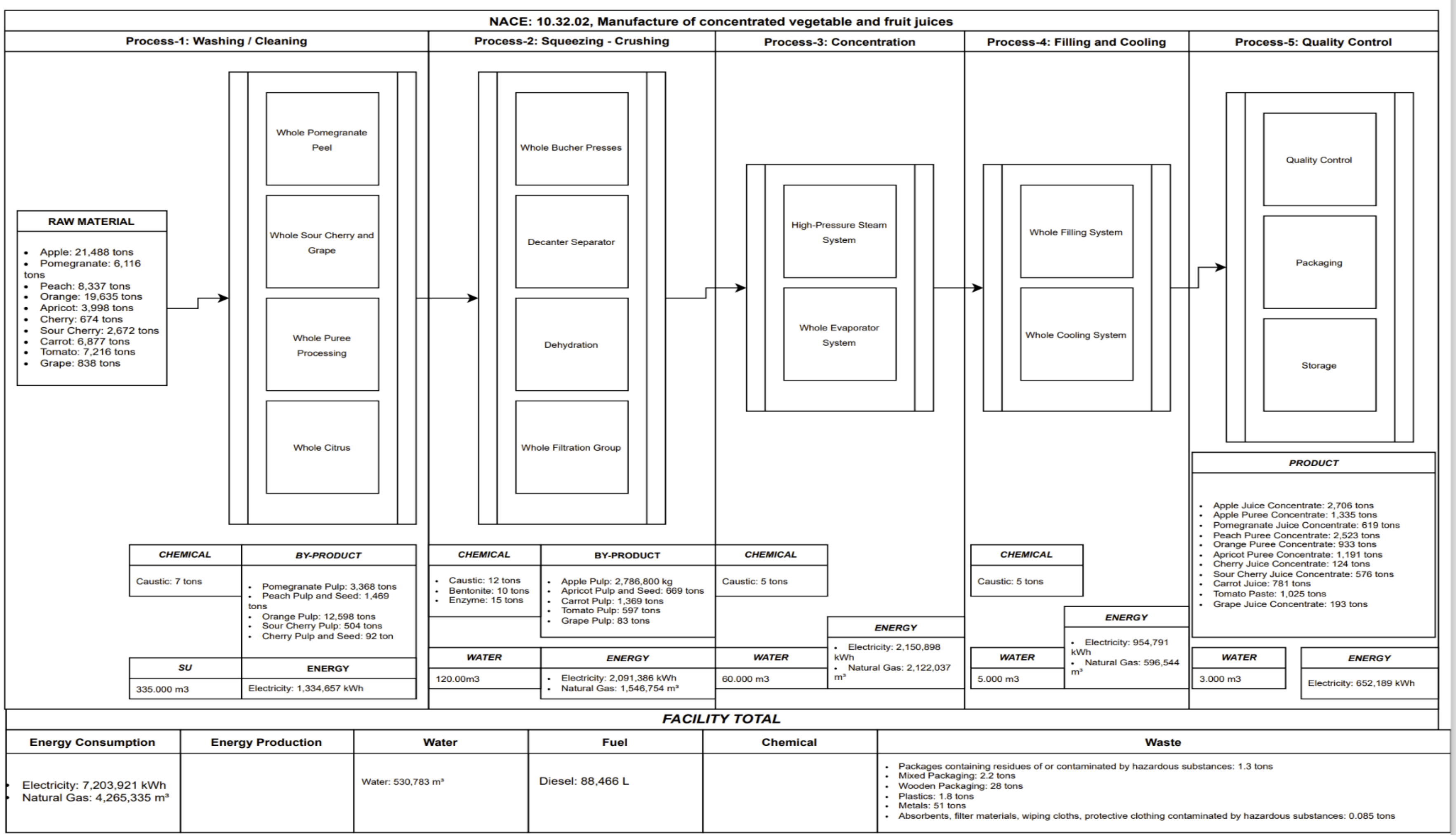
The facility produces apple juice concentrate, pomegranate juice concentrate, tomato paste, peach puree concentrate, apricot puree concentrate, orange juice concentrate, sour cherry juice concentrate, apple puree concentrate, cherry juice concentrate, black carrot, and grape juice concentrate. The production is carried out in five main processes (Table 4.1).

The value stream map of the processes is provided in Figure 4.1. The raw materials and chemicals used in the processes, as well as the waste and by-products, are presented in the diagram with quantities. The type and amounts of energy consumed are also indicated in the figure.

To reduce the volume during the transportation and storage of fruit juices, ensure microbial safety, and extend shelf life, fruits and vegetables are subjected to high-pressure steam, resulting in concentrated juices (Bull et al., 2004; Paula et al., 2015). A significant amount of water evaporates during the high-pressure steam process (Alkaya and Demirer, 2015). Upon examining the input/output and waste data of the processes, it is understood that the difference in the mass balance is the evaporated water.

Table 4.1. Facility (NACE: 10.32.02) Production Processes

Process No	Process Name	Process Description
1	Washing-Cleaning	The facility has 4 main operation lines. The first one processes fruits like grapes, sour cherries, and pomegranates; the second one processes hard fruits like apples and pears; the third one processes fruits for juicing like oranges and mandarins; and the fourth one processes fruits like apricots and peaches. The fruits are washed in different ways according to their stems and seeds.
2	Juicing-Crushing	The fruits are subjected to juicing and processing processes in the operation lines mentioned above according to their types. Some fruits are pureed by heating the juice (90°C). Hard fruits like apples are crushed by applying pressure.
3	Concentration	The fruit juices are concentrated by being treated with high-pressure and high-temperature steam obtained from a natural gas-fired boiler. The concentration process is carried out in two large boilers using steam.
4	Filling and Cooling	The fruit juices are filled into specially manufactured, airtight plastic bags, placed in barrels, and cooled to specific temperatures.
5	Quality Control and Packaging	After the quality of the products is checked, they are packaged and made ready for shipment.



Energy Consumption	Energy Production	Water	Fuel	Chemical	Waste
Electricity: 7,203,921 kWh Natural Gas: 4,265,335 m³		Water: 530,783 m³	Diesel: 88,466 L		Packages containing residues of or contaminated by hazardous substances: 1.3 tons Mixed Packaging: 2.2 tons Wooden Packaging: 28 tons Plastics: 1.8 tons Metals: 51 tons Absorbents, filter materials, wiping cloths, protective clothing contaminated by hazardous substances: 0.085 tons

Figure 4.1. Value Stream Map (VSM) of the Facility (NACE: 10.32.02)

Approximately 42 tons of water evaporate in total during the concentration process in the facility. During the juicing, crushing, and concentration of fruit juices, more electricity and natural gas are consumed compared to other processes.

Studies have been conducted to obtain bioactive compounds from fruit juice industry wastes, revealing their potential for valorization (Kandemir et al., 2022). Extracts obtained from fruit and vegetable pomace are used in the production of antioxidants to preserve food products. Similarly, these pomaces are used in the production of dietary fibers due to their pectin content, enriching the nutritional value of processed foods (Campos et al., 2020). Additionally, fruit and vegetable wastes are considered alternative animal feed, particularly for small and large livestock (Coronel-Lopez et al., 2021).

Another use of pomace and seeds is in biofuel production. These products are commonly used in fuel and energy production by being incorporated into the feedstock or used directly during biofuel production (Christofi et al., 2022).

The economic and environmental benefits of recovering these types of waste in various ways differ from each other. The pectin extraction processes mentioned above are economically very profitable, but their environmental impacts are pretty high compared to other recovery methods. The economic return of biofuel and animal feed production is lower than other methods; however, they stand out as more advantageous methods in terms of environmental impact. The application that has both low environmental impact and high economic gains is the extraction of D-limonene from orange waste. D-limonene is a valuable essential oil used in the food, chemical, and pharmaceutical industries (Suzuki et al., 2023).

In this thesis, it is considered that pomace, pulp, and wastes (23,788 tons in total) can be used during the “Manufacture of other food products (NACE Code: 10.8)” and “Manufacture of prepared animal feeds (NACE Code: 10.9)” as a symbiosis alternative. The sale of fruit peels and pomace waste to a firm producing animal feed and biofuel under industrial symbiosis can be defined as a "by-product" as per Article 19 of the "Waste Management Regulation" published in the Official Gazette dated 02.04.2015 and numbered 29314.

In addition to that symbiosis alternative, closed-loop evaporation systems can be used to condense evaporated water and return it to the system can be considered as another alternative. These systems condense the majority of the evaporated water back into liquid form, allowing it to be reused as process water. Additionally, closed-loop systems can enable the reuse of a portion of cooling water waste in the fruit washing process, significantly reducing the need for fresh water for washing and cleaning operations. Studies show that the implementation of closed-loop cooling systems and other water-saving measures can reduce total cooling water consumption per unit of product from 14.4 m³/m³ to 1.2 m³/m³, resulting in a 57.4% reduction in total water consumption (Alkaya & Demirer, 2015). In the IS scenario, it is assumed that water consumption in the washing/cleaning, crushing/pressing, and concentration processes is reduced by about 50% (250,000 m^3/year).

The symbiosis alternatives in the facility are as follows: (i) recovery of fruit pomace, pulp, and waste (between NACE: 10.32.02, 10.8, and 10.9), and (ii) reduction of water losses within the facility through internal symbiosis (Intra-firm).

4.1.2. NACE: 10.83.01, Manufacture of tea products (black tea, green tea and tea bag and tea extracts, preparations, and concentrations)

The facility produces tea bags, packaged tea (plain and flavored), instant coffee, Turkish coffee, cappuccino, hot chocolate, and packaged granulated sugar. The production is carried out in five main processes (Table 4.2).

Table 4.2. Facility (NACE: 10.83.01) Production Processes

Process No	Process Name	Process Description
1	Tea Pre-Preparation and Blending	Teas imported domestically and internationally are stacked with the help of battery-powered stackers and weighed on hanging scales. After weighing, the teas are poured onto a magnetic conveyor belt to remove ferromagnetic metals. The teas are then brought to fiber separators, where static electricity is used to remove fibers. Now free from fibers, the teas are exposed to an air stream to remove stones. To enhance food safety, the teas pass through metal detectors to eliminate ferrous and non-ferrous metals. Once pre-treatment is completed, the teas are transferred to the blending drum. In the blending drum, a homogenization process lasting approximately five minutes is carried out. If the teas are to be flavored, they are first collected in large bags called "big-bags" and then brought to the flavoring machine. Here, aroma is sprayed onto the teas, which are then rested for two hours. Finally, the flavored or plain teas are filled into silos.

(cont. on next page)

Table 4.2 (cont.)

Process No	Process Name	Process Description
2	Tea Packaging	The teas in the silos are packaged in various forms and shapes by packaging machines, such as loose tea, teapot bag tea, cup bag tea, square teapot tea, set tea, and gourmet tea.
3	Coffee Preparation and Packaging	First, raw coffee beans are roasted according to their recipes. Then, based on the type of product listed in the production plan (flavored, plain, filter coffee, etc.), the coffee is ground and packaged.
4	Instant Packaged Coffee Products Preparation and Packaging	Sugar used in different coffee products or to produce stick sugar products is passed through a sugar grinding machine. To produce "3-in-1," "4-in-1," "2-in-1," cappuccino, hot chocolate, and similar products, coffee, sugar, and chocolate powders are blended according to the production plan and sent to the filling machines. The facility has separate filling machines for stick coffee, hot chocolate, cappuccino, and stick sugar, which are used independently to produce the desired products.
5	Quality Control and Packaging	After the quality control of the products, they are packaged and made ready for shipment.

The value stream map of the processes is provided in Figure 4.2. The raw materials and chemicals used in the processes and the waste and by-products are presented in the diagram in their respective quantities. The type and amounts of energy consumed are also indicated in the figure.

Tea is the most consumed beverage worldwide after water (Tagne et al., 2023) and has become an integral part of social life, especially in Türkiye (Akgün, 2020). Tea contains a significant amount of terpenoids, polyphenols, catechins, and carotenoids. Due to their oxidation-prone moisture and odor absorption properties, teas are inclined to deteriorate rapidly depending on environmental factors. To prevent this, teas should be dried and cooled after weighing (Xu et al., 2019; Mila et al., 2021). Drying and cooling reduce moisture to preserve the tea and affect the final product's aroma and taste (Mila et al., 2021).

After being dried, blended, and optionally flavored, tea is packaged. The packaging process is crucial not only for protecting the product with suitable materials for long-term storage but also for reflecting the value of the tea (Xu et al., 2019).

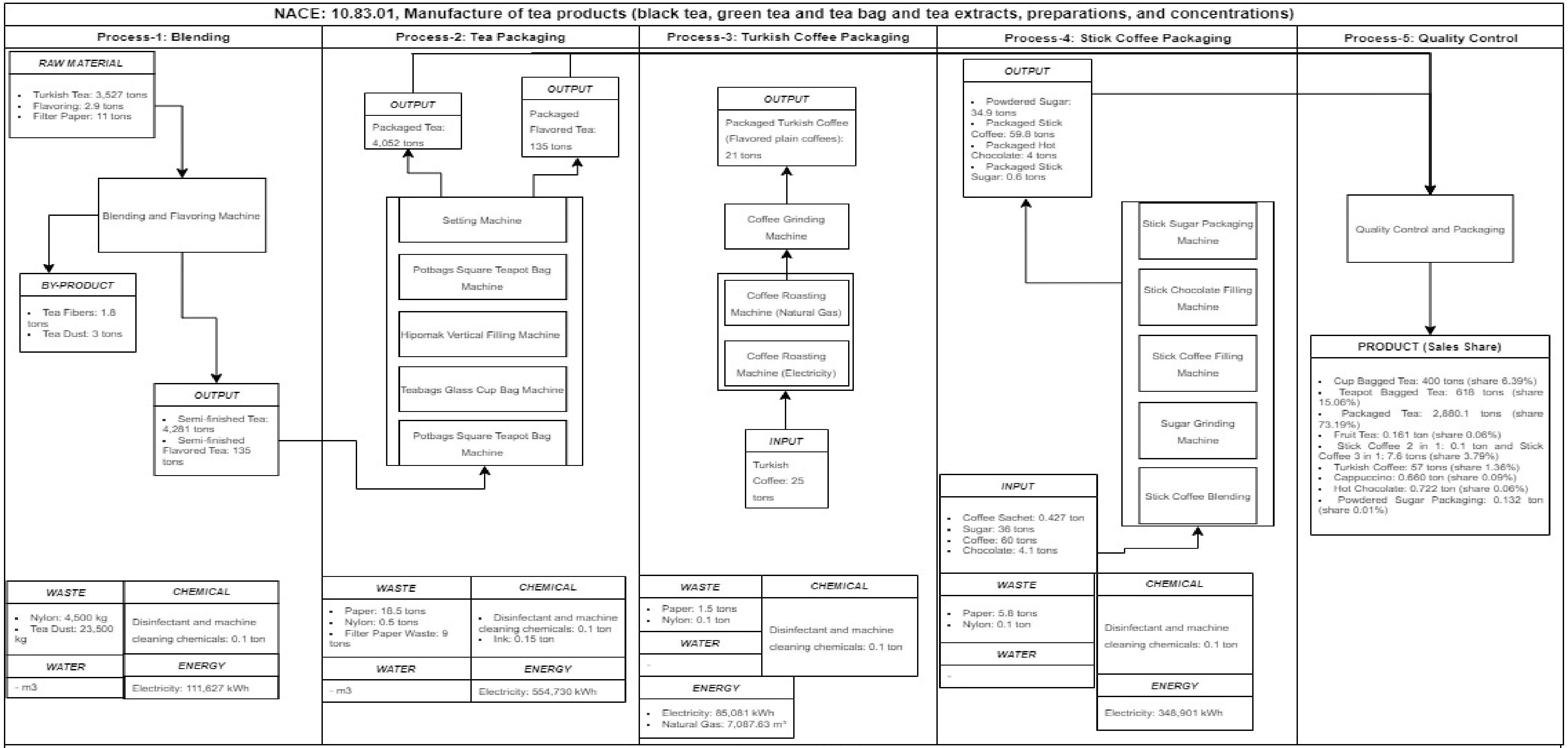
Upon examining the VSM of the facility, it is observed that during the blending and flavoring stage, where various raw teas are mixed, 11 tons of filter paper and 2.9 tons of flavoring agents are used in addition to 3,257 tons of tea. This stage consumes 111,627 kWh of electricity, generating 4.5 tons of nylon and 23.5 tons of tea dust as waste. Following the blending and flavoring process, polyethylene tea bags and cardboard packaging are used in the packaging process, which consumes 554,730 kWh of electricity and generates waste, including plastic, paper, and filter paper. These figures indicate that the packaging stage has the highest environmental impact due to energy consumption and waste generation, which aligns with the literature (Xu et al., 2019).

Similar to tea production, instant coffee production is a process aimed at achieving the expected quality and meeting consumer preferences. In the production of instant coffee, coffee beans are transformed into a powder that quickly dissolves in water to create a beverage similar to freshly brewed coffee. The production process begins with the selection of various coffee beans (Arabica, Robusta, etc.). The beans are roasted according to the recipe, depending on the desired outcome and the characteristics of the beans used (Vareltzis et al., 2020). After roasting, the coffee beans are ground to a fineness that maximizes flavor extraction during brewing while ensuring optimal extraction kinetics (Vareltzis et al., 2020).

The facility has processes for Turkish coffee packaging, instant coffee packaging, and quality control. The Turkish coffee packaging process includes roasting and grinding the coffee using both electricity and natural gas. In this process, 85,081 kWh of electricity and 7,087.63 m³ of natural gas are consumed, and 1.5 tons of paper and 0.1 tons of plastic waste are generated. The instant coffee packaging process involves packaging coffee, sugar, and chocolate. This process consumes 348,901 kWh of electricity. The outputs of this process include 59.8 tons of packaged instant coffee, 34.9 tons of powdered sugar, and 4 tons of packaged hot chocolate, while the primary wastes generated are 5.8 tons of paper and 0.1 tons of plastic. The quality control stage is crucial for ensuring product standards but has significantly less environmental impact regarding energy consumption or waste generation compared to the packaging processes.

Upon on-site inspection of the facility's activities, it was observed that 23.5 tons of tea dust and 1.5 tons of tea fiber waste are generated annually during production and stored within the facility. Such tea wastes contain substances like cellulose, hemicellulose, lignin, polyphenols, and tannins (Almahdawi, 2018). These components make tea waste highly suitable for recycling applications (Debanth et al., 2021).

Tea waste serves as an alternative protein source for ruminant animals, mainly sheep. Experiments on small ruminants have shown that dried tea waste can replace traditional protein sources like soybeans (Almahdawi, 2018). In addition to being used as animal feed, tea waste can also be utilized as fertilizer in plant cultivation.



FACILITY OVERVIEW

ENERGY CONSUMPTION	ENERGY PRODUCTION	WATER	FUEL	CHEMICAL	WASTE
Electricity: 1,100,339 kWh	Solar Energy System: 1,041,601 kWh	Water: 7,376 m³	Diesel: 102,251 L	-	Packages containing residues of or contaminated by hazardous substances: 0.1 ton Fluorescent lamps and other mercury-containing waste: 0.035 ton Other hydraulic oils: 0.2 ton Oil from oil and water separator: 0.2 ton Liquid and solid oils other than 200125: 0.1 ton

Figure 4.2. VSM of the Facility (NACE: 10.83.01)

Studies have found that tea waste provides essential minerals and nitrogen crucial for the optimal growth of Ganoderma lucidum, a mushroom of medical significance (Pekşen & Yakupoğlu, 2009).

In this thesis, it is considered that tea dust (23 ton/year) can be used during the “Manufacture of other food products (NACE Code: 10.8)” and “Manufacture of prepared animal feeds (NACE Code: 10.9)” as a symbiosis alternative.

In addition to that symbiosis alternative, recycling PE packages by manufacturing plastic bags can be another symbiosis scenario. In the facility, polyethylene (PE) packaging is used during the packaging of instant coffee, and the review of 2022 data indicates that approximately 5 tons of plastic waste are generated in the production processes. Various life cycle analyses for coffee packaging have been conducted in the literature, emphasizing that increasing the use of biodegradable packaging reduces the environmental burden on the coffee sector (De Monte et al., 2005). When processed in composting facilities, these sustainable coffee packages can yield efficient soil and fertilizer materials (Kooduvalli et al., 2020). Such eco-friendly packages meet the expectations of consumers who are increasingly demanding greener products (Maspul & Morga, 2021).

During on-site visits to the facility, it was learned from company officials that waste plastic packaging is sent to a waste processing facility licensed by the Ministry of Environment, Urbanization, and Climate Change. One of the industrial symbiosis matches considered for the entire AOIZ is the match between this facility and the facility “NACE: 38.32.02, Recycle of classified nonmetallic waste, scraps, and other components, usually by means of mechanical or chemical replacement” (plastic waste - raw material).

The symbiosis alternatives in the facility are as follows: (i) using of tea dust (between NACE: 10.83.01, 10.8 and 10.9) (23 ton), and (ii) using of plastic waste as a raw material (between NACE: 10.83.01 and 38.32.02) (5 ton).

4.1.3. NACE: 13.10.15, Twisting and spinning of artificial or synthetic fibers (except manufacturing of filament yarns and rayon fibers)

The facility produces 100% polyester, cotton, viscose yarns, and blended yarns. The production is carried out in two main processes (Table 4.3).

Table 4.3. Facility (NACE: 13.10.15) Production Processes

Process No	Process Name	Process Description
1	Yarn Production	Fibers, whether 100% of the same type (cotton, polyester, or viscose) or mixed in different compositions (most commonly 67% polyester, 33% viscose), are first aerated and separated into pieces using the blending and opening system. The fibers are then carded to form a sliver and are combined two or three more times to homogenize. The combined fiber is drawn and twisted into fine yarn. This process is carried out in two ways: the first using a ring system with mechanical bobbins, and the second using air jets in a vortex system.
2	Quality Control and Packaging	After the yarns are stabilized with the help of heat, quality controls are performed, and the products are made ready for sale.

The value stream map of the processes is provided in Figure 4.3. The raw materials and chemicals used in the processes and the waste and by-products are presented in the diagram in their respective quantities. The type and amounts of energy consumed are also indicated in the figure.

The facility produces yarns by processing various fibers such as cotton, polyester, and viscose. The production process consists of several main stages. First, different fibers are homogenized through bale opening, cleaning, and mixing processes to prepare them for the next stages. In the second stage, the fibers are carded into slivers and combined several times to ensure homogeneity. These processes enhance fiber alignment and uniformity, creating smoother slivers by removing short fibers (Mahmood, 2020).

In the final stage of yarn production, the fiber slivers are drawn and twisted into fine yarn. This process is performed either mechanically using the ring system or with air jets using the vortex system. The ring system involves mechanical twisting with the help of bobbins, while the vortex system uses air jet technology, which requires less contact and is a faster process (Erdumlu et al., 2009).

The facility has a high energy consumption. The total electricity consumption is recorded as 44,017,913 kWh, with the majority used in processes such as carding (43%), air conditioning (21%), and ring spinning (16%). Air conditioning is essential for maintaining the appropriate temperature and humidity balance in production areas suitable for yarn production. Carding and spinning processes are energy-intensive and directly affect product quality.

Company officials meticulously manage textile waste generated during yarn production at the facility. These textile wastes are classified and recorded under the terms “üstüpü, pnömofil, meydan, hallaç altı, and şapka telefi”.

During the blending and opening stages, the waste generated from cleaning the raw material and preparing it for subsequent processes is referred to as "pnömofil," which consists of raw material particles in fiber form. Similarly, during the pre-preparation and subsequent combing processes, low-quality and undesired-sized fibers are classified as "hallaç altı" and "şapka telefi." In the carding stage, short fibers separated from the long fibers are called "üstüpü." In contrast, the fiber particles that do not pass the quality control stage or are eliminated at this stage from the CER passage and bobbin winding processes are defined as "meydan atığı" (Bedez Ute et al., 2019).

Textile wastes can be recycled using different methods and reused to produce various products. In polyester, viscose, and cotton yarn facilities, wastes can be processed back into yarn or fiber. At this facility, "üstübü" waste has the potential to be used in making 10-number yarn, "hallaç altı" waste in making 6-number yarn, and "şapka telefi" waste in making 12-number yarn (Kozak, 2010). Of the 3,756 tons of textile waste, 2,601 tons consist of the aforementioned waste types. This thesis considers that these textile wastes can be used directly in the textile sector, including yarn and other textile material manufacturing. Therefore, it can be concluded that there is a symbiotic potential between the “Manufacture of textiles (NACE Code: 13)” as a symbiosis alternative.

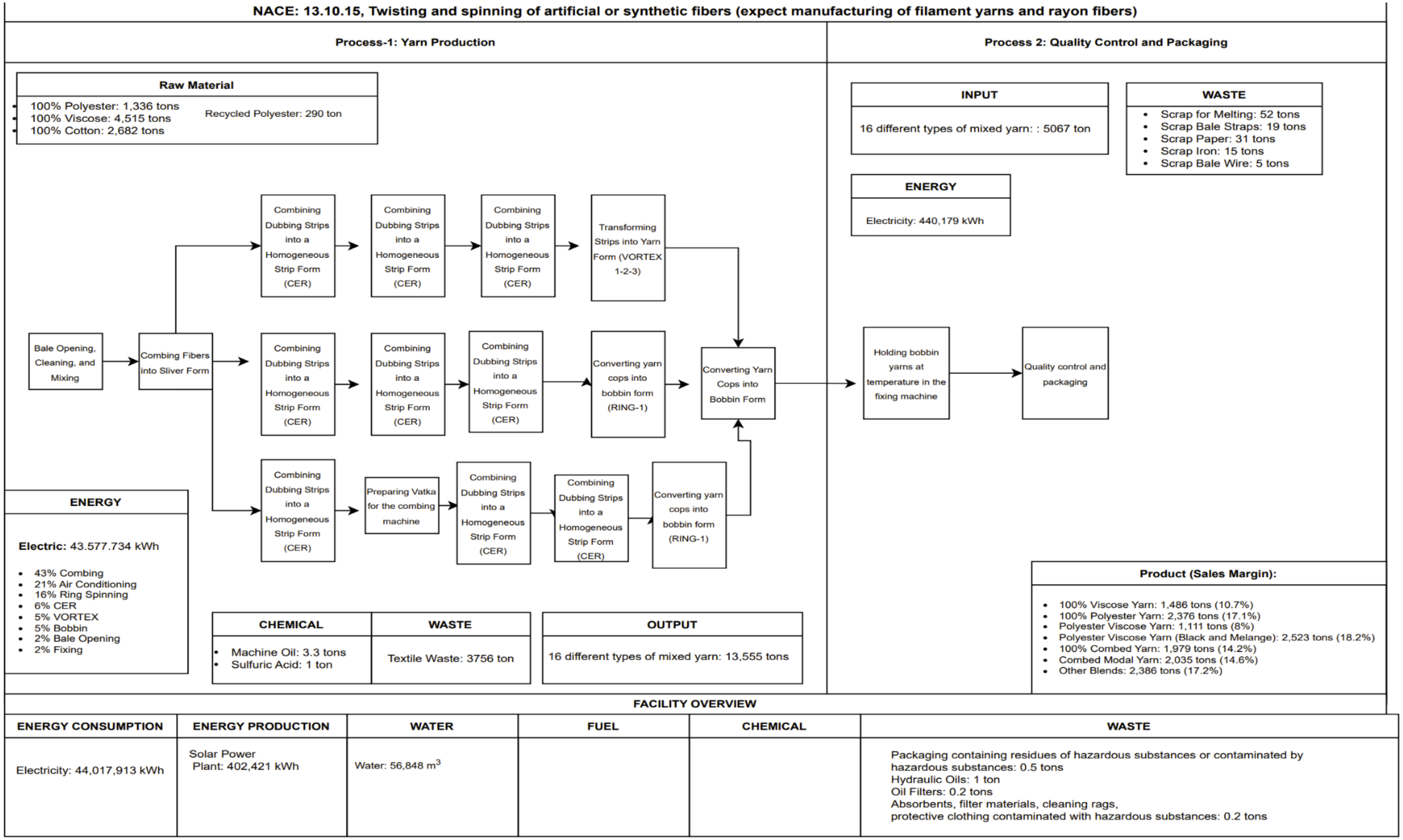


Figure 4.3. VSM of the Facility (NACE: 13.10.15)

This facility is among the highest electricity-consuming facilities examined within the project. Therefore, it is necessary to consider the improvement of the manufacturing scenarios for the processes within the facility.

Mass balances are essential for monitoring material flows in production processes, identifying inefficiencies, reducing waste generation, and optimizing resource use (Alvar-Beltrán et al., 2021). Facilities can enhance their resource efficiency by systematically tracking the inputs and outputs in their processes, ensuring the most accurate results for life cycle inventories used in life cycle analyses (Elomaa et al., 2019).

Based on the data provided by the company, it has been determined that the ratio of textile waste generated to the amount of raw material used in the facility is 43%. A significant portion of the waste occurs during the bale opening and carding stages, where the dimensions of the yarn fibers are adjusted and combined, as indicated by the waste amounts mentioned in the previous section. Similarly, data provided by the company reveals that the machines used in these processes are older compared to those used in other processes.

To reduce the ratio of waste to raw material, the following measures should be taken: (1) implementing recovery opportunities within the scope of industrial symbiosis, (2) improving the mass balance system in the processes, and (3) regularly maintaining and repairing machines to increase their efficiency.

The scenario of a 10% improvement (84402 mWh save) in production efficiency within the facility, leading to a reduction in electricity consumption, has been considered as an in-facility industrial symbiosis alternative. Additionally, this company is one of the two firms examined within the scope of this thesis through LCA analysis. Therefore, LCA will obtain valuable insights regarding these alternatives.

The symbiosis alternatives in the facility are as follows: (i) using of textile waste (between NACE: 13.10.15, and 13), and (ii) optimization of the manufacturing (Intra-firm).

4.1.4. NACE: 13.20.22, Manufacture of woven fabrics from synthetic or artificial filament yarns and discontinuous fibers (including veil fabric woven from synthetic and artificial filament yarns) (except fabrics such as towel, plush, etc., and velvet and tufting

The facility produces colored and non-colored denim fabric. The production is carried out in five main processes (Table 4.4).

Table 4.4. Facility (NACE: 13.20.22) Production Processes

Process No	Process Name	Process Description
1	Yarn Production	After the cotton arrives at the facility, it is cleaned and prepared for subsequent processes. Typically, a 95% cotton blend is used in production, with occasional inclusion of polyester and/or other fibers. However, this section does not involve any washing processes; only mechanical cleaning of the cotton is performed.
2	Yarn Dyeing and Finishing	This process involves dyeing the yarns in different colors and adding various properties such as stiffness, softness, and durability to dyed or undyed yarns. The process includes post-dyeing washing, drying, and sizing operations. Warp yarns are dyed and washed with indigo and/or sulfur dyes in this section, and sizing is done at the exit of continuous open-width yarn dyeing (Slasher) machines. In the constant rope dyeing machine, the yarn is dyed and washed; then the rope is opened and sized in the weaving preparation department.
3	Weaving	In this process, dyed or undyed warp and weft yarns undergo weaving preparation processes (sizing, drawing-in) before being woven according to predetermined weave patterns.
4	Fabric Dyeing and Finishing	In this section, woven fabrics with dyed or undyed yarns undergo pre-treatment processes such as singeing, washing, desizing, bleaching, and mercerizing. Additionally, dyeing or over-dyeing processes are carried out, and appropriate finishing processes are applied as per requirements.
5	Quality Control and Packaging	The finished fabric undergoes quality control, after which it is packaged and made ready for sale.

The VSM of the processes is provided in Figure 4.4. The raw materials and chemicals used in the processes and the waste and by-products are presented in the diagram in their respective quantities. The type and amounts of energy consumed are also indicated in the figure.

In the production of denim fabric from cotton fiber, the first stage is carding the cotton fiber and spinning it into yarn. This process begins with cleaning the cotton and then spinning it into fine yarns. The spun cotton yarns are then subjected to the dyeing process. The most commonly used dye in denim production is indigo, which is applied to the yarns before they are woven together. After the yarns are dyed, the weaving process takes place. During the weaving process, blue warp yarns and white weft yarns are woven in a 3/1 twill pattern. Finally, after the weaving process is completed, the fabric undergoes various washing and finishing processes (Fidan et al., 2021).

High electricity (91,443,998 kWh) and natural gas (15,378,584 m^3) consumption stand out as a significant environmental impact point at the facility. Remarkably, the yarn production (Process-1) and weaving (Process-3) stages have the highest energy consumption in the facility. Total water usage amounts to 1,631,840 m^3, with high water consumption observed in the yarn dyeing and finishing (Process-2) and fabric dyeing and finishing (Process-4) processes, each consuming 625,890 m^3. A large amount of waste is generated during production: 3,323 tons of waste cotton in yarn production (Process-1), 994 tons of waste yarn in yarn dyeing and finishing (Process-2), and 393 tons of waste fabric in fabric dyeing and finishing (Process-4). The total chemical usage is 7,643 tons, with exceptionally high chemical consumption in yarn dyeing and finishing (Process-2) and fabric dyeing and finishing (Process-4). For example, in Process-2, 927 tons of indigo and 1,491 tons of caustic are used, creating an environmental impact.

The recovery and recycling of waste generated during denim production for use as biocomposite material in shoe components can reduce waste volume and replace petrochemical components, thereby decreasing the environmental impact of the footwear industry. In a study, waste from a denim manufacturing factory consisting of shredded and powdered denim fibers was processed for use in various shoe components such as insoles and toe caps. Soft biocomposites made from shredded fibers are particularly suitable for use in shoe insoles, as these materials provide comfort while walking. Dense biocomposites made from powdered fibers are more ideal for use in the toe caps of shoes ensure structural integrity in these areas (Fernandes et al., 2021).

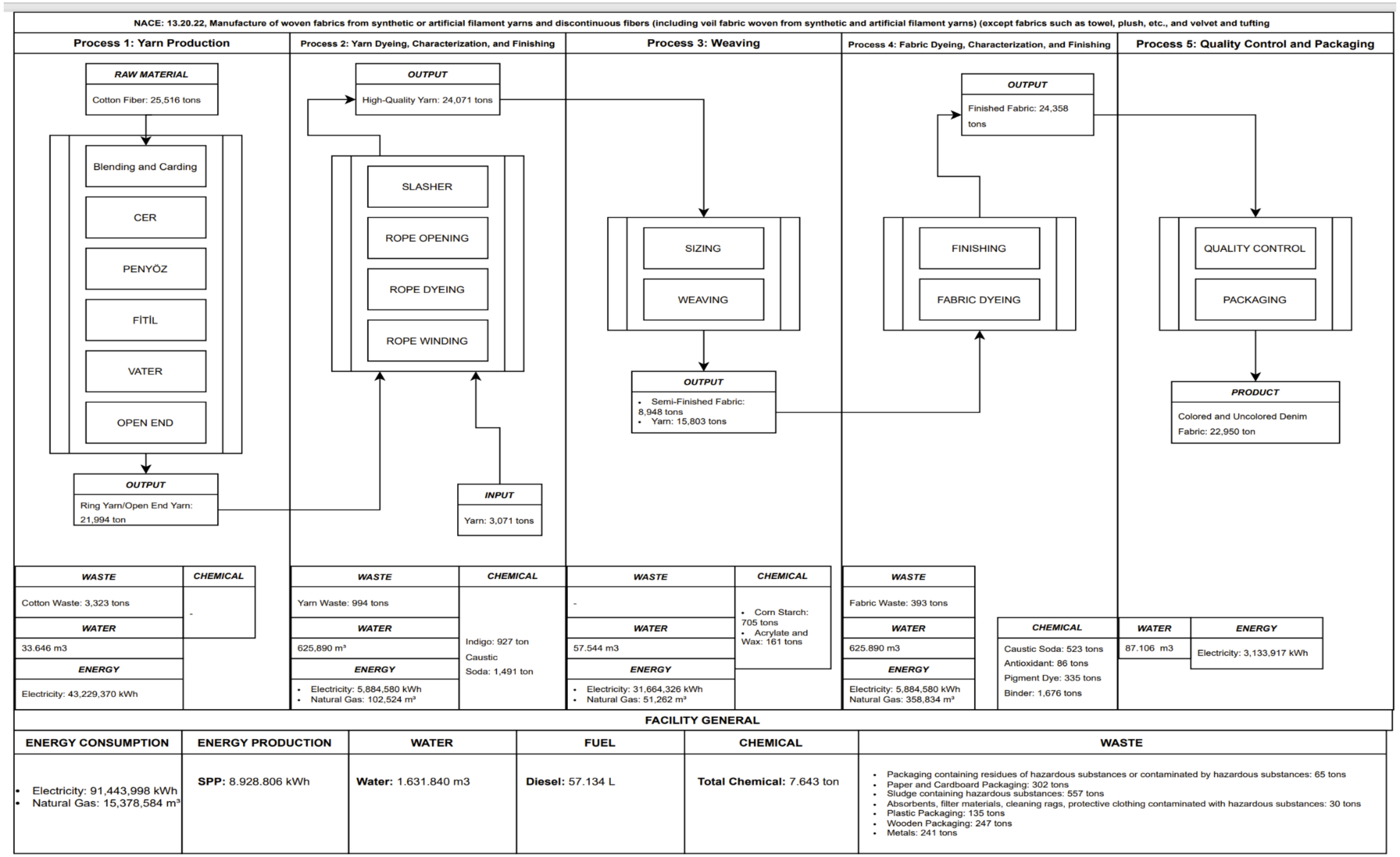


Figure 4.4. VSM of the Facility (NACE: 13.20.22)

Repurposing denim fabric can significantly contribute to reducing environmental impacts, especially considering the high demand for denim and the textile industry being recognized as the second largest environmental polluter (Hakeem & Kim, 2020).

This thesis considers that textile wastes (4710 ton in total) can be used in the textile sector, including yarn and other textile material manufacturing. Therefore, it can be concluded that there is a symbiotic potential between the “Manufacture of textiles (NACE Code: 13)” as a symbiosis alternative.

In addition to that symbiosis alternative, the focus has been on waste heat and water recovery processes between the various production stages of manufacturing. Waste heat generated in Process-1 (Yarn Production) and Process-3 (Weaving) can be used for water heating processes in Process-2 (Yarn Dyeing and Finishing). By using heat exchangers, waste heat can be recovered and utilized to heat water in the dyeing processes. This reduces energy consumption and lowers natural gas usage. The current Solar Power Plant (GES) production (8,928,806 kWh) accounts for 9.76% of the facility's total electricity consumption. Increasing the capacity of the GES and using the excess energy produced in other processes within the facility or selling it to nearby facilities can enhance energy efficiency and reduce the carbon footprint (Paul, 2015).

Regarding water management and recovery, the water used in Process-2 (Yarn Dyeing and Finishing) and Process-4 (Fabric Dyeing and Finishing) can be reclaimed using filtration and treatment systems. This process reduces the facility's water consumption and lowers water costs. Additionally, installing rainwater harvesting systems on the roof and other suitable areas can collect water for use in production processes or landscape irrigation. This method reduces water consumption and enhances environmental sustainability (Fidan et al., 2021).

The symbiosis alternatives in the facility are as follows: (i) using of textile waste (between NACE: 13.20.15, and 13), and (ii) optimization of the manufacturing (Intra-firm.

4.1.5. NACE: 13.20.22, Manufacture of woven fabrics from synthetic or artificial filament yarns and discontinuous fibers (including veil fabric woven from synthetic and artificial filament yarns) (except fabrics such as towel, plush, etc., and velvet and tufting

The facility produces Finished woven fabric. The production is carried out in four main processes (Table 4.5). Since this facility has the same NACE code as the previous facility, it is coded as 13.20.22A.

Table 4.5. Facility (NACE: 13.20.22A) Production Processes

Process No	Process Name	Process Description
1	Yarn Production	In the yarn production process, 100% synthetic fibers (approximately 60-65% polyester, 30-35% viscose, and up to 7% elastane) are used to produce yarn. The fiber is processed in specialized machines and converted into yarn form. A double-twist process is applied to increase the yarn's strength and thickness if needed. This makes the yarn more durable and suitable for the weaving process. In some cases, ready-made yarn is also procured from external sources and integrated into production.
2	Weaving	The yarns are woven on 220 weaving looms according to the specified pattern and structure. The yarns are woven regularly and evenly during this process to achieve the desired fabric properties.
3	Fabric Dyeing and Finishing	The woven fabrics are washed, dyed, and subjected to finishing processes. These processes impart the desired color, hardness, softness, and gloss to the fabrics.
4	Quality Control and Packaging	The finished fabrics undergo quality control. Those without defects are packaged and made ready for sale.

The value stream map of the processes is provided in Figure 4.5. The raw materials and chemicals used in the processes and the waste and by-products are presented in the diagram in their respective quantities. The type and amounts of energy consumed are also indicated in the figure.

The yarn production process, identified as the first process in the facility, stands out as the process with the highest energy consumption. This process consumes 28,899,966 kWh of electricity annually, making it the highest energy-consuming process in the facility. Additionally, 90,000 m^3 of water is used in this process. The raw materials used in yarn production include polyester fiber (4,653 tons), viscose fiber (2,775 tons), and elastane (500 tons), along with chemicals such as blending oil (2 tons).

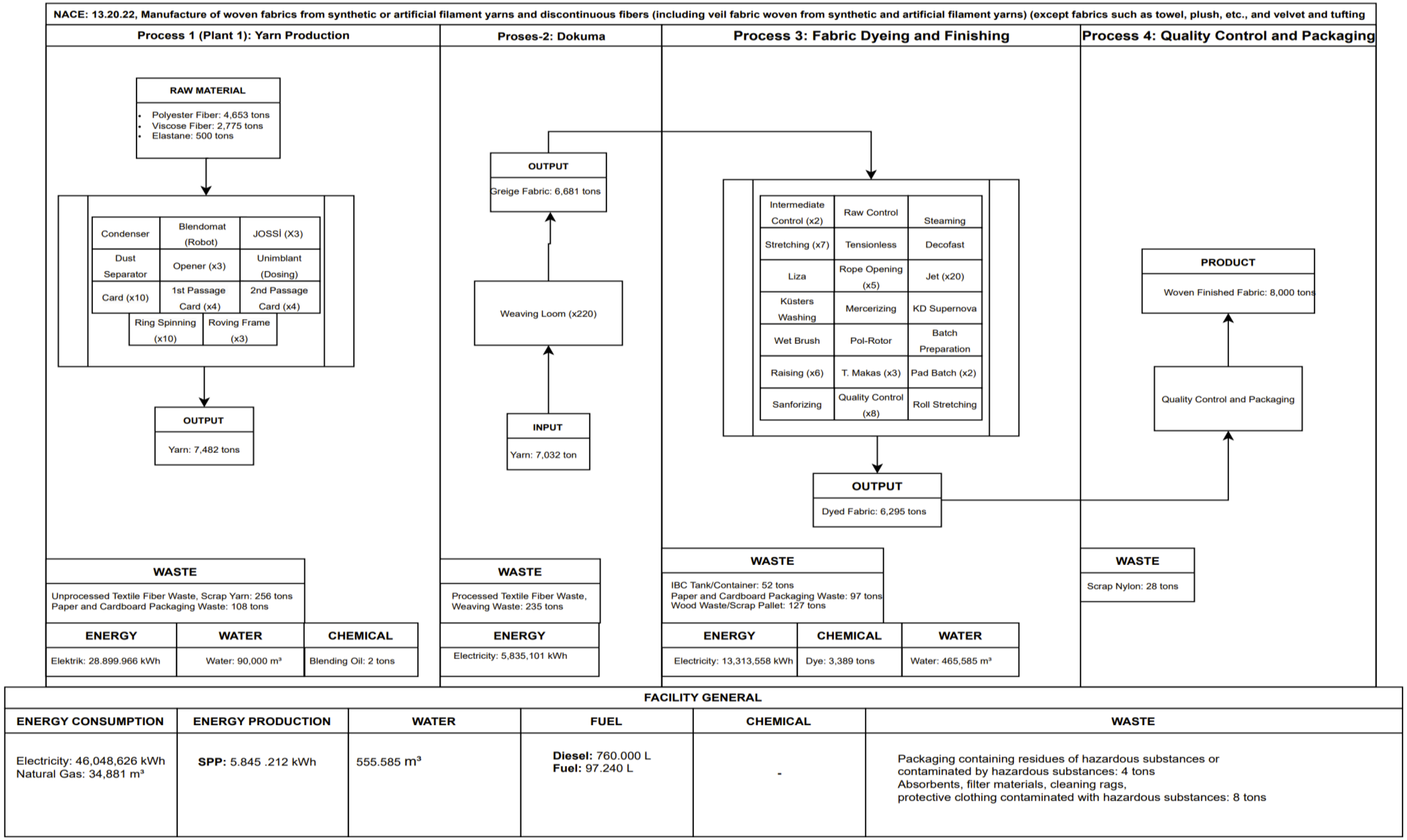


Figure 4.5. VSM of the Facility (NACE: 13.20.22A)

Process-1 results in the production of 256 tons of unprocessed textile fiber waste and scrap yarn, as well as 108 tons of paper and cardboard packaging waste. These data indicate that Process-1 is the most critical environmental hotspot in the facility in terms of energy and resource consumption and waste generation.

The symbiosis opportunities (i) using of textile waste (between NACE: 13.20.15, and 13) (491 tons) and (ii) using of plastic waste as a raw material (between NACE: 10.83.01 and 38.32.02) (24 tons) created for previous facilities generating textile and plastic waste are also applicable to this facility.

4.1.6. NACE: 13.30.01, Bleaching and dyeing services of fabrics and textile products (including wearing apparel)

The facility produces woven fabrics containing cotton, viscose, polyester, linen, tencel, polyamide, and elastane. The production is carried out in four main processes (Table 4.6).

Table 4.6. Facility (NACE: 13.30.01) Production Processes

Process No	Process Name	Process Description
1	Weaving Preparation/Sizing-Warping-Twisting	Yarns that need to be dyed undergo the dyeing process. Once dyeing is completed, the yarns are directly sent to the sizing section. The yarns are endowed with the necessary physical properties during the sizing process, usually using starch. After the sizing process is completed, the yarns are prepared for weaving through the warping and beaming process. At this stage, the strength of the yarns and their suitability for the weaving process are enhanced.
2	Weaving	The yarns are woven on 205 different looms according to the specified pattern and structure. The yarns are woven evenly and uniformly during this process to achieve the desired fabric characteristics. The weaving looms are adjusted and optimized according to the structure of the fabric and the type of yarn to be used.
3	Yarn Dyeing, Fabric Dyeing, and Finishing	This process includes dyeing yarns before weaving, washing, dyeing, and finishing the woven fabric. During the yarn dyeing stage, the yarns undergo various chemical and physical treatments to achieve uniform coloring. The washing of woven fabric removes residual chemicals and dirt. In fabric dyeing, the desired color and shade are applied permanently to the fabric. The finishing process improves the surface properties of the fabric and prepares it for final use.
4	Quality Control and Packaging	The quality control stage determines whether the fabric meets the desired physical and chemical standards. After passing quality control, the fabrics are packaged and made ready for sale.

The value stream map of the processes is provided in Figure 4.6. The raw materials and chemicals used in the processes, along with the waste and by-products, are presented in the diagram in their respective quantities. The type and amounts of energy consumed are also indicated in the figure.

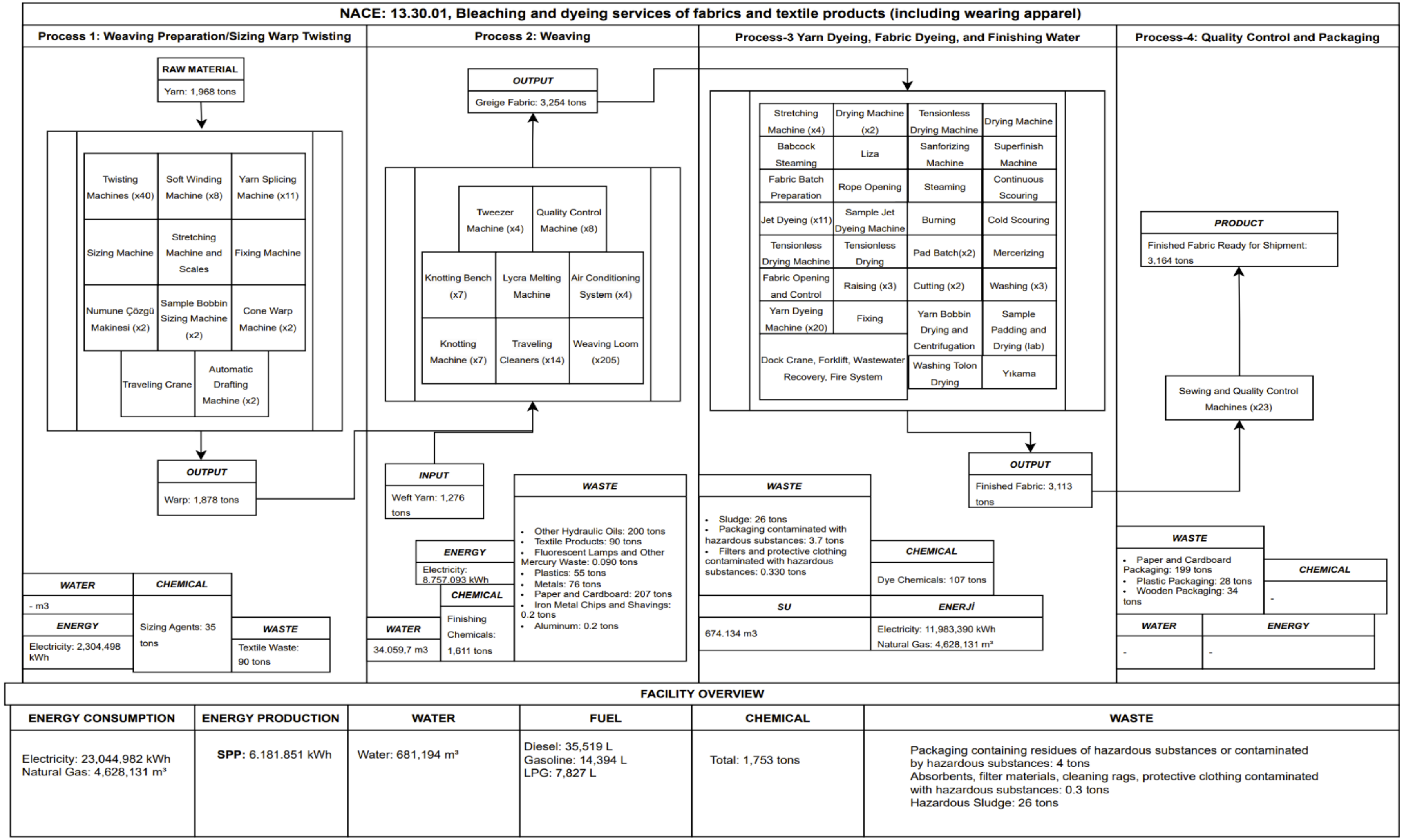
First and foremost, Process-3: Yarn Dyeing, Fabric Dyeing, and Finishing stands out as the process with the highest energy consumption. This process consumes 11,983,390 kWh of electricity and 4,628,131 m^3 of natural gas annually. It also uses a significant amount of water, totaling 674,134 m^3. During this process, 107 tons of chemicals, such as dyeing and finishing chemicals, are used, and it generates 26 tons of sludge and various hazardous wastes (e.g., containers and filters contaminated with hazardous substances). These data indicate that Process-3 is the most critical environmental hotspot in the facility in terms of energy and resource consumption and waste generation.

Secondly, Process-2: Weaving is also noteworthy. This process has high energy requirements, consuming 8,757,093 kWh of electricity and using 34,059.7 m^3 of water. In the weaving process, 1,611 tons of finishing chemicals are used, and various wastes are generated, including 90 tons of textile waste, 200 tons of hydraulic oil waste, 55 tons of plastic, 76 tons of metal, and 207 tons of paper and cardboard waste. Proper management of these wastes is critical to minimize environmental impacts.

Across the entire facility, the total electricity consumption is recorded at 23,044,982 kWh, and natural gas consumption is 4,628,131 m^3. Additionally, the facility uses a total of 1,753 tons of chemicals. In terms of energy production, the solar power system (GES) provides 6,181,851 kWh of energy annually. However, this energy production is insufficient, given the high energy consumption.

From a waste management perspective, various hazardous wastes, water, and chemical wastes present significant issues. Specifically, packaging contaminated with hazardous substances (4 tons), absorbents, filter materials, and cleaning cloths (0.3 tons) should be managed with care. Additionally, hazardous sludges generated from the processes (26 tons) must be appropriately disposed of.

The symbiosis opportunities (i) using of textile waste (between NACE: 13.20.15, and 13) (491 tons) and (ii) using of plastic waste as a raw material (between NACE: 10.83.01 and 38.32.02) (24 tons) created for previous facilities generating textile and plastic waste are also applicable to this facility.



ENERGY CONSUMPTION	ENERGY PRODUCTION	WATER	FUEL	CHEMICAL	WASTE
Electricity: 23,044,982 kWh Natural Gas: 4,628,131 m³	**SPP:** 6.181.851 kWh	Water: 681,194 m³	Diesel: 35,519 L Gasoline: 14,394 L LPG: 7,827 L	Total: 1,753 tons	Packaging containing residues of hazardous substances or contaminated by hazardous substances: 4 tons Absorbents, filter materials, cleaning rags, protective clothing contaminated with hazardous substances: 0.3 tons Hazardous Sludge: 26 tons

Figure 4.6. VSM of the Facility (NACE: 13.30.01)

In addition to this opportunity, paper, cardboard, and metal waste generated in the facility can also be evaluated within the scope of symbiosis. Among the pilot firms, (i) the "NACE: 17.12.07, Manufacture of paper and paperboard (as roll or layer for further industrial procedures) (including bituminous, laminated, coated, and impregnated ones, as well as crepe and wrinkled papers)" facility can utilize paper and cardboard waste (406 ton). Additionally, the "NACE: 38.32.01, Recycle of classified metallic waste, scraps, and other components, usually by means of mechanical or chemical replacement" facility, which is not among the pilot firms, can evaluate metal waste (76 tons) for symbiosis opportunities. These types of facilities have the potential to process waste into new products.

4.1.7. NACE: 13.30.02, Bleaching and dyeing services of textile fibers and yarns (including bleaching)

The facility produces hand knitting, carpet, knitwear, and home textile yarns. The production is carried out in 2 main processes (Table 4.7).

The value stream map of the processes is provided in Figure 4.7. The raw materials and chemicals used in the processes and the waste and by-products are presented in the diagram in their respective quantities. The type and amounts of energy consumed are also indicated in the figure.

The dyeing process is highlighted as having the highest energy and water consumption. Annually, this process consumes 3,634,077 kWh of electricity and 1,292,282 m^3 of natural gas. Additionally, 243,704 m^3 of water are used. The raw materials used in the dyeing process include polyester (1,642 tons), viscose (411 tons), cotton (41 tons), acrylic (493 tons), nylon (246 tons), wool (82 tons), and other materials (1,191 tons). As a result of this process, 32 tons of textile waste and 33 tons of wood waste are generated. The chemicals used include 1,166 tons of dyeing chemicals and 45 tons of disinfectants.

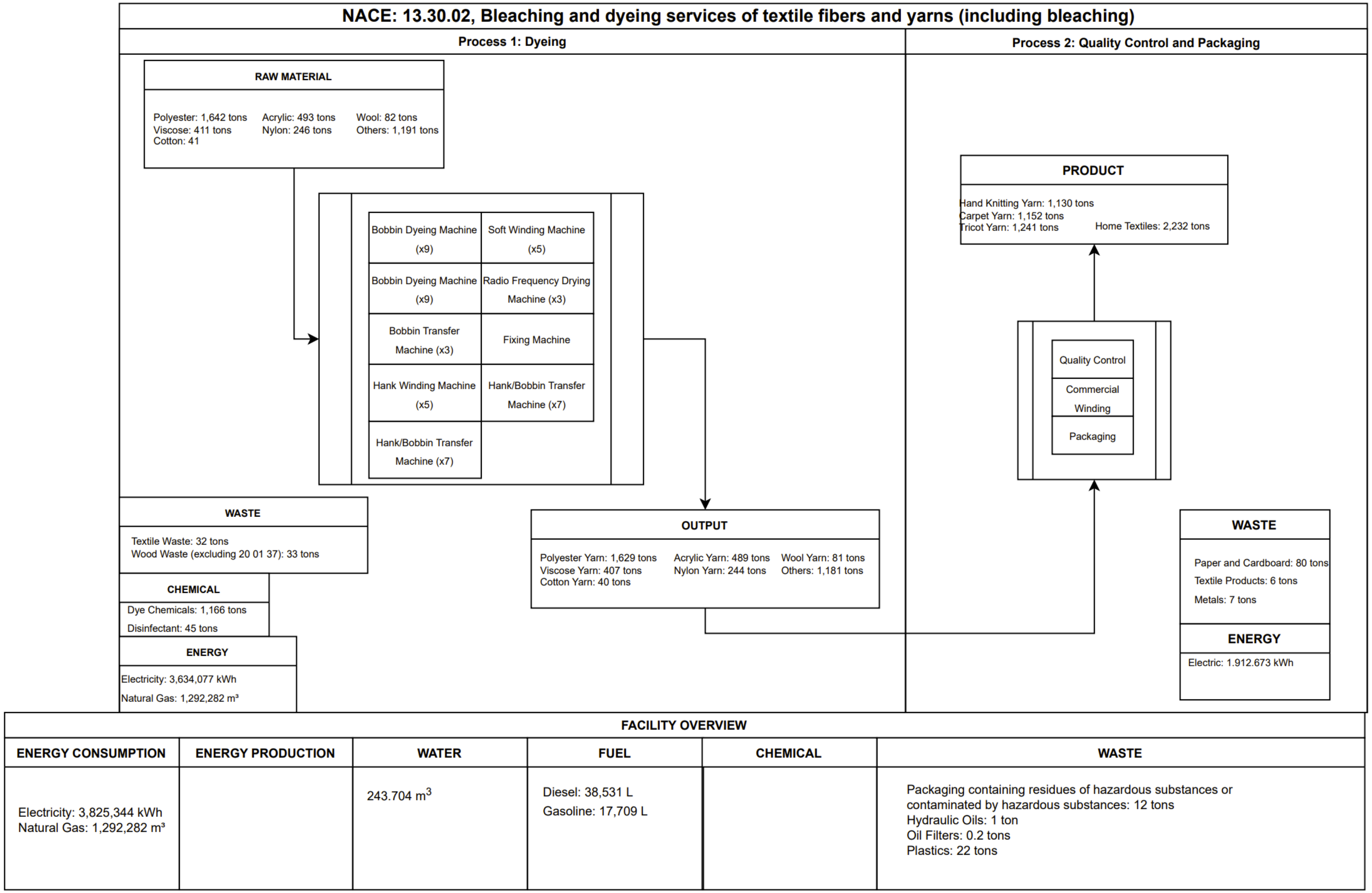
The Quality Control and Packaging process is also significant. This process has a high energy requirement, consuming 1,912,673 kWh of electricity annually. The products produced in this process include hand-knitting yarn (1,130 tons), carpets (1,152 tons), knitwear (1,241 tons), and home textiles (2,232 tons). As a result of this process generated 80 tons of paper and cardboard waste, 6 tons of textile waste, and 7 tons of metal waste.

Table 4.7. Facility (NACE: 13.30.02) Production Processes

Process No	**Process Name**	**Process Description**
1	Dyeing	Yarns from the company's own facilities and other customers are dyed using various techniques. Four types of dyeing processes are applied in the facility: • Bobbin Dyeing: Yarns are dyed on bobbins, ensuring uniform color distribution. • Hank Dyeing: Yarns are dyed in hanks, a method preferred for delicate yarns. • Closed Hank Dyeing: Yarns are dyed in closed vats with controlled temperature and pressure. • Gradient Dyeing: Yarns are dyed with gradient colors, creating complex and aesthetic patterns. After the dyeing process is completed, the yarns are centrifuged in centrifugal machines to remove excess water. Then, the yarns are dried to the desired moisture level using RF Stalam (microwave method) or hank drying machines.
2	Quality Control, Commercial Winding, and Packaging	The dyed yarns are sent to the commercial winding section. The yarns are wound onto paper cones in the desired weight and dimensions in this section. The winding process ensures that the yarns are packaged neatly and without damage

Across the entire facility, the total electricity consumption is recorded at 3,825,344 kWh, and natural gas consumption is 1,292,282 m^3. Additionally, the facility uses 243,704 m^3 of water. Other types of waste include packaging contaminated with hazardous substances (12 tons), hydraulic oils (1 ton), oil filters (0.2 tons), and plastics (22 tons).

The symbiosis opportunities (i) using of textile waste (between NACE: 13.20.15, and 13) (38 ton) and (ii) using of paper, cardboard, as a raw material (between NACE: 17.12.07) (80 ton).



ENERGY CONSUMPTION	ENERGY PRODUCTION	WATER	FUEL	CHEMICAL	WASTE
Electricity: 3,825,344 kWh Natural Gas: 1,292,282 m³		243.704 m^3	Diesel: 38,531 L Gasoline: 17,709 L		Packaging containing residues of hazardous substances or contaminated by hazardous substances: 12 tons Hydraulic Oils: 1 ton Oil Filters: 0.2 tons Plastics: 22 tons

Figure 4.7. VSM of the Facility (NACE: 13.30.02)

4.1.8. NACE: 13.92.06, Manufacture of textile sacks, bags, pouches, and similar products (those used for packing goods)

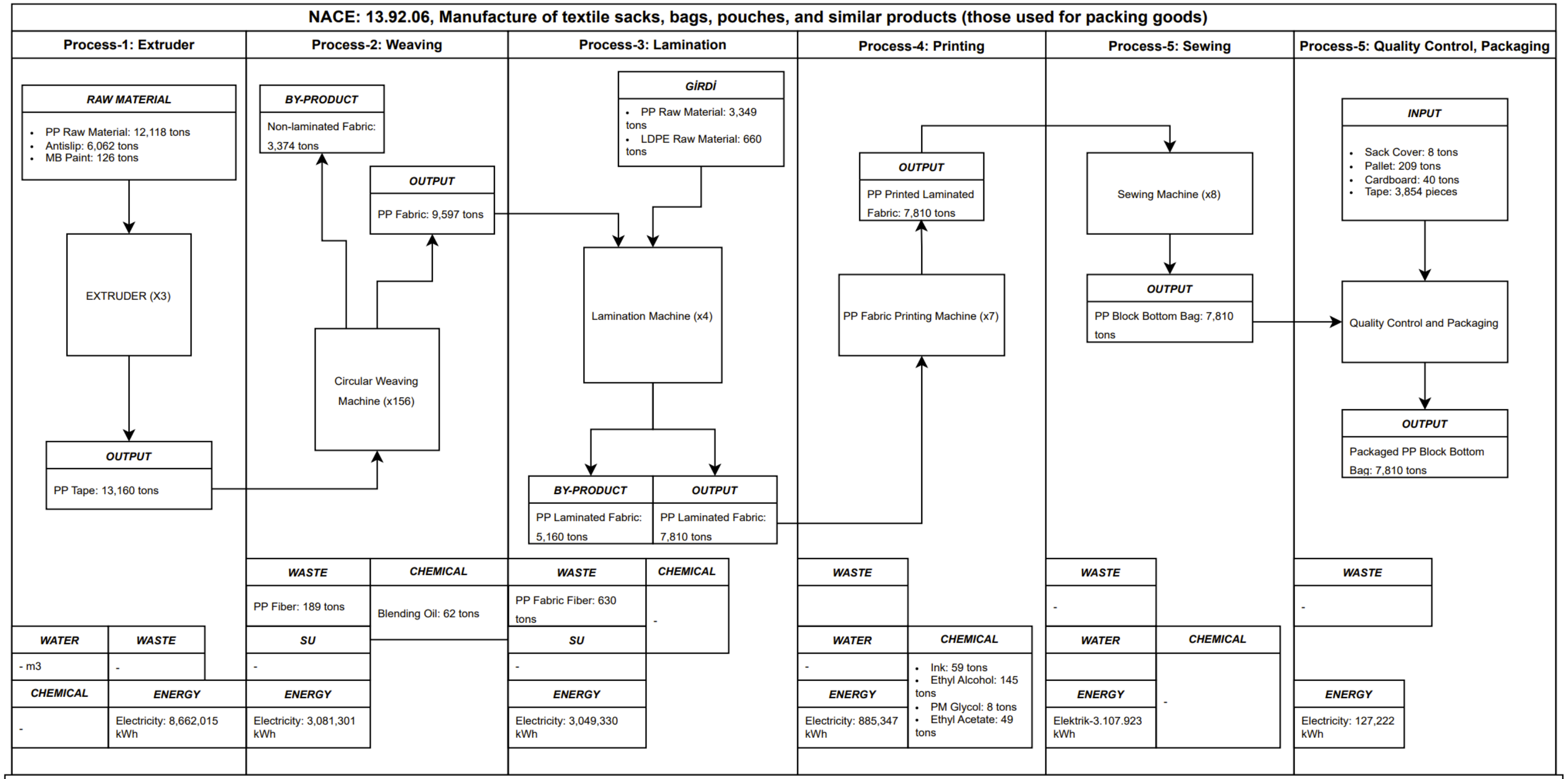
The facility produces polypropylene (pp) fabric, pp block bottom (bb) bag, pp laminated fabric. The production is carried out in six main processes (Table 4.8).

Table 4.8. Facility (NACE: 13.92.06) Production Processes

Process No	Process Name	Process Description
1	Yarn Production	In this process, yarn production is carried out from raw polypropylene (PP) material using extrusion machines. The PP raw material is melted and passed through a fine-mesh mold under pressure. The yarns, which are then cooled and solidified, are brought to the desired strength and thickness through drawing and twisting processes.
2	Weaving	The produced PP yarns are pulled horizontally and vertically on circular weaving machines and then interlaced in two main directions to produce fabrics and bags with the desired thickness.
3	Lamination	A film layer of PP raw material is applied to the surface of fabrics from the weaving process using hot pressing.
4	Printing	Ink prepared by mixing pigment solvents is printed onto the fabrics from the weaving process using printing machines.
5	Confection	The fabrics are cut to the desired sizes in a confection machine, and the edges of the cut fabric pieces are reinforced by sewing in an overlock machine to form bags.
6	Quality Control and Packaging	After quality control, the fabrics are packaged and made ready for shipment.

In the initial stage at the facility, PP granules are melted and extruded into films or strips. These strips are then cooled and drawn to achieve the desired strength (Phillips & Ghosh, 2003). The extrusion processes involve melting and shaping the raw material PP (polypropylene) and other additives to produce PP tape. During extrusion, the melting point of polypropylene is between 165-170°C, and the temperatures in the extruder typically range from 199-232°C (INEOS, 2007). The resulting strips are drawn with hot air to gain strength and can be approximately 50 microns thick and 2.5 mm wide (Phillips & Ghosh, 2003). This process has the highest energy consumption in the facility, using a total of 8,662,015 kWh of electricity. PP tape is the primary input used in the facility's other processes.

The weaving process involves converting the PP tape material produced from extrusion into fabric. This process consumes 3,081,301 kWh of electricity. Circular weaving machines operate at high speeds to weave the tape material into the fabric.



FACILITY OVERVIEW

ENERGY CONSUMPTION	ENERGY PRODUCTION	WATER	FUEL	CHEMICAL	WASTE
Electricity: 19.108.437kWh	**Solar Power:** 1.398.919 kWh	**Su:** 10.422 m^3	**Diesel:** 184.837 L **Gasoline:** 2.331 L	-	Engine and transmission oils: 0.2 tons Fluorescent lamps and other mercury-containing waste: 0.055 tons Absorbents, filter materials, cleaning rags, and protective clothing contaminated with hazardous substances: 1 ton Paper and Cardboard: 296 tons

Figure 4.8. VSM of the Facility (NACE: 13.92.06)

The bags produced by this method are woven in a tubular form without side seams, which makes the bags more durable (Phillips & Ghosh, 2003). These machines are mechanical systems that run continuously and at high speeds, leading to high energy consumption. Lamination processes involve coating the PP fabrics with LDPE (Low-Density Polyethylene) to produce laminated fabrics. This process has an energy consumption of 3,049,330 kWh. Following the lamination process, the confection stage involves cutting the laminated fabrics into specified sizes and stitching them together using sewing machines. This stage ensures that the bags or sacks take their final form. The stitching process typically employs techniques such as double stitching or overlocking to enhance the strength of the products. This stage consumes 3,107,923 kWh of electricity. These processes highlight the energy-intensive nature of producing PP fabrics and bags, from the initial extrusion of PP granules to the final stitching of the products.

In polypropylene (PP) bag production, waste reduction, increased efficiency, and minimized environmental impact are critical goals. Significant improvements have been achieved using the Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) methodology. The DMAIC approach focuses on process improvement by reducing variations and eliminating waste. According to a study in the literature, the primary issues in the PP bag production process were identified and optimized for waste reduction.

Firstly, it was found that the rejection rate of bags was high due to the production of low-strength fabric in the weaving section. The low fabric strength was determined to be caused by low strip durability obtained during the extrusion section. Through experimental design, it was found that the water bath temperature and line speed in the extrusion process had significant effects on strip durability. The optimal levels were identified as a water bath temperature of 40°C and a 300 m/min line speed. By making these adjustments in the process, strip durability was increased, fabric strength was improved, and the bag rejection rate was reduced from 2.8% to 1.2%. This resulted in a 50% reduction in waste. This improvement led to significant annual cost savings of $92,000 (Sajjad et al., 2021)

The facility's polypropylene (PP) waste, particularly from Process-2 Weaving, which generates 189 tons of PP scrap, and Process-3 Lamination, which produces 630 tons of fabric waste, can be considered for recycling. This waste can be sent to plastic recycling facilities to be converted into granules and reused in production processes.

Additionally, the recycled PP materials can be used to manufacture new products within the facility, reducing dependency on raw materials and achieving cost savings.

According to information obtained from company officials, PP scrap and fabric waste are granulated at another facility owned by Abdioğulları and subsequently used in the production of bags and packaging. This activity can be considered an example of intra-firm industrial symbiosis.

When all of these are considered, plastic waste (820 tons) can be used inside the facilities and other facilities like "(NACE Code: 38.32.02)" and "Manufacturing of plastic bag, trash bag, bag, sack, jug bag, net, packing case, box, safe custody, carboy, bottle, jerrycan, whip, spindle, spool, cap, tap, capsule, etc. Packing material production (inclusive bladder)" (NACE Code: 22.22.43) as a symbiosis alternative. The materials are valued in the facility, as well (Intra-firm).

4.1.9. NACE: 16.21.02, Manufacture of plywood, MDF, wallboard, etc., made of compressed fiber, wood, and plates

The facility produces coated and uncoated mdf boards and parquet adhesive. The production is carried out in five main processes (Table 4.9).

Table 4.9. Facility (NACE: 16.21.02) Production Processes

Process No	Process Name	Process Description
1	Chipping and Fiberizing	Wood is broken down into small pieces using a chipper machine. The bark is separated and sent to steam machines as fuel. In one shift (8 hours), 800-1000 tons of chips are produced. The chips are stored in four concrete silos and go through a three-stage screening system before production. Medium-sized chips are sent to production, small chips to the biofuel boiler, and large chips are sent back to the chipper. The chips are softened and fiberized with hot air at 10-12 bar obtained from the biofuel boiler for 4.5 minutes. The fibers are then sent to segment discs and exit from the bottom.
2	Gluing, Drying, and Pressing	Various types of adhesives are produced using methanol, formaldehyde, melamine, and urea. These adhesives are used in board production. Methanol is stored in 450 m³ tanks, and the fibers are glued. The fibers glued with formaldehyde are dried until they reach a 9-9.5% moisture content. The dried fibers are placed in a press machine and subjected to a two-stage (cold and hot) pressing process. The resulting boards are cut to the desired sizes, cooled in a cooling system, and sanded.

(cont. on next page)

Table 4.9 (cont.)

Process No	Process Name	Process Description
3	Impregnated Paper Production and Lamination	Resin-impregnated and dried papers with various designs are produced to be pressed onto the board surfaces. This process is done with impregnation machines and supported by a cooling system. The boards are coated with impregnated paper. The boards are dried after being processed in a melamine press coating machine.
4	Parquet Manufacturing	The coated MDF boards are cut to the desired dimensions, and edge processing is performed. They are then turned into laminated parquet.
5	Adhesive and Formaldehyde Production, Quality Control, and Packaging	Adhesives and formaldehyde are produced for use in production or for direct sale. The products undergo quality control and are packaged and made ready for shipment.

The value stream map of the processes is provided in Figure 4.9. The raw materials and chemicals used in the processes and the waste and by-products are presented in the diagram in their respective quantities. The type and amounts of energy consumed are also indicated in the figure.

The Gluing, Drying, and Pressing process stands out as the process with the highest energy consumption. This process consumes 40,448,653 kWh of electricity annually, making it the most energy-intensive process in the facility. Additionally, the chemicals used in this process include semi-finished adhesive (70,377 tons), paraffin (2,307 tons), and other chemicals (4,861 tons). As a result of this process, 932 tons of wood packaging waste are generated. These data indicate that Process-2 is the facility's most critical environmental hotspot in terms of energy and resource consumption and waste generation.

The first process in the facility, Chipping and Fiberizing, is also noteworthy. This process has high energy requirements, consuming 31,561,237 kWh of electricity annually. The raw materials used in this process include wood (627,892 tons). As a result of this process, 59,612 tons of biomass bark waste (wood waste), 16,249 tons of biomass dust waste, and 8,676 tons of ash waste are generated.

Wood ash, which can replace cement and fine aggregates, helps reduce the consumption of natural resources in constructing materials. It can also be used in road construction and the improvement of weak soils, ensuring the beneficial reuse of waste. Wood ash is suitable for producing geopolymer and alkali-activated materials, significantly contributing to reducing carbon emissions. Additionally, wood ash can be used as an additive in the production of sustainable bricks and panels, which not only reduces the weight of the products but also improves their thermal conductivity.

In composite materials, wood ash serves as a reinforcing agent, enhancing the mechanical properties of polypropylene and natural rubber composites.

When used as a replacement for cement, wood ash can reduce costs by 20-30% and decrease carbon emissions by 80-90%. In road construction, up to 250 tons of wood ash can be used per kilometer, replacing 2.45 tons of gravel per ton of wood ash.

Across the entire facility, the total electricity consumption is recorded at 98,507,789 kWh. Additionally, the facility uses 641,346 m^3 of water. Other types of waste include packaging contaminated with hazardous substances (17 tons), waste chemicals (12 tons), and treatment sludge (39 tons).

To identify industrial symbiosis opportunities for this facility, the efforts to utilize all wood chips produced within the facility in production processes (intra-firm), the usage of waste ash (8,676 tons) in construction sector activities (NACE Code: 41-42), and the recycling of 342 tons of paper and cardboard waste in a facility with NACE Code 17.12.07 will be considered in the industrial symbiosis model presented in this thesis.

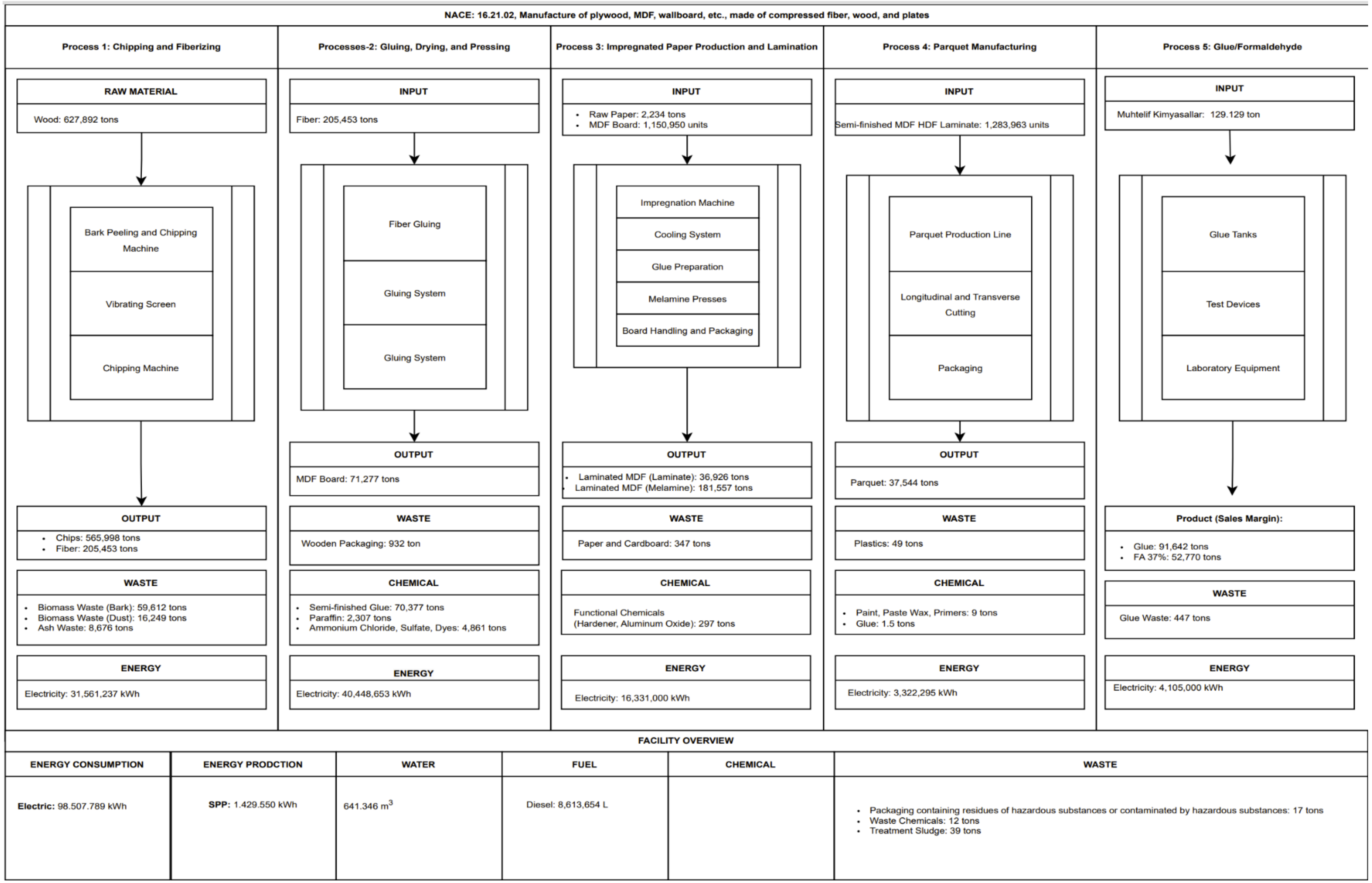


Figure 4.9. VSM of the Facility (NACE: 16.21.02)

4.1.10. NACE: 17.12.07 Manufacture of paper and paperboard (as roll or layer for further industrial procedures) (including bituminous, laminated, coated, and impregnated ones, as well as crepe and wrinkled papers)

The facility produces recycled paper/cardboard production. The production is carried out in three main processes (Table 4.10).

Table 4.10. Facility (NACE: 17.12.07) Production Processes

Process No	Process Name	Process Description
1	Pulp Preparation	In the pulp preparation process, waste cardboard (90%) and/or raw cellulose (10%) are mixed with water and heated to form a pulp. This process ensures a homogeneous mixture of raw materials and achieves the desired consistency for paper production.
2	Paper Making	The paper pulp is passed through wire presses and rollers to be thinned. This thinning process ensures that the pulp forms a smoother and thinner layer. Then, the pulp is heated and dried in steam-heated hot vats and coated with starch to harden it. The starch coating increases the strength and surface smoothness of the paper. The drying process uses eight steam-heated cylinders, which ensure the complete drying of the paper pulp and allow it to be rolled. After the final drying process, the paper is rolled up and prepared for the next stages.
3	Roll Cutting and Labeling	The rolled paper is cut into desired sizes and prepared for shipment. The cutting process ensures that the paper is neatly separated into specified dimensions. The cut paper is labeled and made ready for storage and transport.

The value stream map of the processes is provided in Figure 4.10. The raw materials and chemicals used in the processes and the waste and by-products are presented in the diagram in their respective quantities. The type and amounts of energy consumed are also indicated in the figure.

Firstly, Process-1: Pulp Preparation is the process with the highest energy and water consumption. Annually, this process consumes 11,847,868 kWh of electricity and 619,856 m^3 of water. Raw materials used during the process include corrugated scrap (23,746 tons), trimming paper (15,036 tons), and cellulose (3,450 tons). As a result of this process produces 48,000 tons of pulp, along with 243 tons of plastic scrap waste and 3,010 tons of treatment sludge waste. These data indicate that Process-1 is the facility's most critical environmental hotspot in terms of energy and water consumption and waste generation.

Process-2: Paper Making is also noteworthy. This process has high energy requirements, consuming 5,923,934 kWh of electricity and 21,717 tons of coal annually. Additionally, 32,624 m^3 of water are used. Chemicals used during the process include 1,975 tons of starch and 1,027 tons of production chemicals. This process produces 47,040 tons of paper, along with 17,650 tons of bed ash and 7,386 tons of fly coal ash waste.

(i) The usage of waste ash (25036 tons) in construction sector activities (NACE Code: 41-42) and (ii) using of plastic waste as a raw material (between NACE: 10.83.01 and 38.32.02) are the industrial symbiosis opportunities for this facility.

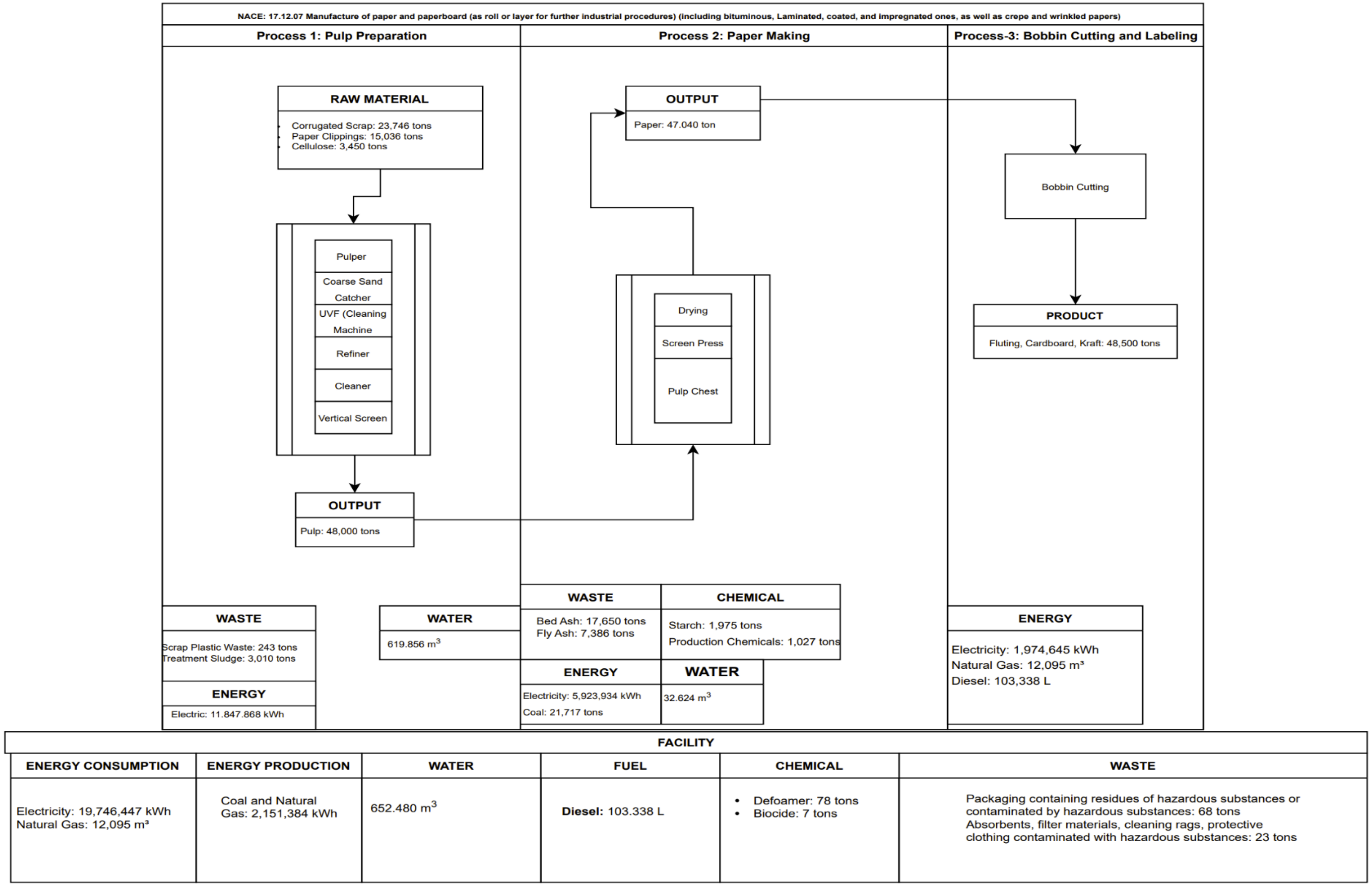


Figure 4.10. VSM of the Facility (NACE: 17.12.07)

4.1.11. NACE: 20.14.01, Manufacture of basic organic chemicals (hydrocarbons, alcohols, acids, aldehydes, ketones, synthetic glycerol, nitrogen functionalized compounds, etc.) (including ethyl alcohol, citric acid)

The facility produces bioethanol, ddgs (distillers dried grains with solubles), crude corn oil, and biocarbon dioxide. The production is carried out in four main processes (Table 4.11).

Table 4.11. Facility (NACE: 20.14.01) Production Processes

Process No	Process Name	Process Description
1	Bioethanol Production	The bioethanol production process begins with the storage of corn. The stored corn is ground into fine particles and moved to the mash preparation stage. During mash preparation, water and enzymes are added to the ground corn to create a mixture suitable for fermentation. Then, yeast is added, and the yeast cells are multiplied. The mash is processed under specific temperature and pressure conditions during fermentation, converting the sugars into ethanol. The ethanol produced from fermentation is purified through distillation and further dehydrated to obtain pure ethanol. Finally, the produced bioethanol is stored and prepared for shipment under appropriate conditions.
2	DDGS (Distillers Dried Grains with Solubles) Production	The DDGS production process involves processing the by-products of fermentation. After fermentation, the remaining mixture is separated into solid and liquid phases using a decanter. The liquid phase is concentrated by removing water through evaporation. The concentrated product is then dried to produce DDGS. Finally, the produced DDGS is stored and prepared for shipment.
3	Crude Corn Oil Production	The crude corn oil production process involves processing the oily syrup left after fermentation. The oily syrup is processed in decanters to separate it into oil and oil-free syrup phases. The separated oil is further processed and purified in separators. Both the crude corn oil and the oil-free syrup are stored and prepared for shipment.
4	Biocarbon Dioxide Production	The biocarbon dioxide production process involves processing the fermentation gas. The carbon dioxide in the gas phase is cleaned in a scrubber device. The cleaned carbon dioxide is compressed in a pressurization unit and then cooled in a chiller unit. The cooled carbon dioxide is processed in dehumidification and deodorization units and finally liquefied. The produced biocarbon dioxide is stored and prepared for shipment.

The value stream map of the processes is provided in Figure 4.11. The raw materials and chemicals used in the processes and the waste and by-products are presented in the diagram in their respective quantities. The type and amounts of energy consumed are also indicated in the figure.

Firstly, Process-1: Bioethanol Production stands out as the process with the highest energy and water consumption. This process consumes 9,411,327 kWh of electricity and 5,545,464 m^3 of natural gas annually. Additionally, 462,045 m^3 of water are used. Raw materials used in bioethanol production include corn (89,000 tons) and various chemicals (amylase, protease, urea, yeast, liquid caustic, sulfate, and activated carbon). This process produces 3 tons of used activated carbon, 1 ton of plastic packaging, 4 tons of non-ferrous metal, and 10 tons of metal waste. As a by-product, 25,810 tons of mash are obtained. These data indicate that Process-1 is the facility's most critical environmental hotspot in terms of energy and water consumption and waste generation.

For DDGS production, 5,240,649 kWh of electricity and 4,433,271 m^3 of natural gas are consumed annually. Additionally, 35,542 m^3 of water are used. As a by-product, 25,517 tons of DDGS are obtained.

Across the entire facility, the total electricity consumption is recorded at 19,389,920 kWh, and natural gas consumption is 9,978,735 m^3. Additionally, 568,671 m^3 of water is used facility-wide.

DDGS is a by-product of the dry milling processes used to produce ethanol from corn. It primarily consists of distillers' grains and solubles, which are used mainly as animal feed. Unfermented grain components, yeast cells, and other residues are separated as a by-product at the end of the ethanol production process.

The composition of DDGS makes it highly valuable in the animal feed industry due to its nutritional value. DDGS contains components such as crude protein, crude fat, crude fiber, and ash. Additionally, it includes polymeric sugars like cellulose, starch, xylose, and arabinose. These sugars can be converted into fermentable sugars through enzymatic hydrolysis, making DDGS a potential nutrient source for ethanol production (Kim et al., 2007).

Agricultural wastes (e.g., corn cobs, wheat straw, rice husk) are collected and ground into smaller pieces. Acidic or basic solutions are used to break down the lignin structure, facilitating the hydrolysis of cellulose and hemicellulose. Cellulose and hemicellulose are then broken down into simple sugars (glucose and xylose) using enzymes. Cellulases and hemicellulases convert these polymers into monomers.

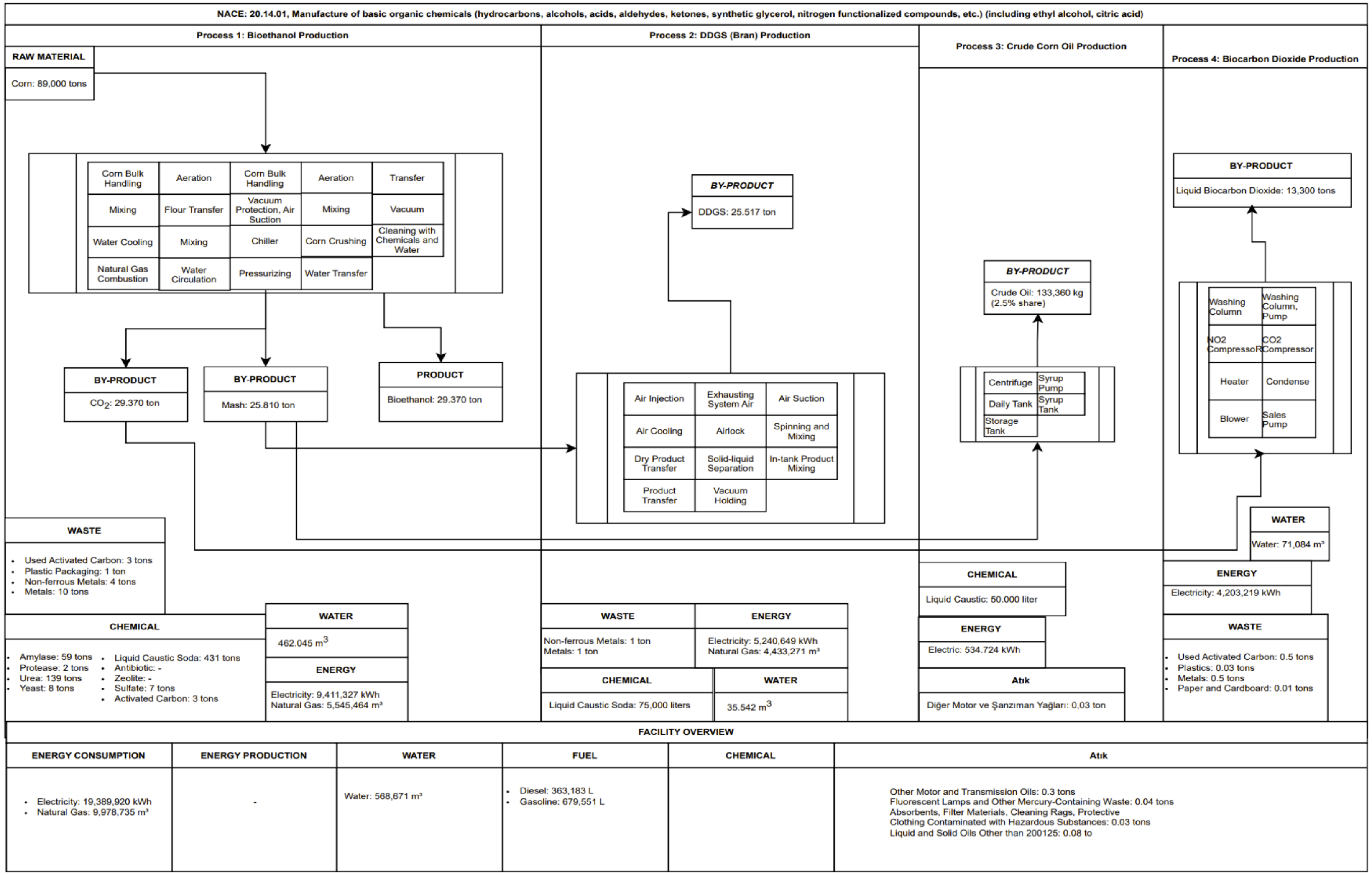


Figure 4.11. VSM of the Facility (NACE: 20.14.01)

The resulting sugars from hydrolysis are fermented by microorganisms (usually yeast or bacteria) into ethanol. Yeast species like Saccharomyces cerevisiae convert glucose into ethanol and carbon dioxide. The ethanol mixture produced from fermentation is purified through distillation to obtain 95-99% pure ethanol, which is used as fuel (Awasthi et al., 2022).

In the studies, it is observed that DDGS is used in the symbiotic relation with the "Manufacture of prepared animal feeds (NACE Code: 10.9)". In addition, a potential symbiotic relationship between the previous facility and this one is their shared use of biofuel. The symbiotic relationship can be sustained through the sharing of information and data, as well as the execution of joint projects.

4.1.12. NACE: 20.14.01, Manufacture of basic organic chemicals (hydrocarbons, alcohols, acids, aldehydes, ketones, synthetic glycerol, nitrogen functionalized compounds, etc.) (including ethyl alcohol, citric acid)

The facility produces citric acid (lemon salt). The production is carried out in five main processes (Table 4.12). Since this facility has the same NACE code as the previous facility, it is coded as 20.14.01A.

Table 4.12 Facility (NACE: 20.14.01A) Production Processes

Process No	Process Name	Process Description
1	Corn Milling, Liquefaction, and Filtration	Corn with specific moisture and starch values undergoes milling and mixing processes. After these processes, the starch in the corn is broken down into sugar by enzymes. The obtained sugar is then subjected to a filtration process and included in the next process. At this stage, silage is produced as a by-product.
2	Fermentation and Filtration	The obtained sugar is fermented with the help of Aspergillus niger mold at a temperature of 37°C to produce citric acid. After the fermentation process is completed, the citric acid undergoes filtration. At this stage, silage is also produced as a by-product.
3	Extraction and Filtration	The liquid obtained from the fermentation process undergoes reactions with calcium carbonate and citric acid, resulting in a 55-60% citric acid aqueous solution. During this process, calcium sulfate ($CaSO_4$) is produced as a by-product. The liquid is then filtered using perlite to remove unwanted substances and deodorized with activated carbon.

(cont. on next page)

Table 4.12 (cont.)

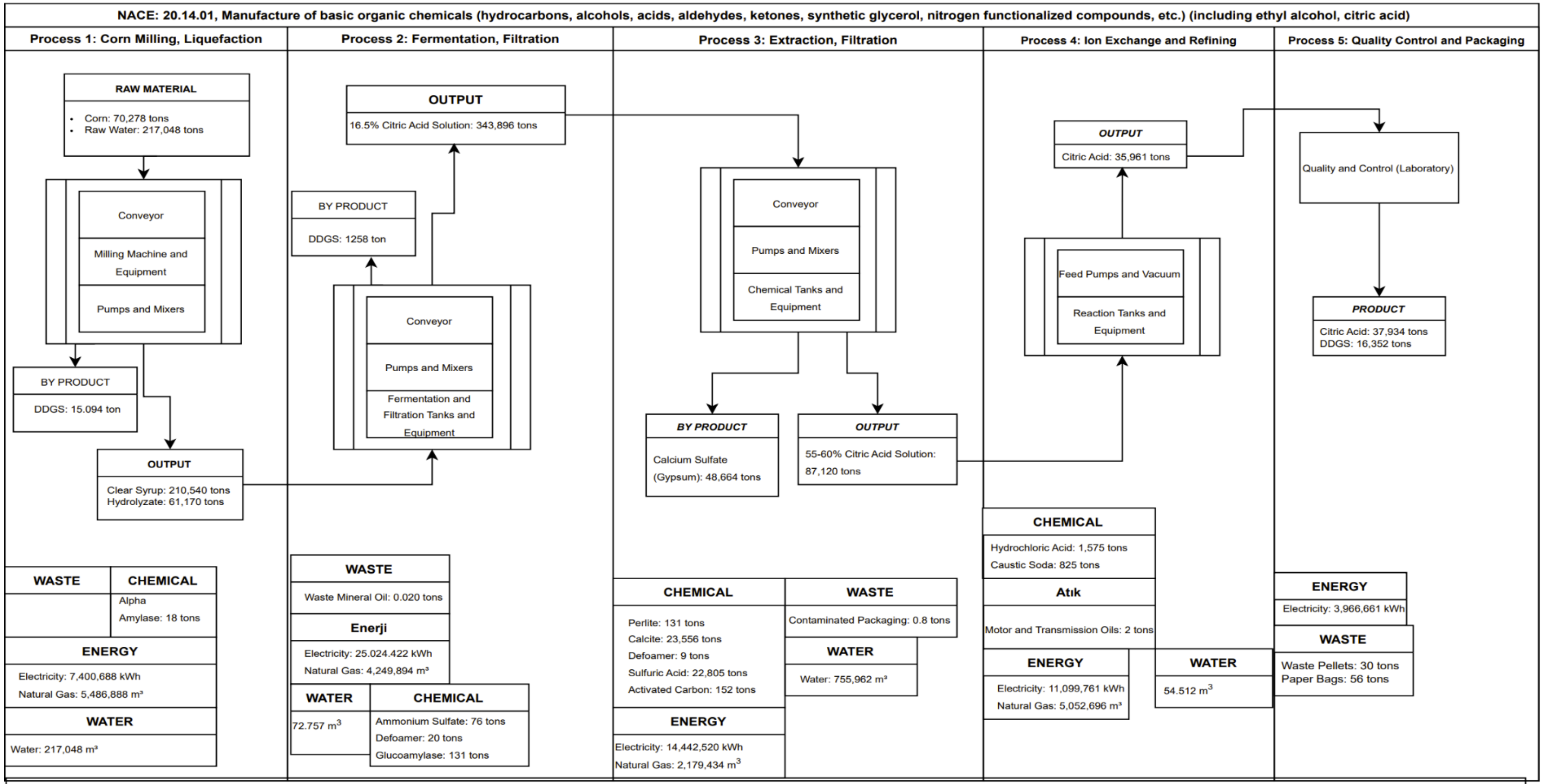
Process No	Process Name	Process Description
4	Ion Exchange and Refining	The crude citric acid obtained after extraction is separated from metal ions such as iron in an ion exchanger. At this stage, the concentration of citric acid is reduced to 45%. It then undergoes evaporation and concentration processes, followed by crystallization, increasing the purity to 90-95%.
5	Quality Control and Packaging	The obtained product is subjected to quality control processes to check its size, purity, moisture content, concentration, color, and odor. After passing all these controls, the product is packaged and prepared for shipment.

The value stream map of the processes is provided in Figure 4.12. The raw materials and chemicals used in the processes and the waste and by-products are presented in the diagram in their respective quantities. The type and amounts of energy consumed are also indicated in the figure.

Process-2: Fermentation and Filtration is the process with the highest energy consumption. This process consumes 25,024,422 kWh of electricity and 4,249,894 m^3 of natural gas annually. Additionally, 76 tons of ammonium sulfate, 20 tons of defoamer, and 131 tons of glucoamylase are used as chemicals. The process produces 343,896 tons of 16.5% citric acid solution, along with 0.020 tons of waste mineral oil and 1,258 tons of DDGS by-products. These data indicate that Process-2 is the facility's most critical environmental hotspot regarding energy and resource consumption and waste generation.

Process-3: Extraction and Filtration is also noteworthy. This process has high energy requirements, consuming 14,442,520 kWh of electricity and 2,179,434 m^3 of natural gas annually. The chemicals used in this process include 131 tons of perlite, 23,556 tons of calcite, 9 tons of defoamer, 22,805 tons of sulfuric acid, and 152 tons of activated carbon. The process generates 48,664 tons of calcium sulfate (gypsum) as a by-product and 0.8 tons of contaminated packaging waste. Additionally, 755,962 m^3 of water are used.

Across the entire facility, the total electricity consumption is recorded at 61,934,052 kWh, and natural gas consumption is 16,968,912 m^3. Additionally, the facility uses 1,092,546 m^3 of water. Other types of waste include packaging contaminated with hazardous substances (1.6 tons), paper and cardboard (9 tons), plastic packaging (33 tons), wastewater treatment sludge (143 tons), and other filter cakes and used absorbents (2 tons).



FACILITY GENERAL

ENERGY CONSUMPTION	ENERGY PRODUCTION	WATER CONSUMPTION	FUEL	CHEMICAL	WASTE
• Electricity: 61,934,052 kWh • Natural Gas: 16,968,912 m³	-	1.092.546 m^3			Packaging containing residues of hazardous substances or contaminated by hazardous substances: 1.6 tons Paper and Cardboard: 9 tons Plastic Packaging: 33 tons Wastewater Treatment Sludge: 143 tons Other Filter Cakes and Used Absorbents: 2 tons Absorbents, Filter Materials, Cleaning Rags, Protective Clothing Contaminated with Hazardous Substances: 0.9 tons

Figure 4.12. VSM of the Facility (NACE: 20.14.01A)

Recycled gypsum (48,000 tons) can be utilized in various areas within the construction industry. It is mainly used in concrete, soil stabilization, the ceramic industry, recycled aggregates, cement production, plaster, and blocks and walls. Studies have shown that the use of recycled gypsum reduces carbon emissions (Jafari and Sadeghian, 2024).

This thesis considers that waste gypsum can be used during the construction sector activities NACE Code: 41-42 and 20.14.01 for complementary processes and information sharing.

4.1.13. NACE: 20.42.04, Manufacture of shampoo, hair cream, hair spray, hair conditioner, hair straightening and perming products, hair lotions, hair dyes, etc.

The facility produces shampoo, conditioner, liquid soap, and baby diapers. The production is carried out in three main processes (Table 4.13).

Table 4.13. Facility (NACE: 20.42.04) Production Processes

Process No	Process Name	Process Description
1	Raw Material Preparation and Bottling	In the raw material preparation process, plant-based raw materials such as sodium laureth sulfate, cocamidopropyl betaine (betaine), and cocoamide are mixed with approximately 70% water and rested in a stock tank. To reduce electricity costs, a cold process is preferred. 55% of the raw materials are sourced from abroad, while 45% are sourced domestically. Citric acid is used to adjust the pH value of the products to 5.5. The products held in tanks are bottled, labeled, and packaged in various forms. The facility has four production lines: three for liquid products and one for petroleum jelly, which is produced particularly in winter.
2	Baby Diaper Production	The production of baby diapers is carried out on a fully automated line without human intervention. Defective products are detected by sensors and removed from the production line. A mixture of SAP (Super Absorbent Polymer) and cellulose is used as an absorbent material.
3	Quality Control and Packaging	After the quality control of the products, they are packaged and prepared for shipment.

The VSM of the processes is provided in Figure 4.13. The raw materials and chemicals used in the processes and the waste and by-products are presented in the diagram in their respective quantities. The type and amounts of energy consumed are also indicated in the figure.

Process-1: Bottling is the process with the highest energy consumption. This process consumes 158,149 kWh of electricity for liquid filling and 133,819 kWh of electricity for petroleum jelly filling annually. Deionized water (2,753 tons), various chemicals, and plant extracts are used as raw materials during this process. As a result of this process, 18 tons of paper and cardboard waste, 13 tons of plastic waste, and 0.4 tons of contaminated waste are generated. These data indicate that Process-1 is the facility's most critical environmental hotspot in terms of energy consumption and waste generation.

Process-2: Baby Diaper Production is also noteworthy. This process has high energy requirements, consuming 924,565 kWh of electricity annually. During the process, nonwoven fabric (685 tons), cellulose (811 tons), SAP (775 tons), and various chemicals are used. This process generates 2.2 tons of paper and cardboard, 2.5 tons of plastic, and 39 tons of PE-printed bag waste.

The firm commonly uses raw material materials under "NACE: 13.92.06, Manufacture of textile sacks, bags, pouches, and similar products (those used for packing goods)." Both facilities use raw materials from PP (polypropylene). Collaboration and communication are essential for future opportunities. Potential partnerships should be considered in projects related to PP raw materials.

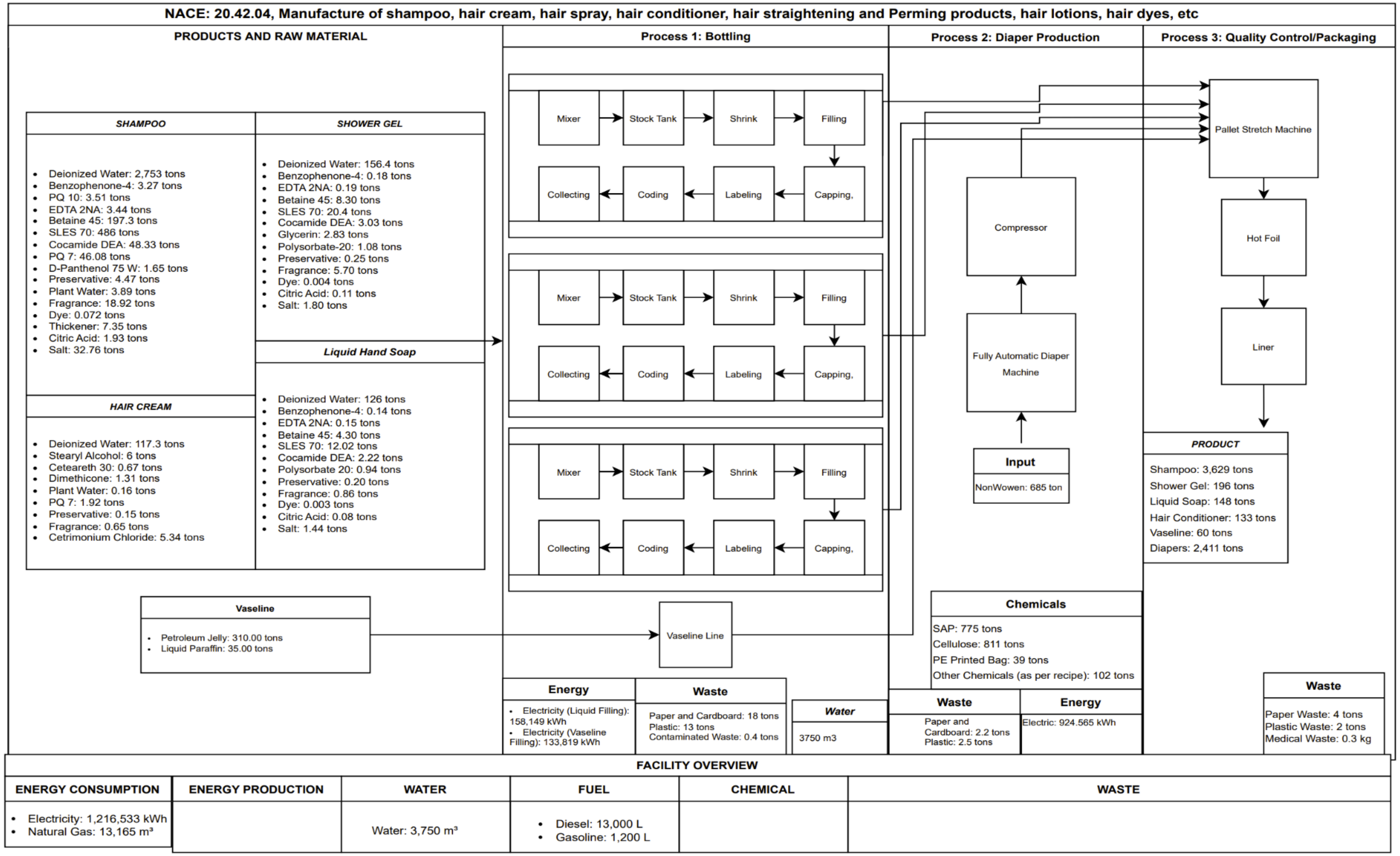


Figure 4.13. VSM of the Facility (NACE: 20.42.04)

4.1.14. NACE: 22.21.03, Manufacture of ware plastic tubes, pipes, hoses, and fittings (including artificial intestines)

The facility produces perforated pipe. The production is carried out in 2 main processes (Table 4.14).

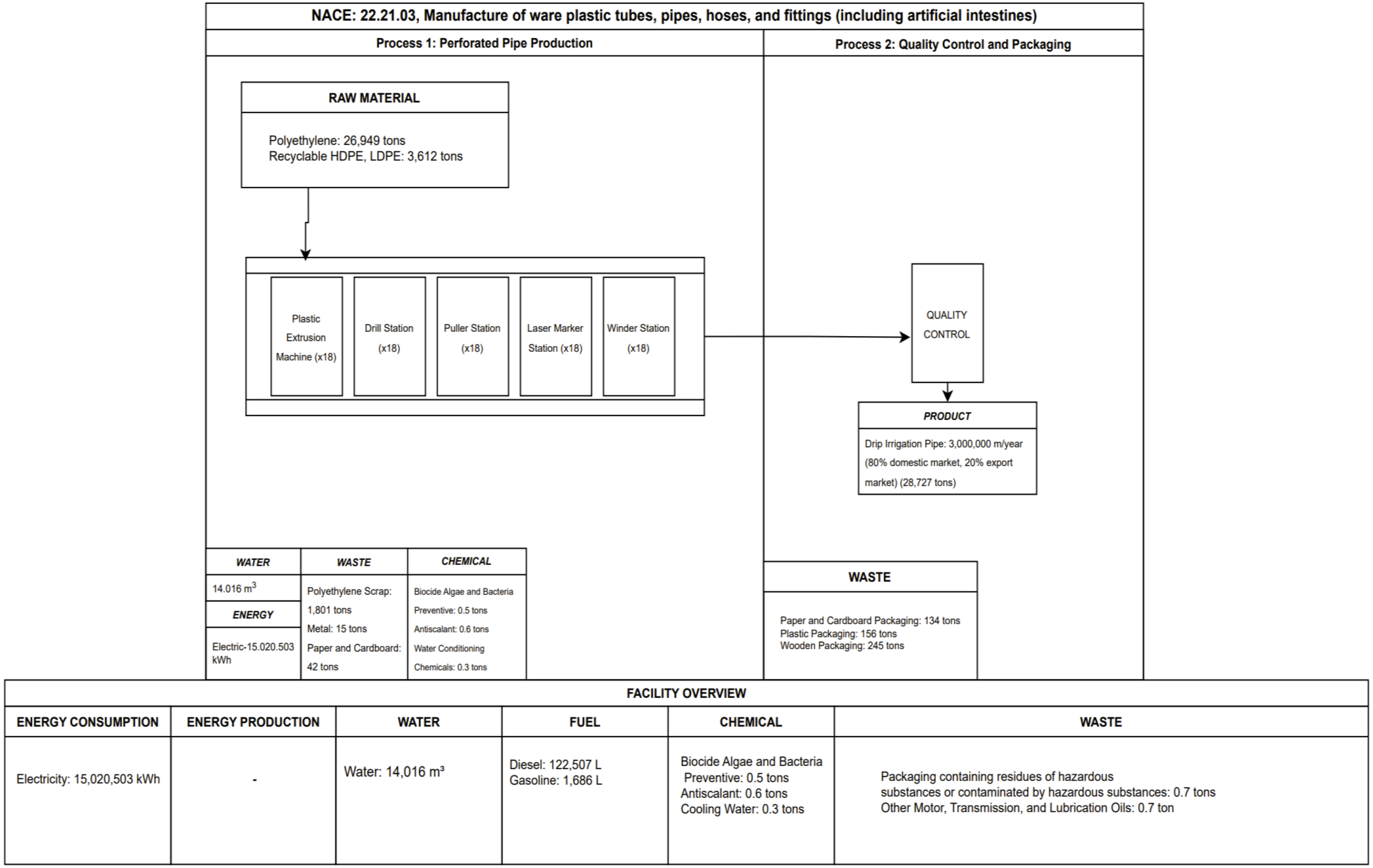
Table 4.14. Facility (NACE: 22.21.03) Production Processes

Process No	Process Name	Process Description
1	Perforated Pipe Production	Polyethylene raw material is melted at high temperatures through the extrusion process to form a dough-like consistency in the perforated pipe production process. The raw material is melted under specific temperature and pressure conditions during this process and brought to a homogeneous consistency. The dough-like polyethylene is then passed through special molds to be shaped into pipes. The pipes are produced at this stage with the desired diameter and thickness. Drippers, which regulate water flow, are installed at specific intervals along the produced pipes, and holes are drilled. These drippers ensure the even distribution of water through the pipes. The facility produces two types of pipes: thick-walled and thin-walled, based on the wall thickness, including multi-year (16, 20 cm) and seasonal (16, 22, 25 cm) pipes. The production process is optimized according to different wall thicknesses and diameters.
2	Quality Control and Packaging	The produced pipes undergo a quality control process and are then prepared for shipment.

The VSM of the processes is provided in Figure 4.14. The raw materials and chemicals used in the processes and the waste and by-products are presented in the diagram in their respective quantities. The type and amounts of energy consumed are also indicated in the figure.

The production and transportation of HDPE (High-density polyethylene) pellets for polyethylene pipe production generate 4.64 kg of CO2 eq, which is a concern for climate change. The pipe production process includes energy-intensive steps such as extrusion, cooling, hot stamping, and cutting. During the extrusion process, 0.728 kg CO_2 eq are produced, while the cooling process generates 0.133 kg CO_2 equivalent emissions.

At the end of their life cycle, HDPE pipes are typically sent to landfills without recycling, significantly impacting the environment. The disposal process generates 0.268 kg CO_2 eq in terms of climate change (Sangwan & Bhakar, 2017).



FACILITY OVERVIEW

ENERGY CONSUMPTION	ENERGY PRODUCTION	WATER	FUEL	CHEMICAL	WASTE
Electricity: 15,020,503 kWh	-	Water: 14,016 m³	Diesel: 122,507 L Gasoline: 1,686 L	Biocide Algae and Bacteria Preventive: 0.5 tons Antiscalant: 0.6 tons Cooling Water: 0.3 tons	Packaging containing residues of hazardous substances or contaminated by hazardous substances: 0.7 tons Other Motor, Transmission, and Lubrication Oils: 0.7 ton

Figure 4.14. VSM of the Facility (NACE: 22.21.03)

The Perforated Pipe Production process consumes 15,020,503 kWh of electricity annually. Additionally, 14,016 m^3 of water are used in this process. The amount of polyethylene used during the perforated pipe production is 26,949 tons. This process generates 1,801 tons of polyethylene scrap, 15 tons of metal waste, and 42 tons of paper/cardboard waste. These data indicate that Process-1 is the facility's most critical environmental hotspot in terms of energy and resource consumption and waste generation.

The production of HDPE pipes involves mixing recycled HDPE with virgin HDPE in specified ratios, followed by processing in an extrusion machine. The proportion of recycled material varies depending on the pipe grade and the source of the material. Recycled HDPE particles and virgin HDPE granules are combined in the predetermined ratios. The mixture ratios are adjusted based on the quality of the recycled material and the desired properties of the final product.

The mixture is placed into the feed hopper of the extrusion machine. During the extrusion process, the material is moved forward by a screw while being heated and melted. The molten material is then passed through the extrusion die to form the desired pipe shape. Temperature and pressure are controlled during this process to ensure the homogeneity of the mixture and achieve the appropriate viscosity of the material. It has been observed that, up to 96% of waste pellets can be reused in production (Istrate et al., 2021).

In this thesis, it is considered that PE scrap (1801 tons) can be used by NACE Code: 38.32.02. This kind of can also be used in this facility thanks to the presence of the extrusion machine.

Paper waste can be utilized in various ways within the framework of industrial symbiosis, thereby reducing the need for raw materials and minimizing waste disposal issues. These types of waste can be subjects of industrial symbiosis through methods such as recycling and repulping, incineration and anaerobic digestion for energy recovery, and use as raw materials in the construction and packaging industries (Ruggeri, 2022). “NACE: 17.12.07” facility has a symbiosis potential with this firm.

4.1.15. NACE: 22.21.04, Manufacture of semi-manufacture plastics profiles, rods, plates, sheets, blocks, film, foil, tape, etc., and monofilament manufacturing (including nylon tarpaulins)

The facility produces plastic bag, greenhouse cover, and stretch film production. The production is carried out in four main processes (Table 4.15).

Table 4.15. Facility (NACE: 22.21.04) Production Processes

Process No	Process Name	Process Description
1	Raw Material Preparation and Extrusion	Polyethylene is commonly used, though sometimes compostable and biodegradable materials like corn starch-based polymers are preferred. The production process is carried out at different temperatures depending on the raw material. Using the extrusion method, the raw material is melted and formed into rolls of semi-finished products. These semi-finished rolls are then prepared for the subsequent stages where the final products are shaped and processed.
2	Printing	If required, the products are sent to a printing facility where designs and text are applied. This printing process enhances brand visibility and adds aesthetic appeal to the products.
3	Cutting and Assembly	The semi-finished products, once printed, undergo cutting and thermal sealing processes. The cutting process shapes the products to the desired dimensions and forms. Thermal sealing processes join the edges of the products, enhancing their durability. At this stage, the products take their final form.
4	Quality Control and Packaging	The finished products then go through a quality control phase where their size, durability, print quality, and other physical properties are thoroughly inspected. Products that meet quality standards are packaged and made ready for storage and shipment.

The value stream map of the processes is provided in Figure 4.2. The raw materials and chemicals used in the processes and the waste and by-products are presented in the diagram in their respective quantities. The type and amounts of energy consumed are also indicated in the figure.

Process-1 is the most energy-intensive process, consuming 26,977,556 kWh of electricity annually. The raw materials used during this process include 7,000 tons of HDPE, 27,310 tons of LDPE (Low-Density Polyethylene), and 14,629 tons of LLDPE (Linear Low-Density Polyethylene). The outputs of this process include 30,000 tons of plastic bags, greenhouse covers, and stretch film. Chemicals such as 1.5 tons of hydraulic oil and 241 tons of masterbatch are also used.

The printing process is also significant, consuming 762,252 kWh of electricity annually. During this process, 9,500 tons of semi-finished products are used to produce 9,480 tons of printed rolls. Chemicals used in this process include 18 tons of methyl proxitol, 14 tons of isopropanol, 19 tons of ethyl acetate, and 20 tons of ink. Additionally, 1.5 tons of other hydraulic oils, 8.6 tons of metals, and 26 tons of plastic packaging waste are produced.

Paper, cardboard, and metal waste generated in the facility can be evaluated within the scope of symbiosis. Among the pilot firms, (i) the "NACE: 17.12.07, Manufacture of paper and paperboard (as roll or layer for further industrial procedures) (including bituminous, laminated, coated, and impregnated ones, as well as crepe and wrinkled papers)" facility can utilize paper and cardboard waste (91 ton). Additionally, the "NACE: 38.32.02, Recycle of classified nonmetallic waste, scraps, and other components, usually by means of mechanical or chemical replacement" facility, which is not among the pilot firms, can evaluate metal waste (610 tons) for symbiosis opportunities.

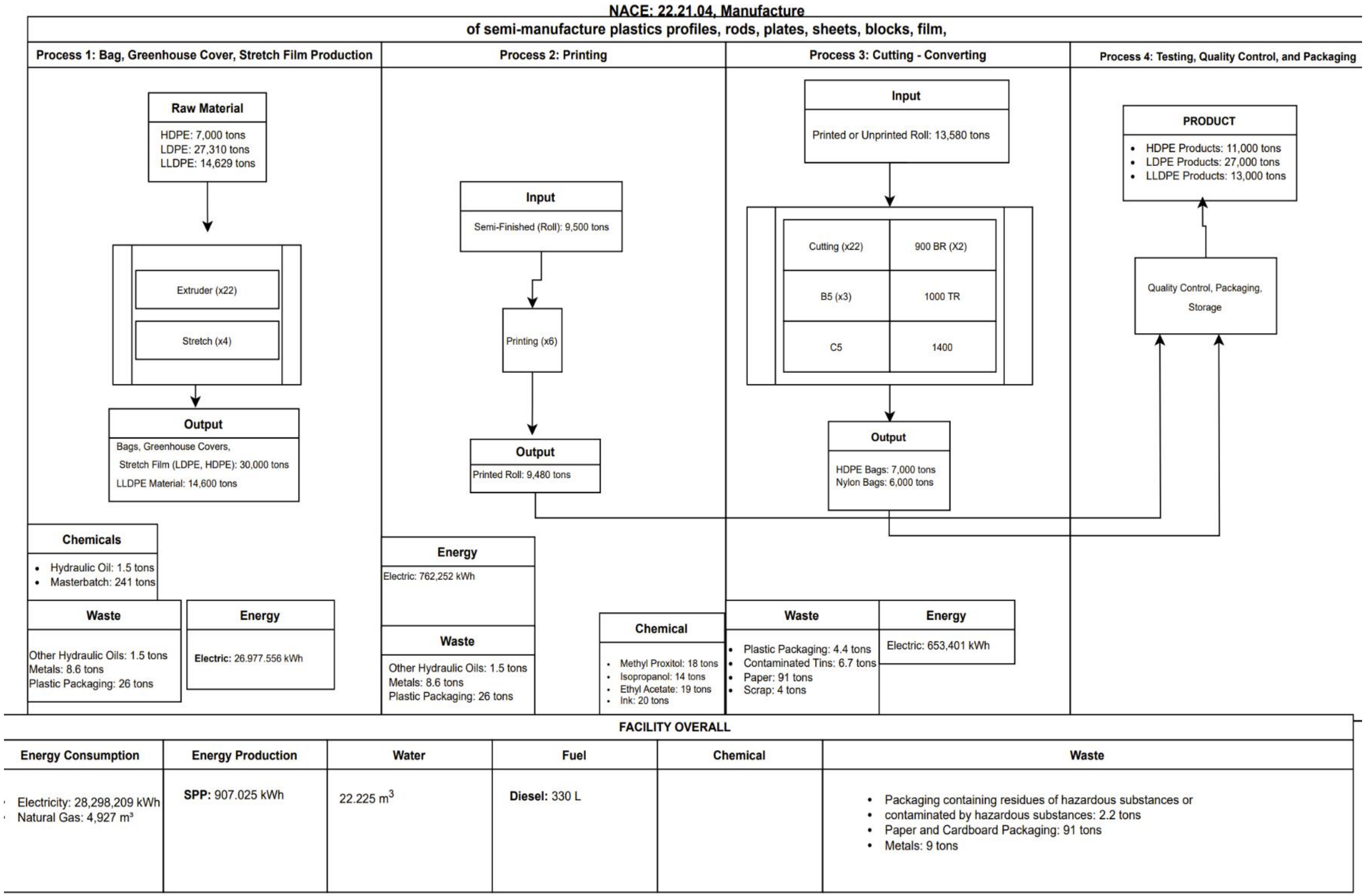


Figure 4.15. VSM of the Facility (NACE: 22.21.04)

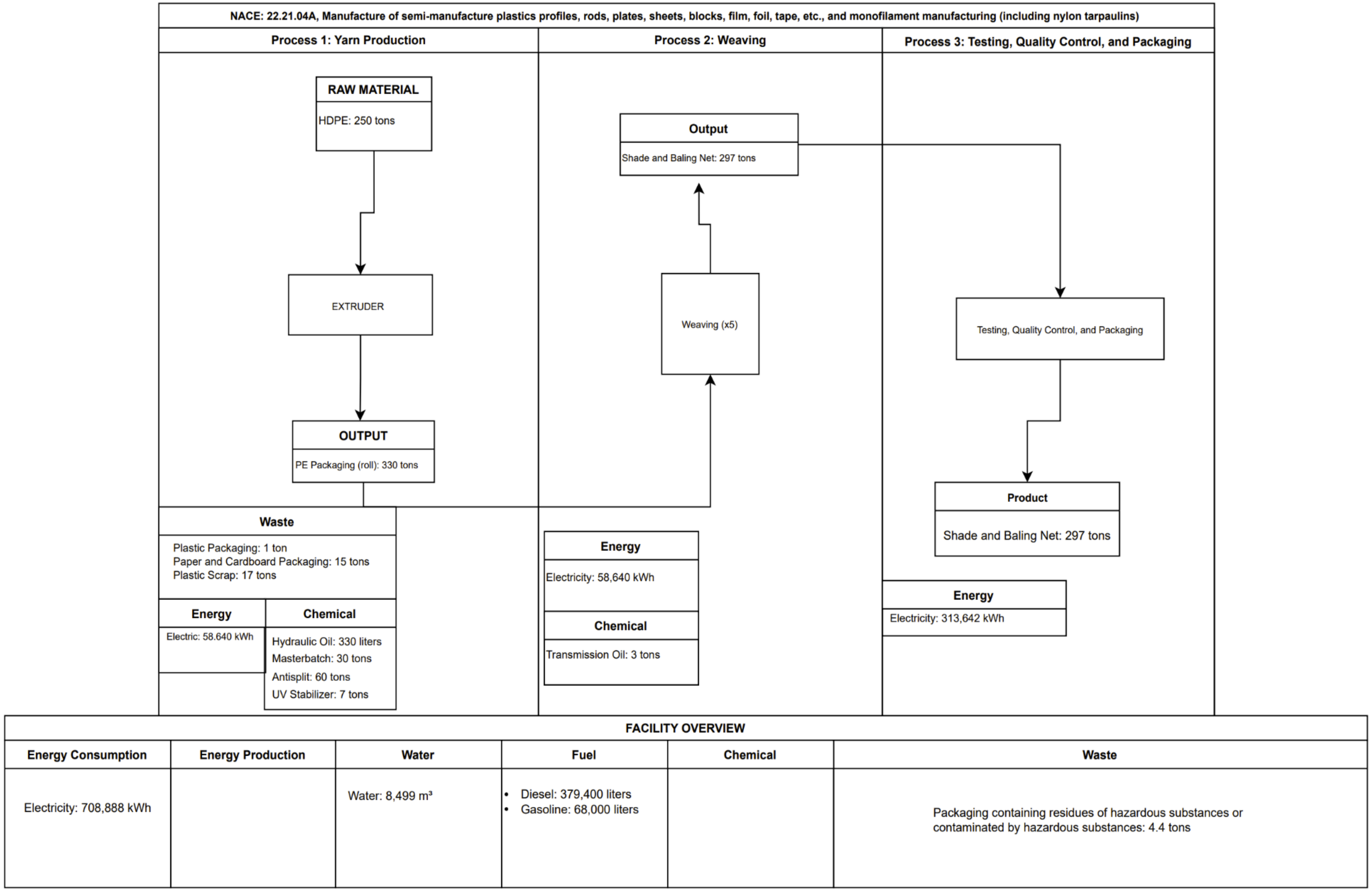
4.1.16. NACE: 22.21.04, Manufacture of semi-manufacture plastics profiles, rods, plates, sheets, blocks, film, foil, tape, etc., and monofilament manufacturing (including nylon tarpaulins)

The facility produces shade and baling nets production. The production is carried out in three main processes (Table 4.16). Since this facility has the same NACE code as the previous facility, it is coded as 22.21.04A.

Table 4.16. Facility (NACE: 22.21.04A) Production Processes

Process No	**Process Name**	**Process Description**
1	PE Roll Production	The production process of polyethylene (PE) rolls begins with extrusion. The raw material is passed through an extruder to produce semi-finished rolls. These semi-finished rolls are then cut into threads. The facility has one extruder for this process. The cut threads are prepared for subsequent weaving processes.
2	Thread and Weaving	The obtained threads are used for the weaving process. The facility has five Rascher weaving machines that process the threads into the desired patterns and structures. During this process, the threads are woven evenly and consistently to ensure the quality of the final products.
3	Quality Control and Packaging	Products that meet quality standards are packaged and prepared for storage and shipment.

The VSM of the processes is provided in Figure 4.16. The raw materials and chemicals used in the processes, along with the waste and by-products, are presented in the diagram in their respective quantities. The type and amounts of energy consumed are also indicated in the figure.



FACILITY OVERVIEW

Energy Consumption	Energy Production	Water	Fuel	Chemical	Waste
Electricity: 708,888 kWh		Water: 8,499 m³	Diesel: 379,400 liters Gasoline: 68,000 liters		Packaging containing residues of hazardous substances or contaminated by hazardous substances: 4.4 tons

Figure 4.16. VSM of the Facility (NACE: 22.21.04A)

Process-1: Yarn Production stands out as the process with the highest energy consumption. In this process, 58,640 kWh of electricity is consumed annually. During this process, HDPE (347 tons) is used as a raw material, and 330 tons of PE packaging (rolls) are produced. The chemicals used during the process include hydraulic oil (330 L), masterbatch (30 tons), antistatic (60 tons), and UV (7 tons). Additionally, 1 ton of plastic packaging, 15 tons of paper and cardboard packaging, and 17 tons of plastic scrap waste are generated.

Weaving is also noteworthy. This process has a high energy requirement, with an annual electricity consumption of 627,284 kWh. The amount of transmission oil used during the process is specified as 3 tons. The outputs include 297 tons of shading and baling nets.

Among the pilot firms, (i) the "NACE: 17.12.07" facility can utilize paper and cardboard waste (15 tons). Additionally, the "NACE: 38.32.02 " facility, which is not among the pilot firms, can evaluate metal waste (18 tons) for symbiosis opportunities. Additionally, due to having the same production processes as the previous facility and being part of the same company, it is an essential symbiosis partner with that facility.

4.1.17. NACE: 24.20.10, Manufacture of tube, pipe, hollow profiles, and related fittings from steel/iron (cold-drawn or cold-rolled)

The facility produces spiral welded steel pipe. The production is carried out in five main processes (Table 4.17).

Table 4.17. Facility (NACE: 24.20.10) Production Processes

Process No	Process Name	Process Description
1	Pipe Manufacturing	Sheets with a thickness of 4-25 mm and a width of 400-2000 mm are delivered to the facility in rolls. The rolled sheets are uncoiled and flattened using hydraulic presses. This process ensures the sheets have a smooth surface. The flattened sheets are then formed into spiral pipes. Two bending line machines are used for this process.

(cont. on next page)

Table 4.17 (cont.)

Process No	Process Name	Process Description
2	Welding	The joints of the pipes are welded both internally and externally using submerged arc welding machines. This process ensures the pipes have a robust structure. The welds are inspected and verified through ultrasonic testing.
3	Beveling	The welded pipes are cut and beveled at their ends using a plasma cutter. This process ensures that the pipes can be properly connected and are leak-proof. Pipes coming out of the welding lines are inspected. Any incomplete or faulty welds are manually corrected at the welding-repair station.
4	Hydrotesting	The pipes undergo a water pressure test to ensure they are leak-proof. This test confirms the pipes' integrity.
5	Painting and Coating	The pipes are blasted to clean their surfaces and prepare them for painting or coating. After blasting, the pipes are primed and coated internally with primer and solvent-free paint and externally with polyethylene, solvent-free paint, and primer, per customer requirements. The coating process involves heating the polyethylene to 200°C and applying it to the rotating pipe. This step protects the pipes from corrosion. After coating, the pipes are cooled and dried. Additional paints can be applied upon request. There is one painting and coating line available.

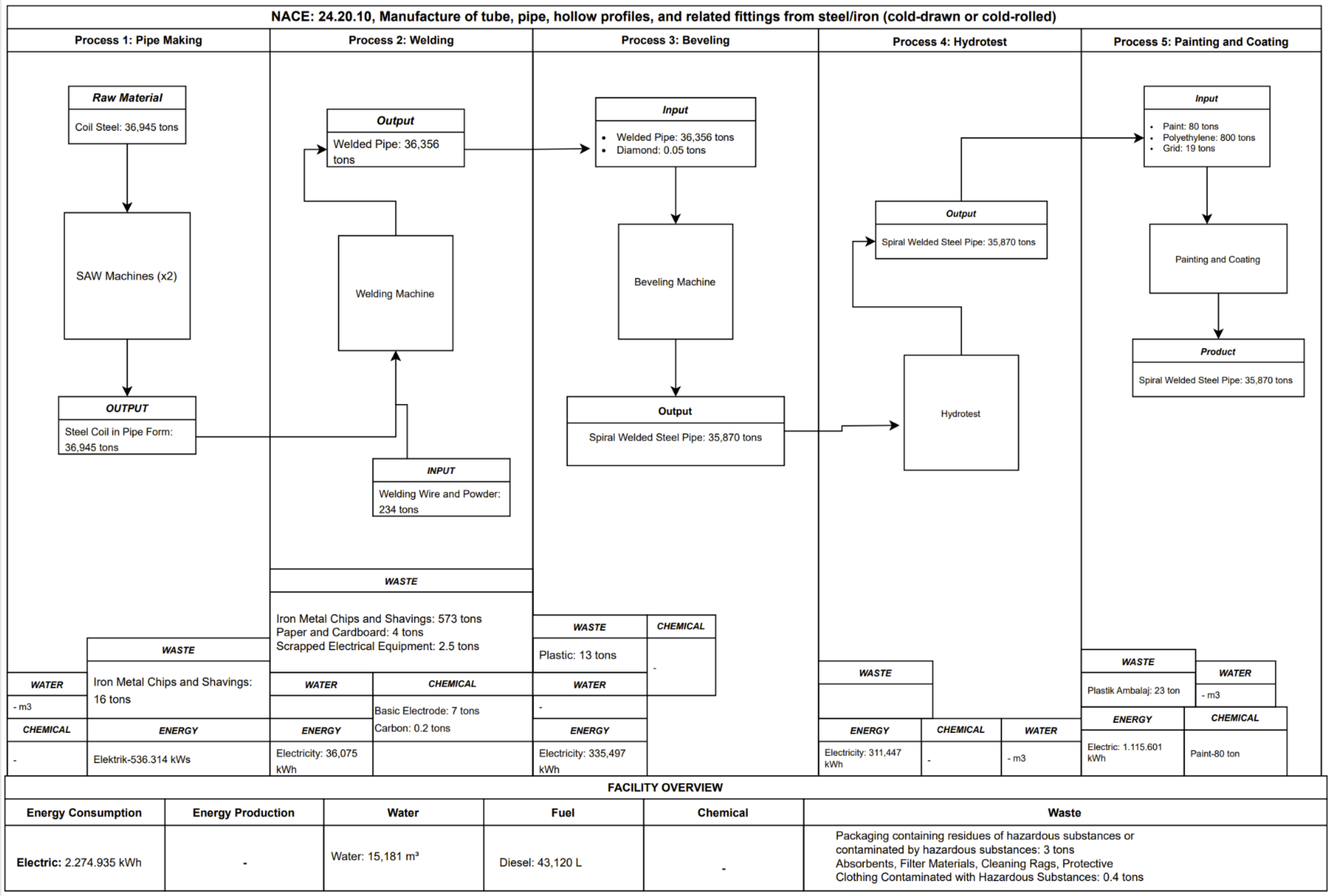
The value stream map of the processes is provided in Figure 4.17. The raw materials and chemicals used in the processes and the waste and by-products are presented in the diagram in their respective quantities. The type and amounts of energy consumed are also indicated in the figure.

The painting and coating process has the highest energy consumption, with an annual electricity usage of 1,115,601 kWh. During painting and coating, 800 tons of polyethylene, 19 tons of grit, and 80 tons of paint are used. As a result of this process, 23 tons of plastic packaging waste are generated. These data indicate that Process-5 is the most critical environmental hotspot in terms of energy and resource consumption and waste production.

The pipe manufacturing process is also noteworthy, with a high energy requirement of 536,314 kWh of electricity. During pipe manufacturing, 36,945 tons of rolled steel sheets are used, and the process results in 16 tons of iron metal shavings and scrap waste. Proper management of these wastes is crucial to minimize environmental impacts.

The total electricity consumption recorded for the entire facility is 2,274,935 kWh. Additionally, 15,181 m^3 of water are used throughout the facility. Proper management is also necessary for hazardous waste, including 3 tons of packaging contaminated with hazardous substances and 0.4 tons of absorbents, filter materials, cleaning rags, and protective clothing contaminated with hazardous substances.

In this IS model, a scenario will be developed involving this company where 590 tons of metal waste are processed by a firm coded as " the "NACE: 38.32.01, Recycle of classified metallic waste, scraps, and other components, usually by means of mechanical or chemical replacement" " that is not part of the project scope, but it theoretically exists in this study.



FACILITY OVERVIEW

Energy Consumption	Energy Production	Water	Fuel	Chemical	Waste
Electric: 2.274.935 kWh	-	Water: 15,181 m³	Diesel: 43,120 L	-	Packaging containing residues of hazardous substances or contaminated by hazardous substances: 3 tons Absorbents, Filter Materials, Cleaning Rags, Protective Clothing Contaminated with Hazardous Substances: 0.4 tons

Figure 4.17. VSM of the Facility (NACE: 24.20.10)

4.1.18. NACE: 25.61.01, Activities of metal heat treatment and anodizing, hardening, varnishing, etc., surface treatments, electrolysis, sherardizing or metallic coating with chemical treatment (except tin and nickel coating), and coating activities with plastic

The facility produces galvanized wire. The production is carried out in three main processes (Table 4.18).

Table 4.18. Facility (NACE: 25.61.01) Production Processes

Process No	Process Name	Process Description
1	Wire Drawing	Rods purchased as raw material are passed through tungsten carbide dies with the help of rolling soap to thin them to the diameter required by the customer. The wire drawing process is done in two stages. In the first stage, using six machines, the diameter can be reduced to a minimum of 1.80 mm. In the second stage, the semi-finished product from the first stage is further thinned to a diameter of 1 mm.
2	Galvanizing	The thinned wire is softened/reduced in strength by baking it at 850°C. The wire from the oven undergoes surface cleaning with acid (HCl) and is then passed through a salt (Flax) bath before being galvanized in a zinc bath at 450°C.
3	Quality Control and Packaging	First, raw coffee beans are roasted according to their recipes. Then, based on the type of product listed in the production plan (flavored, plain, filter coffee, etc.), the coffee is ground and packaged.

The VSM of the processes is provided in Figure 4.18. The raw materials and chemicals used in the processes and the waste and by-products are presented in the diagram in their respective quantities. The type and amounts of energy consumed are also indicated in the figure.

Galvanized wire is obtained by coating it with zinc to protect it from corrosion (Li et al., 2020). The zinc coating provides a barrier against corrosion, extending the life of the wire. Galvanized wire is also known for its strength and durability, making it a popular choice for various industrial and construction applications (Xiong et al., 2021; Zhao et al., 2023). It is widely used in applications such as concrete reinforcement, fence construction, and electrical installations.

The wire drawing stage involves pulling the wire through a die to reduce its diameter. During this process, waste such as rolling mill scale (222 tons/year), rolling mill soap waste (60 tons/year), and rod scrap (242 tons/year) are produced. Analysis of the company's VSM indicates that the wire drawing process is the most electricity-intensive, consuming 4,329,472 kWh annually.

The galvanizing stage involves immersing the wire in a molten zinc bath to create a protective coating. First, the wire is heated in a furnace to remove impurities and rust, then subjected to an HCl acid bath to clean the surface. Afterward, the wire is dipped into the zinc bath, making it corrosion resistant.

Due to its high energy consumption, the galvanizing process is the most chemical-intensive, waste-producing, and carbon-emission-heavy process. In this stage, 1,731,789 kWh of electricity and 1,611,615 m^3 of natural gas are used as energy sources. The produced zinc ash (200 tons) and wire scrap (217 tons) are considered hotspots in the VSM, having potential for recovery. The final stage of the galvanizing process, cooling, involves immersing the wire in water to solidify the zinc coating. The water consumption at this stage stands out at 37,990 m^3 annually.

In steel wire manufacturing facilities, rolling mill scale, a byproduct of the rolling process, is considered a rich source of iron with a small amount of additives. This type of waste can be transformed into valuable products such as high-purity iron, low-carbon steel, and free-cutting steel, which can serve as alternative sources in cast iron production (Eissa et al., 2015).

Another application of rolling mill scale is its use as an alternative construction material for fine aggregate. Rolling mill scale can be incorporated into concrete paving blocks, contributing to sustainable construction practices. Studies have shown that replacing 60% of the sand with mill scale during concrete production yields a product closest to its original form (Parvathikumar et al., 2021).

Zinc ash, a solid waste between 70% and 96% zinc, is considered a highly valuable secondary material. Zinc recovery rates of up to 99% from zinc ash can be achieved through pyrometallurgical and hydrometallurgical processes (Takacova et al., 2010).

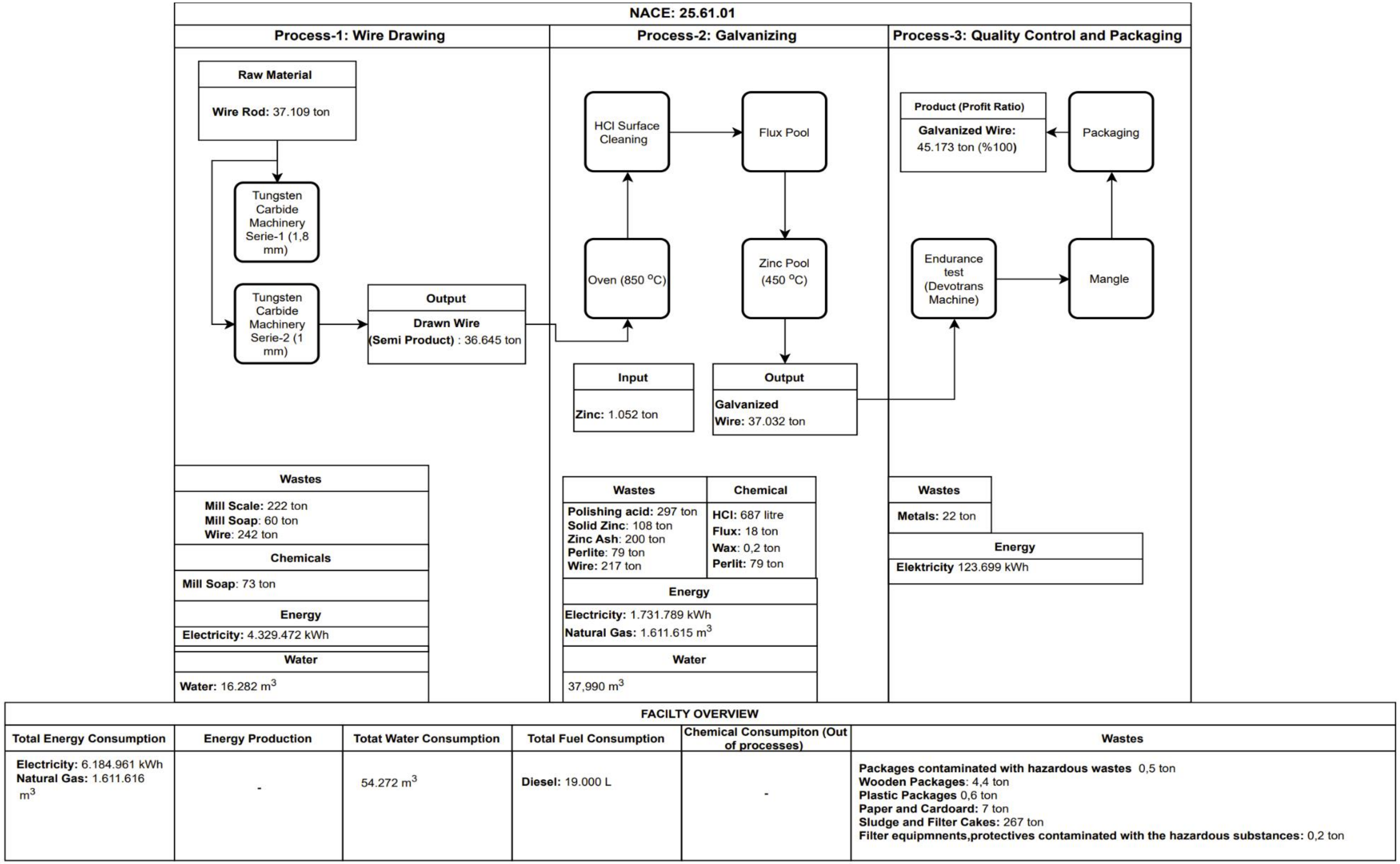


Figure 4.18. VSM of the Facility (NACE: 25.61.01)

The $FeCl_2$ content in spent pickling acids can be oxidized and recycled for use in phosphorus removal in wastewater treatment plants. The most important step in this process is minimizing the zinc content in the spent pickling acids. During acid surface cleaning, hooks, chains, and other equipment used can cause zinc contamination in the HCl solution. Coating such equipment with titanium can increase the usability of spent pickling acids in wastewater treatment plants and reduce HCl usage by 15% (Stocks et al., 2005).

The recovery of rolling mill scale as a construction material in the wire drawing process (NACE Code: 41-42) and achieving 15% energy savings through waste heat recovery (Intra-firm), along with the recovery of 70% zinc from zinc ash, reduction of waste pickling acid, and 15% energy savings through waste heat recovery in the galvanizing process (Intra-firm), have been evaluated as symbiosis scenarios. Additionally, this company is one of the two firms examined within the scope of this thesis through LCA analysis. Therefore, valuable insights with these alternatives will be obtained by LCA.

4.1.19. NACE: 27.11.01, Manufacture of electric motors, generators, and transformers (except parts and components)

The facility produces power and distribution transformers. The production is carried out in five main processes (Table 4.19).

Table 4.19. Facility (NACE: 27.11.01) Production Processes

Process No	Process Name	Process Description
1	Coil Winding	The coil winding process is carried out with 22 low and high voltage coil winding machines. Copper and aluminum foils, insulated paper, and aluminum wires are used in this process. Coil winding is done in two stages: low voltage and high voltage. Low voltage coils are wound with thicker wires, while high voltage coils are wound with thinner wires to ensure high voltage endurance.
2	Core Manufacturing and Assembly	The core manufacturing and assembly start with the production of cores made from silicon steel. The cores are cut and shaped to specific thicknesses and dimensions during this process. The cores are placed and fixed onto the coils during the coil assembly stage. Additionally, insulators and electrical lines are drawn, completing the core assembly.

(cont. on next page)

Table 4.19 (cont.)

Process No	Process Name	Process Description
3	Tank Manufacturing	Transformer tanks and covers are made from ST37 and CCR sheets. These sheets have suitable properties for durability and corrosion resistance. The manufactured tank and covers are painted to protect against corrosion and provide an aesthetic appearance. The painting process also ensures the longevity of the tank and covers.
4	Transformer Assembly	The transformer is assembled by combining all parts. During this stage, connection points and electrical compatibility are checked to ensure the transformer operates safely and efficiently.
5	Testing, Quality Control, and Packaging	The assembled transformers undergo testing and quality control. Products that pass quality control are packaged and prepared for shipment.

The VSM of the processes is provided in Figure 4.19. The raw materials and chemicals used in the processes, along with the waste and by-products, are presented in the diagram in their respective quantities. The type and amounts of energy consumed are also indicated in the figure.

Coil Winding stands out as the process with the highest energy consumption, using 606,495,529 kWh of electricity annually. During this process, 770 tons of aluminum foil and 8,260 tons of copper wire are used as raw materials. The process results in 10 tons of aluminum foil and copper wire waste. These data indicate that Process-1 is the most critical environmental hotspot in terms of energy consumption and waste production.

Transformer Assembly is also noteworthy. This process has a high energy requirement, consuming 174,141,579 kWh of electricity and 228,037 m^3 of natural gas annually. The output of this process is 18,620 tons of transformers.

In this IS model, a scenario will be developed involving this company where 492 tons of metal waste are processed by a firm coded as " the "NACE: 38.32.01; Recycle of classified metallic waste, scraps, and other components, usually by means of mechanical or chemical replacement” that is not part of the project scope but it theoretically exists in this study.

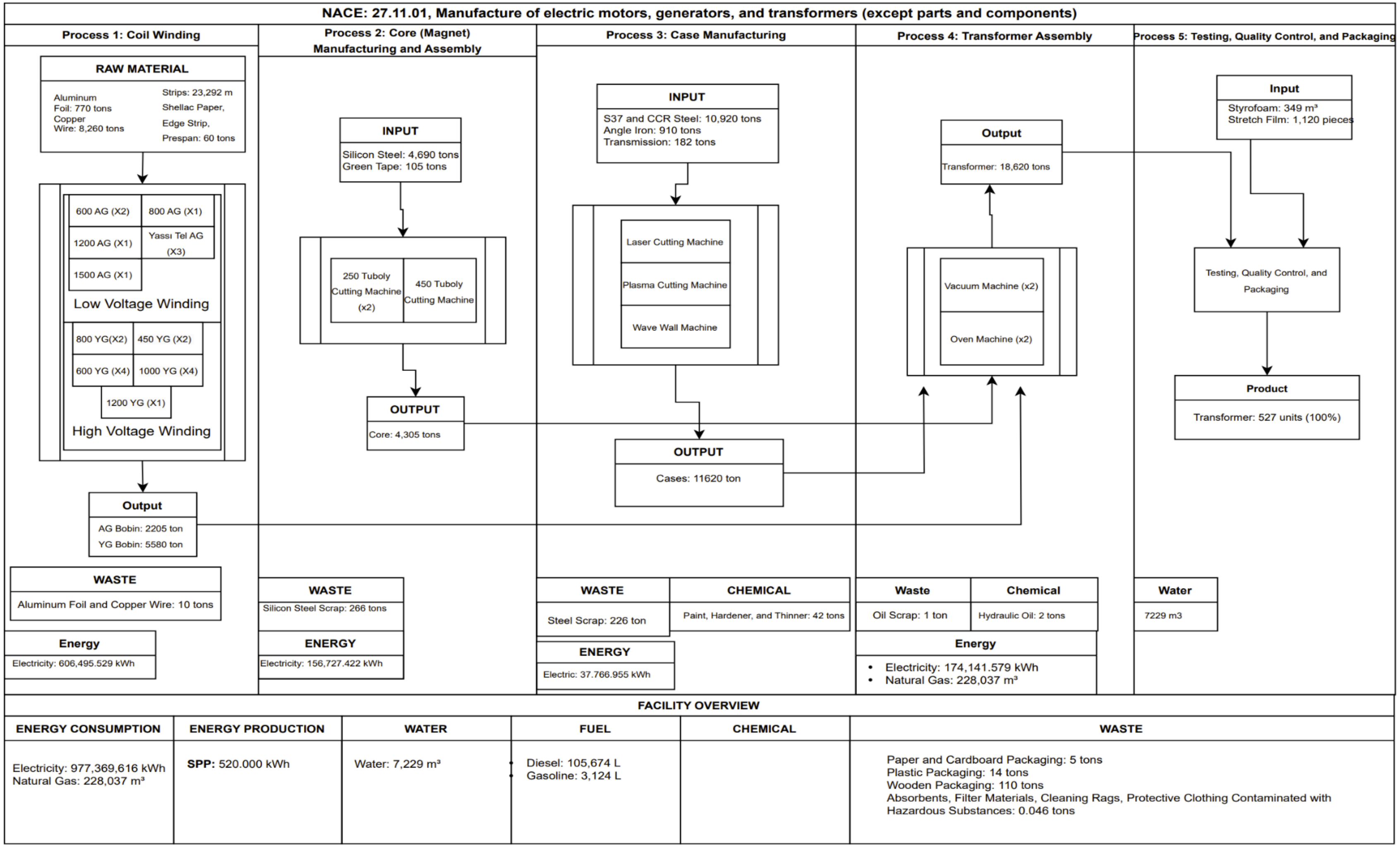


Figure 4.19. VSM of the Facility (NACE: 27.11.01)

4.1.20. NACE:28.22.13, Manufacture of another lifting, handling, loading, or unloading machinery (traction mechanisms for cable cars, chairlifts, etc., loading machines and others for agricultural use, smart shelf systems, and others)

The facility produces silos and conveyor systems. The production is carried out in four main processes (Table 4.20).

Table 4.20. Facility (NACE: 28.22.13) Production Processes

Process No	Process Name	Process Description
1	Cutting and Shaping	Galvanized steel sheets and profiles in rolls are cut and shaped to specific dimensions, and necessary holes are punched. This process uses three different techniques: plasma, laser, and knife. All punching operations are performed using punch machines. Shaping processes, such as ovalizing the sheets, are carried out using bending machines.
2	Welding and Part Assembly	The parts from the cutting and shaping process are welded together. During this stage, anti-rust painting is applied to the profiles to protect the parts from corrosion. After the welding process is completed, the details of the elevators are assembled. The assembled elevators are prepared for shipment in a disassembled state.
3	Casing Production	HDPE pellets are processed using an extruder and injection molding machine (Plastic Injection Module Machine - PIMM) for the production of elevator buckets. In this process, the pellets are melted and formed into scoops and buckets through molds. Waste generated during manufacturing is shredded into granules and reintegrated into the production process. A closed-circuit cooling water system is used during production to ensure the products cool quickly and evenly..
4	Quality Control and Packaging	Sugar used in different coffee products or to produce stick sugar products is passed through a sugar grinding machine. To produce "3-in-1," "4-in-1," "2-in-1," cappuccino, hot chocolate, and similar products, coffee, sugar, and chocolate powders are blended according to the production plan and sent to the filling machines. The facility has separate filling machines for stick coffee, hot chocolate, cappuccino, and stick sugar, which are used independently to produce the desired products.

The VSM of the processes is provided in Figure 4.20. The raw materials and chemicals used in the processes and the waste and by-products are presented in the diagram in their respective quantities. The type and amounts of energy consumed are also indicated in the figure.

Cutting and Shaping stands out as the process with the highest energy consumption, using 522,090 kWh of electricity annually. Various raw sheet and pipe materials (totaling 3,808 tons) are used during this process. The process results in 509 tons of scrap sheet and 40 tons of scrap metal waste. Additionally, 2,218 liters of hydraulic oil are used. These data indicate that Process-1 is the most critical environmental hotspot in terms of energy consumption and waste production.

Welding and Part Assembly are also noteworthy. This process has a high energy requirement, consuming 48,870 kWh of electricity annually. Various metal parts and gaskets (totaling 38,425 tons) are used during the process. The process results in 359 tons of metal waste and 9,509 liters of paint waste. Additionally, 1,242 liters of hydraulic oil are used.

In this IS model, a scenario will be developed involving this company where 492 tons of metal waste are processed by a firm coded as " the "NACE: 38.32.01; Recycle of classified metallic waste, scraps, and other components, usually using mechanical or chemical replacement," that is not part of the project scope but it theoretically exists in this study.

In addition, this facility uniquely possesses a three-dimensional single machine among firms with extrusion machines. Sharing opportunities related to this topic and conducting studies to share new extrusion usage methods or techniques could be important.

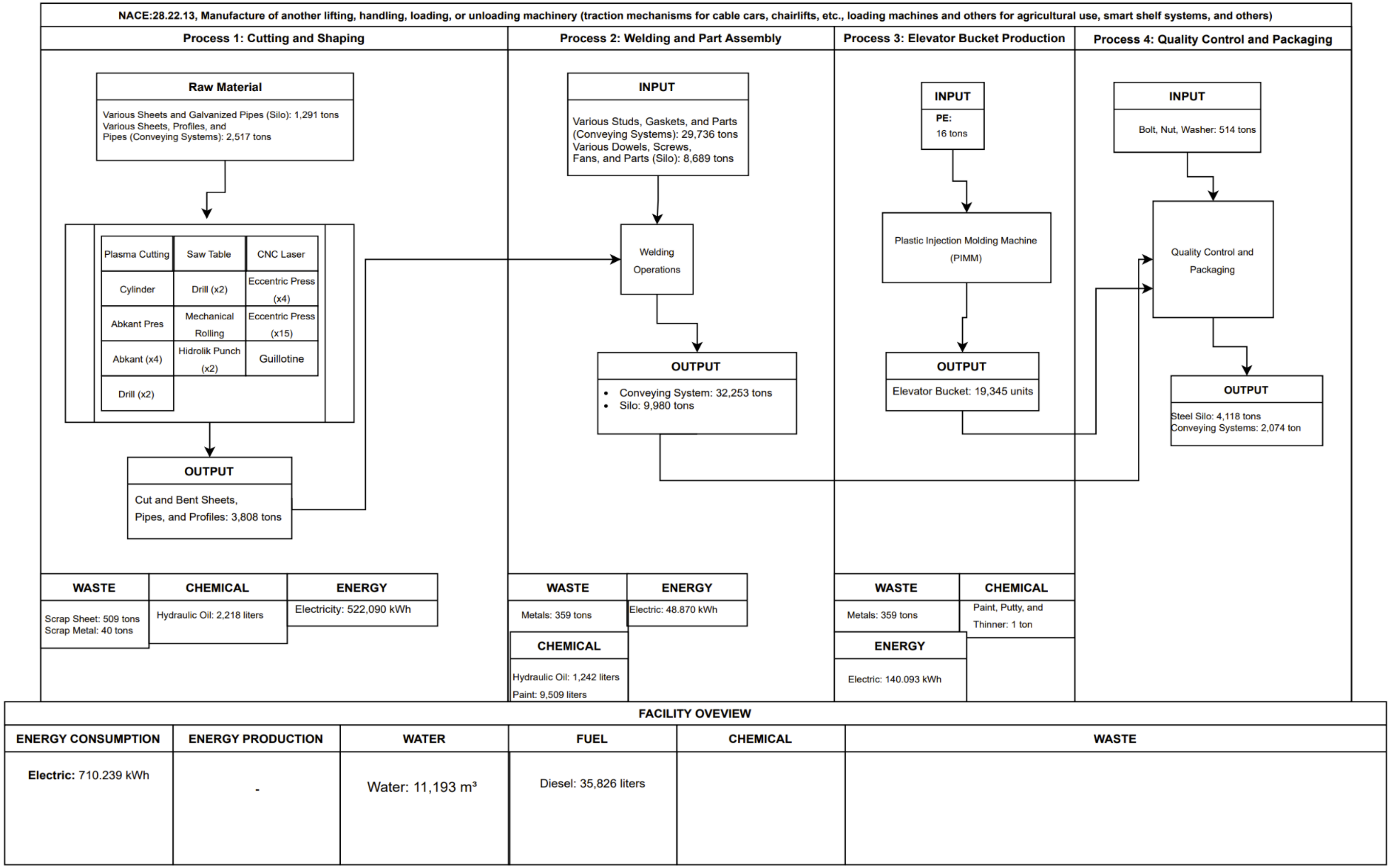


Figure 4.20. Value Stream Map of the Facility (NACE: 28.22.13)

4.1.21. NACE: 28.92.11, Manufacture of parts of boring, drilling, earthmoving, and excavation machines, cranes and mobile lifting frames, and machine parts used in sorting, grinding, and mixing of Earth, stone, and similar materials or other works (including bulldozer)

The facility produces forklifts, bucket, trailer. The production is carried out in five main processes (Table 4.21).

Table 4.21. Facility (NACE: 28.92.11) Production Processes

Process No	Process Name	Process Description
1	Cutting and Bending	In the first stage of the production process, iron sheets and profiles are cut and bent according to product-specific specifications. Laser and CNC plasma machines are used for cutting while bending operations are performed using press brakes.
2	Welding and Joining	The metal parts cut in the first stage are joined using various welding techniques. Gas metal arc welding and oxy-fuel welding methods ensure that the parts are joined in a durable and strong manner, establishing the structural integrity of the product.
3	Painting	After the metal surfaces are cleaned through sandblasting, primer and topcoat applications are carried out. Priming ensures better adhesion of the paint to the metal and provides corrosion protection. The topcoat adds aesthetic appeal and additional protection to the material. Painting operations are conducted in specialized paint shops.
4	Assembly	The manufactured metal parts are assembled with components sourced externally, such as tires, steering, seats, electrical systems, and engines, on the assembly line. This process gives the product its final form, using various hand tools and automated systems during assembly.
5	Quality Control and Packaging	Each product undergoes a detailed quality control process before shipment. Products that pass quality inspection are packaged with protective materials and made ready for shipment.

The VSM of the processes is provided in Figure 4.21. The raw materials and chemicals used in the processes and the waste and by-products are presented in the diagram in their respective quantities. The type and amounts of energy consumed are also indicated in the figure.

Steel sheets and profiles are first shaped into various forms. These shaped parts are then sent to the welding workshop for joining. Here, the joints of the steel sheets and profiles are welded together to form a complete bucket. In the fourth stage, the buckets are painted in various colors according to customer requirements in the paint shop.

Finally, in the fifth stage, the produced buckets undergo final product inspection and quality control in the final inspection area (Sukdeo et al., 2020).

In the cutting and bending process at the facility, 1,881,851 kWh of electricity is consumed annually. Additionally, this process generates 1,498 tons of sheet scrap and 76 tons of metal shavings. The management of 11 tons of grinding parts and metals containing hazardous materials also requires careful attention. The welding and joining process notably consumes pure oxygen, with an annual usage of 99,854 tons. This process results in 264 tons of improperly welded sheet waste, creating a significant environmental burden. Proper management and recycling of this waste are necessary.

In the painting process, the use of paint, thinner, and other chemicals involves environmentally harmful substances, necessitating careful management. This process consumes 313,642 kWh of electricity and 34,881 m^3 of natural gas annually, contributing to greenhouse gas emissions and increasing environmental impacts. The painting process also produces 10 tons of scrap tin and 3 tons of hazardous paint sludge, which must be managed carefully.

The assembly process generates 2.6 tons of hydraulic oil waste annually. According to information from facility officials, the electricity consumption in this process can be considered the same as that in the painting process. Literature studies indicate that welding and painting processes are the most sensitive and amenable to improvements when lean manufacturing practices are implemented in such a production facility. These processes are identified as critical stages due to a high number of potential defects such as visible rust, scratches, and dents. Improvements in these processes can significantly reduce defect numbers and environmental impacts (Sukdeo et al., 2020).

The direct use of metal scrap obtained from industries such as the automotive industry in the construction sector, specifically in the production of facade systems, can achieve the recovery of scrap metal sheets. A scenario comparing the reuse of sheet metal scrap to produce metal exterior facade systems for buildings, which provide thermal and sound insulation, quantitatively showed a reduction in capital cost and energy consumption by 40% ($400/ton) and 67% (10,000 MJ/ton), respectively. Such approaches not only promote environmental quality and the circular economy but also have the potential to conserve natural resources and create new jobs and relationships (Neves et al., 2019; Ali et al., 2019).

This thesis considers that steel can be used during the construction sector activities NACE Code: 41-42 and/or 38.32.02.

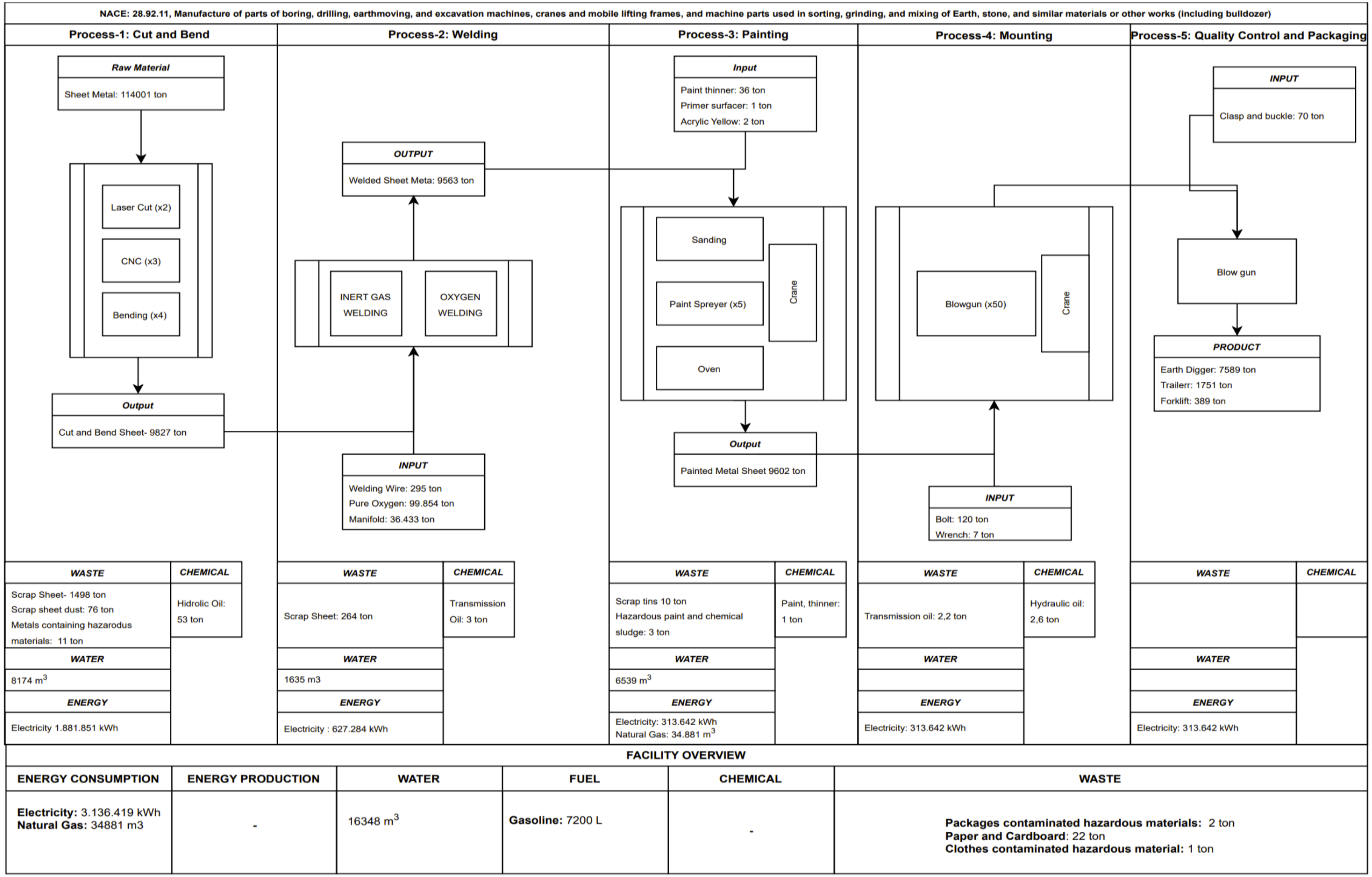


Figure 4.21. VSM of the Facility (NACE: 28.92.11)

4.1.22. NACE: 28.94.05, Manufacture of machinery for textile yarn and fabric washing, bleaching, dyeing, finishing, cleaning, wringing, winding, impregnation, cutting, serging, and the like and machines used in felt manufacturing and finishing

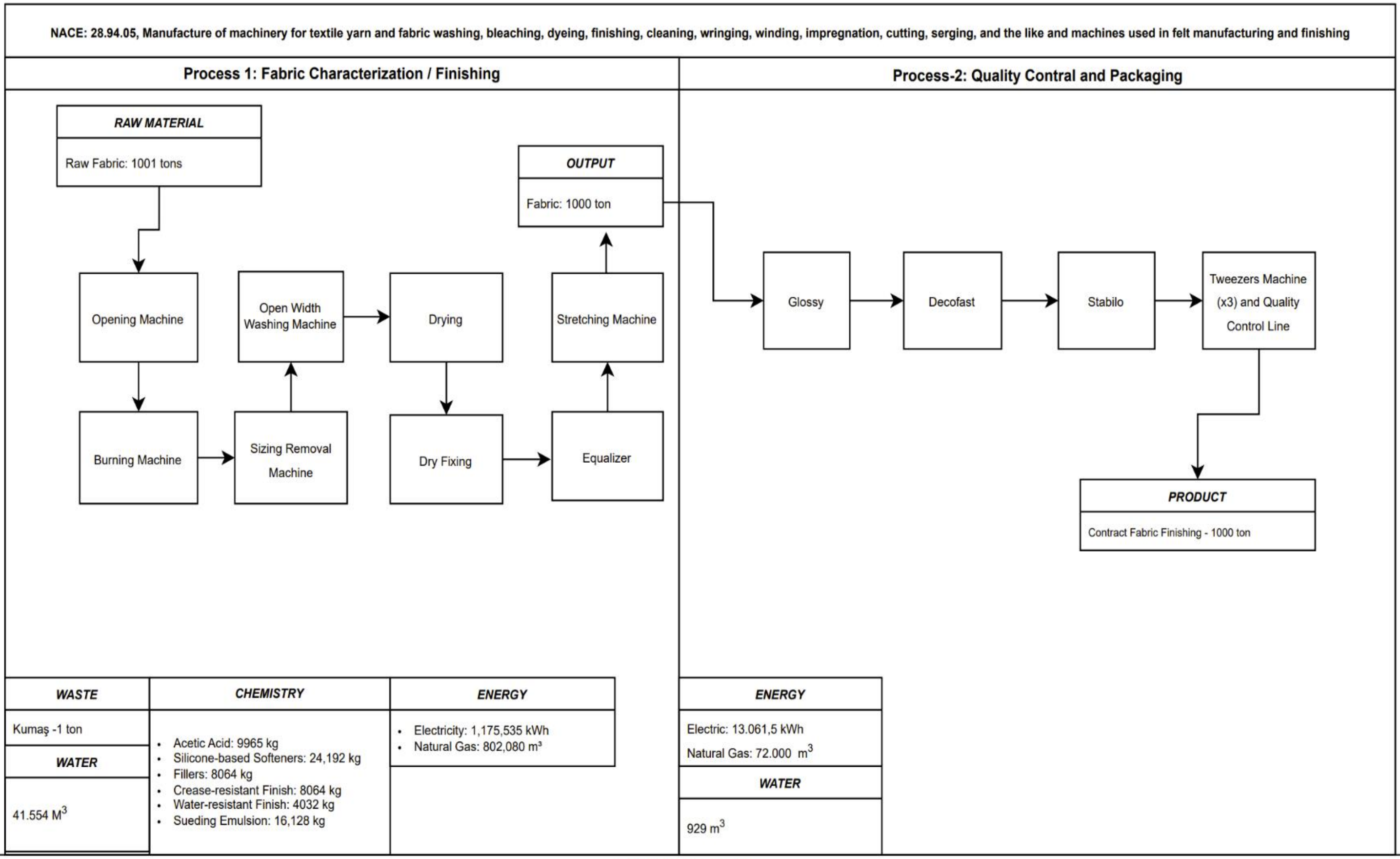
The facility produces Ready-to-Wear Raw Fabric. The production is carried out in 2 main processes (Table 4.22).

Table 4.22. Facility (NACE: 28.94.05) Production Processes

Process No	Process Name	Process Description
1	Fabric Characterization/Finishing	First, the fabrics are washed with water to remove any remaining dirt and chemicals. Then, the cotton parts on the fabrics are burned off with a low flame to smoothen the fabric surface. Next, the fabrics are heated to adjust their width, length, and weight to the desired measurements. During this stage, the dimensions and weight of the fabric are precisely adjusted. Certain chemicals are added to the fabrics for the desired stiffness, softness, and gloss. These processes improve the texture and appearance of the fabric. Finally, the democratizing process is applied to thin, iron, crush, emboss, and add volume to the fabrics. The decatizing process gives the fabrics their final form and an aesthetic appearance.
2	Quality Control and Packaging	The finished fabrics undergo quality control and are then packaged, making them ready for sale.

The VSM of the processes is provided in Figure 4.22. The raw materials and chemicals used in the processes and the waste and by-products are presented in the diagram in their respective quantities. The type and amounts of energy consumed are also indicated in the figure.

Fabric Characterization/Finishing is observed to have the highest energy and water consumption. This process consumes 1,175,535 kWh of electricity and 802,080 m^3 of natural gas annually. Additionally, it uses 41,554 m^3 of water. The chemicals used in this process include acetic acid (9,965 kg), silicone-based softeners (24,192 kg), fillers (8,064 kg), wrinkle-resistant finishes (8,064 kg), waterproof finishes (4,032 kg), and shearing emulsions (16,128 kg). This process results in the production of 1 ton of fabric waste. These data indicate that Process-1 is the most critical environmental hotspot in terms of energy and resource consumption and waste production.



FACILITY OVERVIEW

Energy Consumption	Energy Production	Water	FUEL	CHEMICAL	WASTE
• Electricity: 1,306,150 kWh • Natural Gas: 929,485 m³		**Water:** 42.483 m^3	**Dizel:** 900 L **Benzin:** 300 L		• Packaging containing residues of hazardous substances or • contaminated by hazardous substances: 1.2 tons • Mixed Packaging: 0.039 tons • Paper and Cardboard: 0.4 tons • Textile Products: 0.4 tons • Plastic: 0.2 tons

Figure 4.22. VSM of the Facility (NACE: 28.94.05)

Process-2: Quality Control and Packaging is also significant in terms of energy consumption and waste production. This process consumes 130,615 kWh of electricity and 72,000 m^3 of natural gas annually. Additionally, it uses 929 m^3 of water. This process generates hazardous material-contaminated packaging (1.2 tons), mixed packaging waste (0.039 tons), paper and cardboard waste (0.4 tons), textile product waste (0.4 tons), and plastic waste (0.2 tons). Proper management of these wastes is essential.

Facility-wide, the total electricity consumption is recorded at 1,306,150 kWh, and natural gas consumption is 929,485 m^3. Additionally, the facility uses 42,483 m^3 of water. Other waste types include hazardous material-contaminated packaging (1.2 tons) and mixed packaging waste (0.039 tons).

The symbiosis alternative in the facility is using of textile waste (between NACE: 28.94.05 and 13) (1 ton).

4.1.23. NACE: 29.20.01, Manufacture of trailers, semi-trailers, and other vehicles not having mechanically propelled components (bodywork, frames, axles, and other parts of these vehicles)

The facility produces semi-trailers, containers, flatbed, and lowbed. The production is carried out in four main processes (Table 4.23).

Table 4.23. Facility (NACE: 29.20.01) Production Processes

Process No	Process Name	Process Description
1	Part Preparation (Turning, Cutting, Bending)	sheet metal, profiles, and other metal materials are processed according to the respective vehicle project's design outputs and product tree plan. In this process, materials are cut using a CNC Plasma machine and bent with a press brake to form semi-finished products. The cutting process ensures that metal parts are cut to the required dimensions and shapes, while the bending process shapes the parts to the desired angles and forms. Additionally, necessary parts are processed with a lathe to achieve precise dimensions and surface quality.

(cont. on next page)

Table 4.23 (cont.)

Process No	Process Name	Process Description
2	Welded Assembly	The semi-finished parts are assembled through the welded manufacturing preparation process. At this stage, components such as the base, rear cover, side panels, and front body are created. These parts are welded together to form a unified superstructure and chassis. The welded assembly process enhances part durability and ensures structural integrity. Different welding methods, such as MIG, TIG, or spot welding, can be used in this process. The thermal effects on materials during welding are considered to minimize negative impacts such as deformation and stress.
3	Surface Protection	Parts that have undergone welded assembly are subjected to surface protection treatments. First, the metal surfaces are cleaned, and surface contaminants such as dirt, oil, and rust are removed by washing with thinner. After cleaning, the parts are primed to fill surface pores and provide corrosion protection. Finally, the primed parts are painted.
4	Assembly:	Parts that have completed surface protection processes are moved to the assembly line. At this stage, the electrical system, brake systems, and other assembly accessories (hydraulic materials, springs and axles, shock absorbers, tires, etc.) are installed onto the vehicle superstructure. The assembly process ensures that the vehicle's functions are fully and correctly operational. Each component's compatibility and functionality are carefully checked at this stage.
5	Quality Control and Shipment	During the quality control stage, the products are checked for design and functional requirements compliance. The dimensional accuracy of each part, the quality of the assembly, and overall functionality are tested. Products that pass quality control are prepared for shipment.

The VSM of the processes is provided in Figure 4.23. The raw materials and chemicals used in the processes and the waste and by-products are presented in the diagram in their respective quantities. The type and amounts of energy consumed are also indicated in the figure.

The cut parts are brought to the welding stage. MIG Welding (Metal Inert Gas Welding) is an arc welding method that uses an electric arc formed between a continuously fed wire electrode and the workpiece to join metals. A shielding gas is used to protect the molten weld pool from environmental contamination. TIG Welding (Tungsten Inert Gas Welding) is an arc welding method where metals are joined by an electric arc formed between a non-consumable tungsten electrode and the workpiece. Like in MIG welding, a shielding gas is used to protect the weld pool and the hot tungsten electrode from atmospheric contamination (Akinlabi et al., 2021).

The production process in the facility is carried out using crane and conveyor systems. The use of such systems speeds up the production process and increases efficiency. After welding, the products pass through primer and painting booths and then

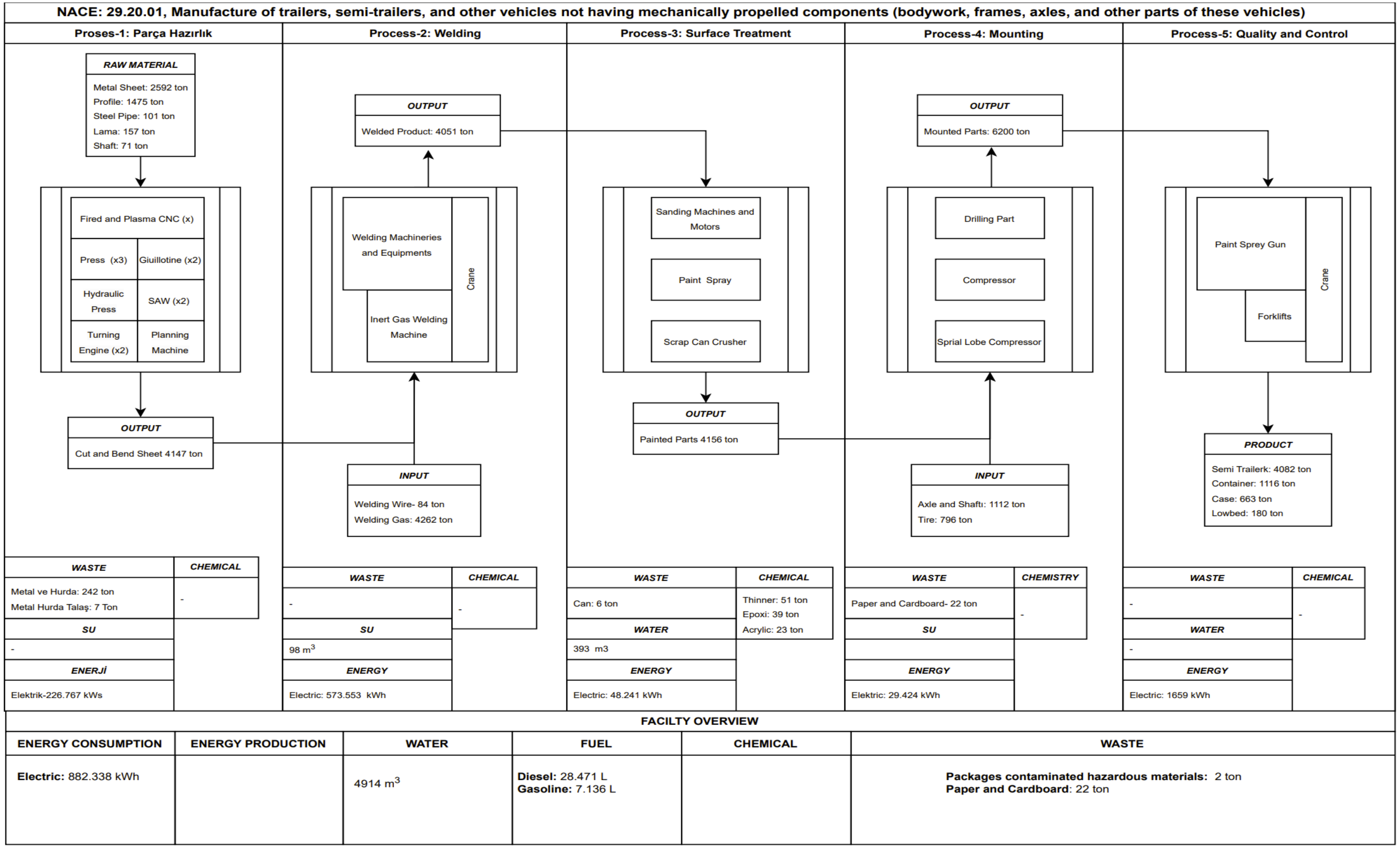


Figure 4.23. VSM of the Facility (NACE: 29.20.01)

brake systems, support wheels, and axles are mounted at the assembly station (Tirsan/Kässbohrer, 2016). Among the processes in the facility, the Welded Assembly process has the highest energy consumption, using a total of 573,553 kWh of electrical energy. This amount constitutes a significant portion of the facility's overall energy consumption. Additionally, 4,262 tons of welding gas and 84 tons of welding wire are used in this process. Considering the environmental impacts of welding gases and chemicals, it is clear that this process is one of the facility's critical environmental hotspots.

Another notable process in terms of waste production is the Part Preparation stage. This process generates 242 tons of metal scrap and 7 tons of metal shavings. Additionally, the amount of electrical energy used in this process is recorded as 226,767 kWh. Considering energy consumption and waste production, the Part Preparation process is also among the environmental hotspots.

The Surface Protection operations are noteworthy for their chemical usage. In this process, 51 tons of thinner, 39 tons of epoxy, and 23 tons of acrylic are used. The Assembly process consumes less energy (29,424 kWh) and produces less waste (22 tons of paper and packaging waste) compared to other methods. However, careful attention is still required regarding waste management.

In the facility, the 242 tons of metal scrap and 7 tons of metal shavings generated in Process-1 present a significant industrial symbiosis opportunity for the company. These materials can be recycled by recycling firms or utilized in other industrial facilities (NACE: 38.32.01). This symbiosis alternative, previously presented for another firm, has demonstrated potential cost savings of up to 40% and energy savings of up to 67% (Neves et al., 2019; Ali et al., 2019).

4.1.24. NACE: 38.32.02, Recycle of classified nonmetallic waste, scraps, and other components, usually using mechanical or chemical replacement

The facility produces drawstring garbage bags, rolled garbage bags, flat cut bags, courier bags. The production is carried out in four main processes (Table 4.24).

Table 4.24. Facility (NACE: 38.32.02) Production Processes

Process No	**Process Name**	**Process Description**
1	Recycling	Waste bags sourced from abroad (typically from the UK) are sorted, washed, and then heated in extruders to be converted into polyethylene (PE) pellets. The total capacity of the three extruders, each with an hourly capacity of 1.5 tons, has an average utilization rate of 65%.
2	Bag Production	the PE pellets obtained from recycling (80-85%) are mixed with externally sourced PE pellets (15%) in specific ratios according to the intended use. These mixtures are processed in approximately 20 extruders using the blown film extrusion method to produce rolled bags. Courier bags are also produced in this process.
3	Cutting, Printing, Drawstring	The rolled bags are cut, and printed, some are equipped with drawstrings, and fragrance is added.
4	Quality Control and Packaging	After the quality control of the products, they are packaged and made ready for shipment.

The VSM of the processes is provided in Figure 4.24. The raw materials and chemicals used in the processes and the waste and by-products are presented in the diagram in their respective quantities. The type and amounts of energy consumed are also indicated in the figure.

During the recycling process of waste plastic bags, the shredding of the bags and the removal of contaminants such as oil and dust from the plastic surfaces using water and surfactants are performed in the same unit (Chandara et al., 2015).

The shredded and washed waste bags are then fed into an extruder machine. The extrusion process involves converting solid plastic material into a molten viscous liquid and then into a solid or flexible film product for practical use. The plastic material, which can also undergo winding and cutting in the extrusion machines, is pelletized to be used as raw material in subsequent stages (Khan et al., 2014).

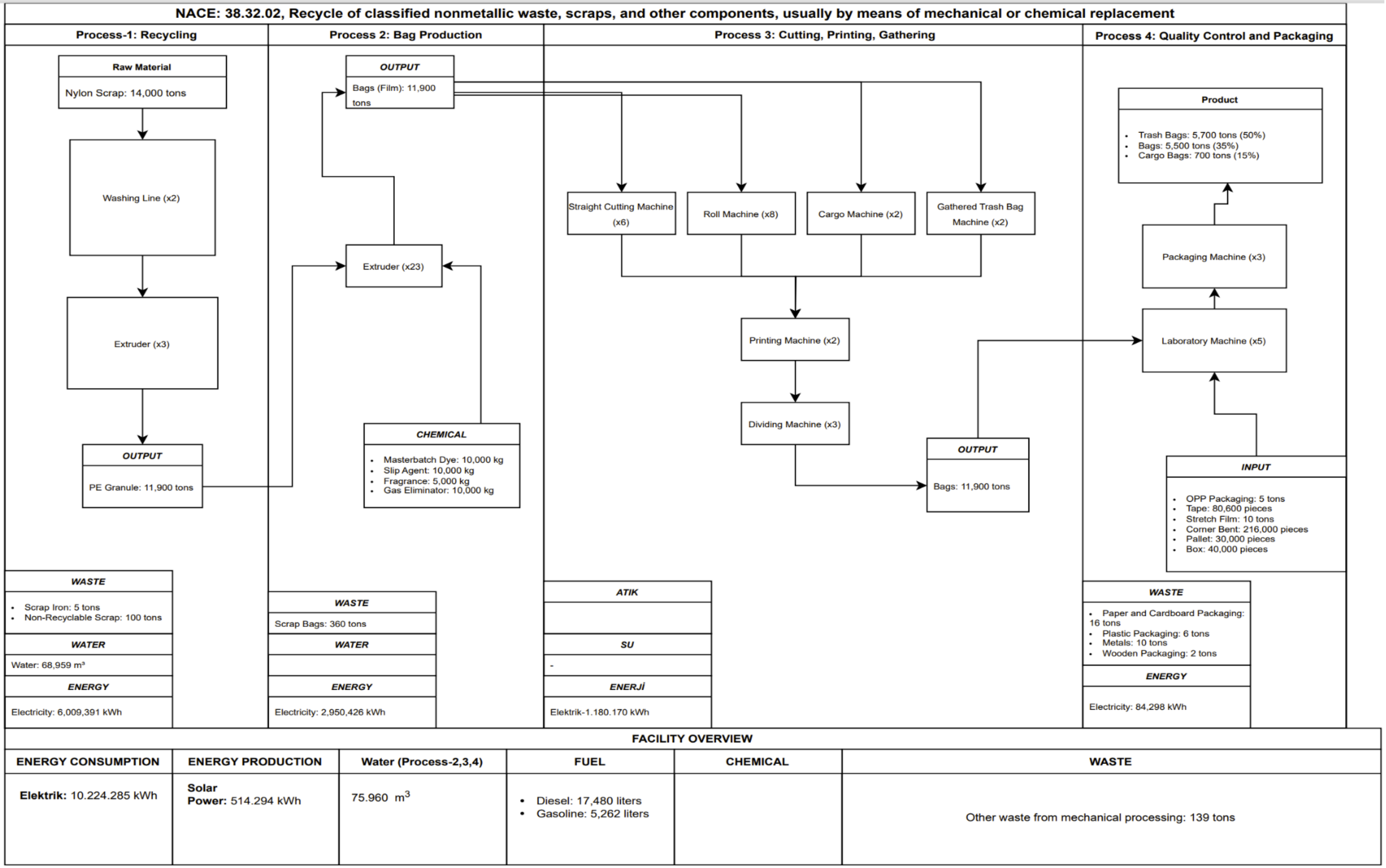


Figure 4.24. VSM of the Facility (NACE: 38.32.02)

In the bag production process, the pelletized PE raw material is collected in a hopper and fed into a barrel by a screw system. As the screw rotates, the PE pellets move through the barrel. Friction and heat cause the PE to melt. The molten PE is then passed through a grid that acts as a filter, after which it is blown and forms a bubble shape. This is then cooled and formed into a film (Rujnic-Sokele and Baric, 2014)

An industrial symbiosis exists between the Recycling Process and the Bag Production-Cutting, Printing and Drawstring-Quality Control and Packaging Processes. This symbiosis involves the reintegration of scrap bags back into production through recycling. This practice, referred to as Facility Industrial Symbiosis, requires collaboration between different processes within a single facility, where the waste from one process becomes the input for another. This approach aligns with circular economy principles and focuses on establishing a closed system with intensive material and information exchanges within the facility (Mulrow et al., 2017).

This facility sends waste plastic bags generated during bag production processes or received for recycling but not recyclable to a licensed firm for incineration. However, this energy recovery option poses significant environmental and health risks due to the release of toxic fumes and toxins like dioxins and furans into the atmosphere. To mitigate these risks, strict controls must be implemented at incineration facilities, and advanced filtration technologies should be applied (Nagy and Kuti, 2016).

The pyrolysis method presents a more sustainable solution as an alternative to incineration. Pyrolysis involves the thermal decomposition of waste plastic bags in an oxygen-free environment, resulting in valuable by-products that can be used as energy sources. The solid, liquid, and gaseous products generated from pyrolysis can be used for energy production (Dong et al., 2018), or the carbon-rich solid pyrolysis products can be utilized in agriculture for soil improvement (Hopewell et al., 2009).

The potential gains from the recovery of waste bags, defined as "non-recyclable meltable waste," through pyrolysis and construction engineering applications will be incorporated into the symbiosis system.

4.2. IS Modeling

Table 4.25 is prepared to perform a network analysis for the IS model and consists of two main parts. Nodes show the facilities and edges (Song et al., 2018; Chopra et al., 2014), indicating the symbiotic relationship defined in the previous section.

Table 4.25. Network Analysis Databank: Nodes and Edges of the IS Model

Nodes			**Edges**				
ID	Label	Project Status	# of the Symbiotic Relations	Source ID	Target ID	Type	Relation
1	10.32.02	Included	1	8	8	Undirected	Intra-firm
2	10.83.01	Included	2	8	26	Undirected	Inter-firm
3	13.10.15	Included	3	18	25	Undirected	Inter-firm
4	13.20.22	Included	4	18	18	Undirected	Intra-firm
5	13.20.22A	Included	5	3	27	Undirected	Inter-firm
6	13.30.01	Included	6	3	3	Undirected	Intra-firm
7	13.30.02	Included	7	24	25	Undirected	Inter-firm
8	13.92.06	Included	8	2	28	Undirected	Inter-firm
9	16.21.02	Included	9	2	29	Undirected	Inter-firm
10	17.12.07	Included	10	2	24	Undirected	Inter-firm
11	20.14.01	Included	11	1	28	Undirected	Inter-firm
12	20.14.01A	Included	12	1	29	Undirected	Inter-firm
13	20.42.04	Included	13	1	1	Undirected	Intra-firm
14	22.21.03	Included	14	1	11	Undirected	Inter-firm
15	22.21.04	Included	15	4	4	Undirected	Intra-firm
16	22.21.04A	Included	16	4	27	Undirected	Inter-firm
17	24.20.10	Included	17	21	25	Undirected	Inter-firm
18	25.61.01	Included	18	21	30	Undirected	Inter-firm
19	27.11.01	Included	19	23	30	Undirected	Inter-firm
20	28.22.13	Included	20	14	14	Undirected	Intra-firm
21	28.92.11	Included	21	14	24	Undirected	Inter-firm
22	28.94.05	Included	22	14	10	Undirected	Inter-firm
23	29.20.01	Included	23	10	24	Undirected	Inter-firm
24	38.32.02	Included	24	10	25	Undirected	Inter-firm
25	41-42	Excluded	25	17	30	Undirected	Inter-firm
26	22.22.43	Excluded	26	18	24	Undirected	Inter-firm
27	13	Excluded	27	22	27	Undirected	Inter-firm
28	10.8	Excluded	28	6	27	Undirected	Inter-firm
29	10.9	Excluded	29	6	30	Undirected	Inter-firm
30	38.32.01	Excluded	30	6	24	Undirected	Inter-firm

(cont. on next page)

Table 4.25. (cont.)

Nodes				Edges			
ID	Label	Project Status	# of the Symbiotic Relations	Source ID	Target ID	Type	Relation
			31	**6**	**10**	**Undirected**	**Inter-firm**
			32	5	24	Undirected	Inter-firm
			33	5	27	Undirected	Inter-firm
			34	9	25	Undirected	Inter-firm
			35	9	9	Undirected	Intra-firm
			36	9	10	Undirected	Inter-firm
			37	11	29	Undirected	Inter-firm
			38	11	9	Undirected	Inter-firm
			39	12	11	Undirected	Intra-firm
			40	12	25	Undirected	Inter-firm
			41	15	10	Undirected	Inter-firm
			42	15	24	Undirected	Inter-firm
			43	16	10	Undirected	Inter-firm
			44	16	24	Undirected	Inter-firm
			45	16	15	Undirected	Intra-firm
			46	19	30	Undirected	Inter-firm
			47	13	8	Undirected	Inter-firm
			48	20	24	Undirected	Inter-firm
			49	20	30	Undirected	Inter-firm
			50	7	10	Undirected	Inter-firm
			51	7	27	Undirected	Inter-firm

The "ID" column lists the unique identifier for each node in the network. The "Label" column contains specific labels assigned to each node, possibly representing different facilities or entities within the industrial symbiosis network. The "Project Status" column indicates whether the node is included or excluded in the pilot facilities. The "# of the Symbiotic Relations" column shows the number of symbiotic relationships in the model.

The "Source" column indicates the starting node of a relationship, while the "Target" column indicates the ending node of a relationship. The "Type" column marks the edges as "Undirected," suggesting that the relationships are bidirectional, meaning the interaction can occur in both directions. In this study, all the symbiotic relations are bidirectional. The "Relation" column specifies whether the relationship is intra-firm (within the same firm) or inter-firm (between different firms).

For example, an inter-firm edge between Source 8 (13.92.06) and Target 26 (22.22.43) indicates a symbiotic relationship between two firms. An edge between Source

3 (13.10.15) and Target 3 is intra-firm, indicating a symbiotic relationship within the same firm.

At the end, information in Table 4.25 is uploaded to the Gephi Software, and the IS model interpretation that shows the relationship between the facilities is obtained. The model interpretation is shared in Figure 4.25.

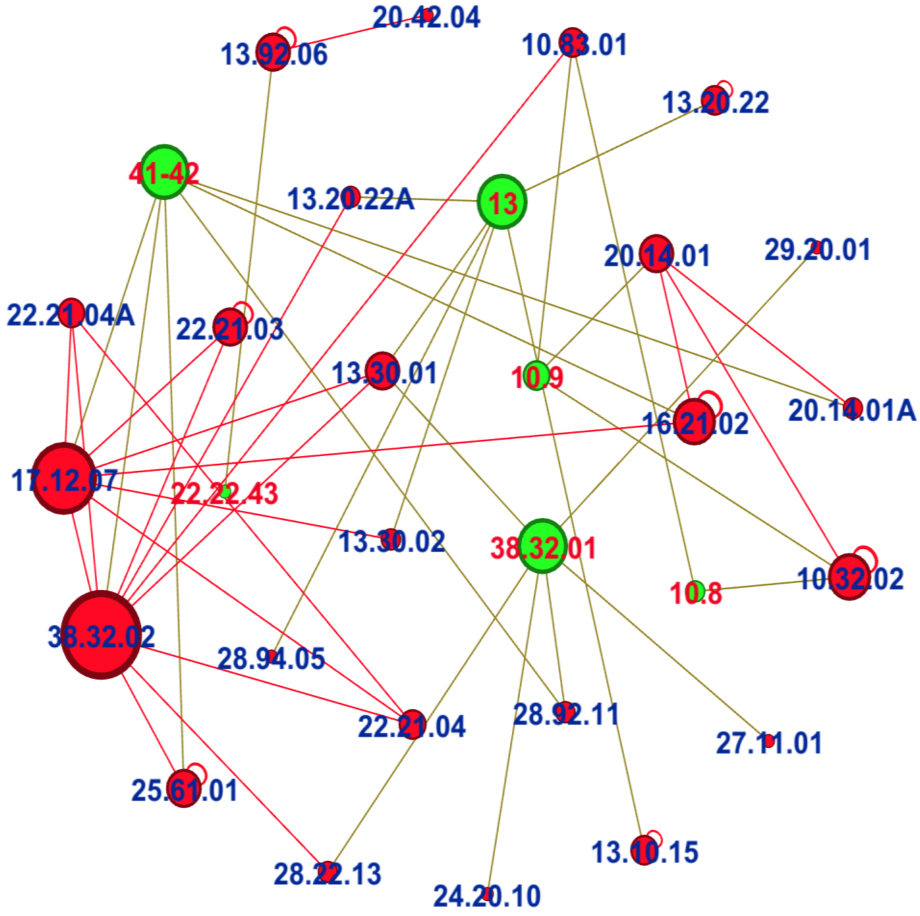


Figure 4.25. IS Model Interpretation

In this illustration, red nodes are included in the pilot facilities, while the green nodes are not. Red hooks on the nodes show the intra-firm symbiosis opportunity. The sizes of the nodes are proportional to the number of symbiotic relationships of each facility. Therefore, it can be seen from the Figure 4.25. the facility with NACE code “38.32.02” has the biggest number of interconnections with the other facilities in the proposed IS model. The manufacturing sector of this facility is “Recycle of classified nonmetallic waste, scraps, and other components, usually by means of mechanical or chemical replacement”. “Manufacture of paper and paperboard (as roll or layer for further industrial procedures) (including bituminous, laminated, coated, and impregnated ones, as well as crepe and wrinkled papers) (17.12.07)" and "Recycle of classified metallic waste, scraps, and other components, usually by means of mechanical or chemical replacement (38.32.02)" are the other sectors that have high industrial symbiosis potential.

In an industrial symbiosis system, facilities like steam boilers and waste processing plants should be strategically positioned at the center of the symbiosis network and collaborate with many facilities (Park et al., 2018). In addition, geographical proximity is another critical factor that enhances synergetic opportunities between industries, thereby facilitating industrial symbiosis (Jacobsen, 2006). When companies are close to each other, exchanging materials, energy, water, and by-products becomes easier, creating a network of resource sharing and environmental management (Chertow & Lombardi, 2005). In this hypothetical IS system, assuming that the pilot companies are in the same region, the symbiotic relationships created with the companies marked in green and not located among the pilot regions lead to the fact that they may be less effective than other internal interactions in the symbiosis which are labeled by red.

4.3. Interpretation of the Results of the IS

4.3.1. LCA Analysis of Two Pilot Facility

In this section, the LCA analysis of the "NACE: 13.10.15- Twisting and spun of artificial or synthetic fibers (except manufacturing of filament yarns and rayon fibers)" and "NACE: 25.61.01- Activities of metal heat treatment and anodizing, hardening, varnishing, etc. surface treatments, electrolysis, sherardizing or metallic coating with chemical treatment (except tin and nickel coating) and coating activities with plastic" will be interpreted.

4.3.1.1. NACE: 13.10.15- Twisting and spun of artificial or synthetic fibers (except manufacturing of filament yarns and rayon fibers)

This facility's ID is 3 in the IS model. In the "4.1 Manufacturing Processes and VSMs of the Facilities" part of the thesis, the summary tables of the facilities that shows the raw material consumption, waste generation, energy and water consumption amounts can be enough for the life cycle inventory of the facility. However, the types of raw materials and the electricity consumption in each process can be given in detail to analyze the facility more precisely. Inventory of the facility that shows the consumption amounts and emission factors are given in Annex-1. This inventory shows the details regarding the LCA studies using CCalC-2 software. In addition, multiple environmental impacts of the facilities, including acidification, eutrophication, ozone layer depletion, photochemical (summer) smog, and human toxicity, are summarized in Annex-1.

The functional unit of the study is yearly yarn production in 2022 (kg/year). System boundaries are defined as gate-to-gate. However, in order to evaluate the possible gains of IS opportunities covering raw material saving and decreasing waste generation in this thesis, carbon emission of the raw materials and the wastes are added to the calculations. In Table 4.26, a carbon footprint overview of the facility is given. When the table is considered, it can be seen that the contribution of the raw material consumption is bigger than the electricity consumption and waste generation during the production processes. Raw material consumption has many more environmental impacts than the other processes (see Appendix-A).

The IS opportunities of this facility are recycling and reusing textile wastes and optimizing processes to increase electricity consumption efficiency. When the scenarios that 10% decrease in electricity consumption and 2601 tons decrease in textile waste generation are applied, results will give a clue for prioritizing these two IS scenarios. The results are compared in Figure 4.27.

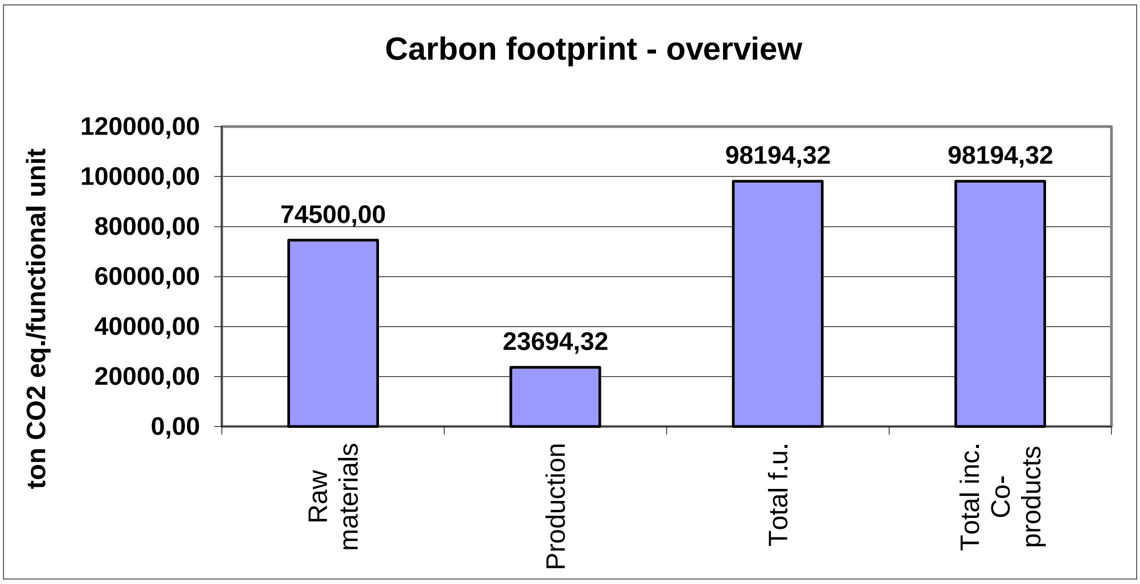


Figure 4.26. Carbon Footprint of the Facility (NACE: 13.10.15)

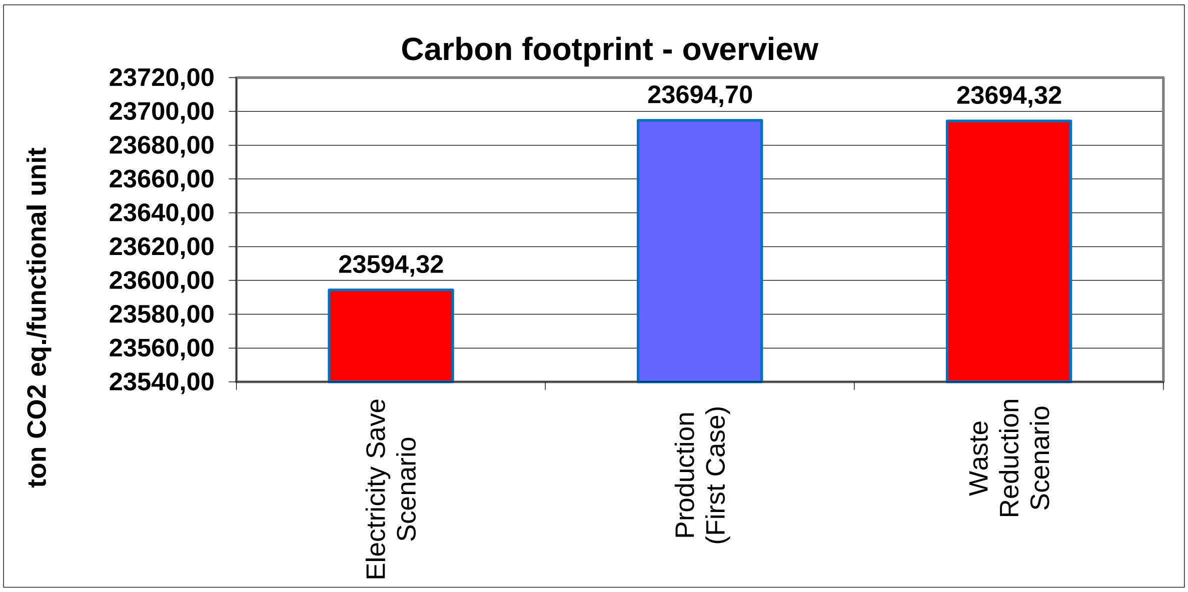


Figure 4.27. Comparison of the Results of IS Scenarios for the Facility (NACE: 13.10.15)

When the table above is considered, decreasing waste generation by about 70% has much less effect than the scenario in which the electricity consumption is decreased by about 10%. This analysis shows that electricity is a more sensitive parameter than the amount of disposed textile waste. Therefore, optimizing the processes to decrease the electricity consumption is a more effective IS scenario, which can be an example of intra-firm IS.

In studies carried out in different facilities in China, India, Egypt, and America, the emission amount per 1 kg of cotton yarn production varies between 0.62 and 0.89 kg CO_2 eq (Bevilacqua et.al, 2014), while in this study, this value was found to be approximately 19.6 kg CO_2 eq. Among the reasons for this situation are potential shortcomings in the data, the high waste amount mentioned in the evaluations related to the facility in section 4.1 of this thesis, and the fact that machines older than 20 years are in use in the facility. At the end of the IS scenario application, 4,401,791 kWh of electricity was saved, and 2601 tons of waste reduction was expected. Therefore, the total CO_2 emission will save about 2,300 tCO_2/ year. This decreases the emission amount per 1 kg of cotton yarn production to 19 kg CO_2 eq.

4.3.1.2. NACE: 25.61.01- Activities of metal heat treatment and anodizing, hardening, varnishing, etc. surface treatments, electrolysis, sherardizing or metallic coating with chemical treatment (except tin and nickel coating) and coating activities with plastic

This facility’s ID is 3 in the IS model. Inventory of the facility that shows the consumption amounts and emission factors are given in Annex-2. This inventory shows the details regarding the LCA studies using CCalC-2 software. In addition, multiple environmental impacts of the facilities, including acidification, eutrophication, ozone layer depletion, photochemical (summer) smog, and human toxicity, are summarized in Annex-1.

The functional unit of the study is yearly galvanized wire production in 2022 (kg/year). System boundaries are defined as gate-to-gate. However, in order to evaluate the possible gains of IS opportunities covering raw material saving and decreasing waste generation in this thesis, carbon emission of the raw materials and the wastes are added to the calculations. In Figure 4.28, a carbon footprint overview of the facility is given.

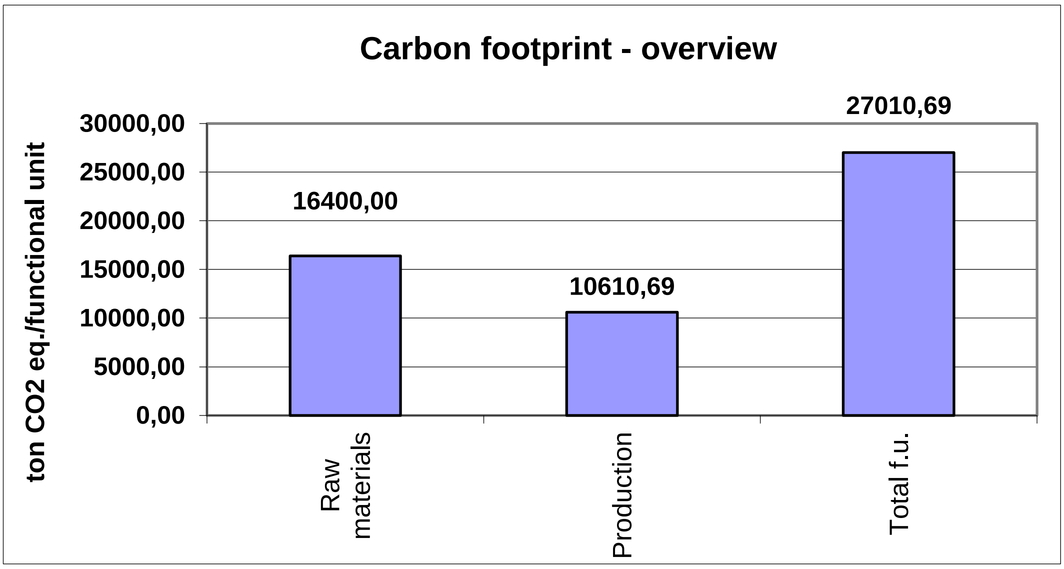


Figure 4.28. Carbon Footprint of the Facility (NACE: 25.61.01)

Raw material consumption of the facility consists of the chemicals, additives and steel wire mentioned in Section 4-1 and Annex-2. On the other hand, production steps cover electric and natural gas consumption. In this facility, LCA is achieved by assessing the facility by dividing the units by wire drawing, galvanization quality control, and packaging process. The carbon footprint of the production stages is given in Figure 4.29. In accordance with the IS scenarios for this Facility, the processes are optimized, and natural gas and electricity consumption will be decreased. The savings from the natural gas and electricity will be compared to evaluate their contribution to the carbon emission of the Facility.

In the IS scenario for this facility, the first 15% of saving electric and then 15% of natural gas are also compared in Figure 4.29.

It can be noted that natural gas is consumed in the galvanization process, and the 15% saving on natural gas is more effective than the 15% saving on electricity. In this facility, 37,012 tons of galvanized steel wire is produced annually, and the total CO_2 eq is 27,010,685 kg. Therefore, the carbon footprint of 1 kg of galvanized wire is 0,73 kg CO_2 eq. In the study held in Spain, two different hot-dip galvanization plants for galvanized steel production have been analyzed. The results show that the carbon footprint of 1kg product in those facilities varies between 1,4 and 2,6 kg CO_2 values. When all the IS scenarios are applied, 143,378 kg of CO_2 emissions will be reduced (see 4.3.2). Therefore, the carbon footprint of 1 kg of galvanized wire becomes 0,72 kg CO_2 eq. The IS model studied in this thesis does not affect the product's carbon footprint dramatically. However, the total emission reduction and energy savings are notable and will be discussed in the following section.

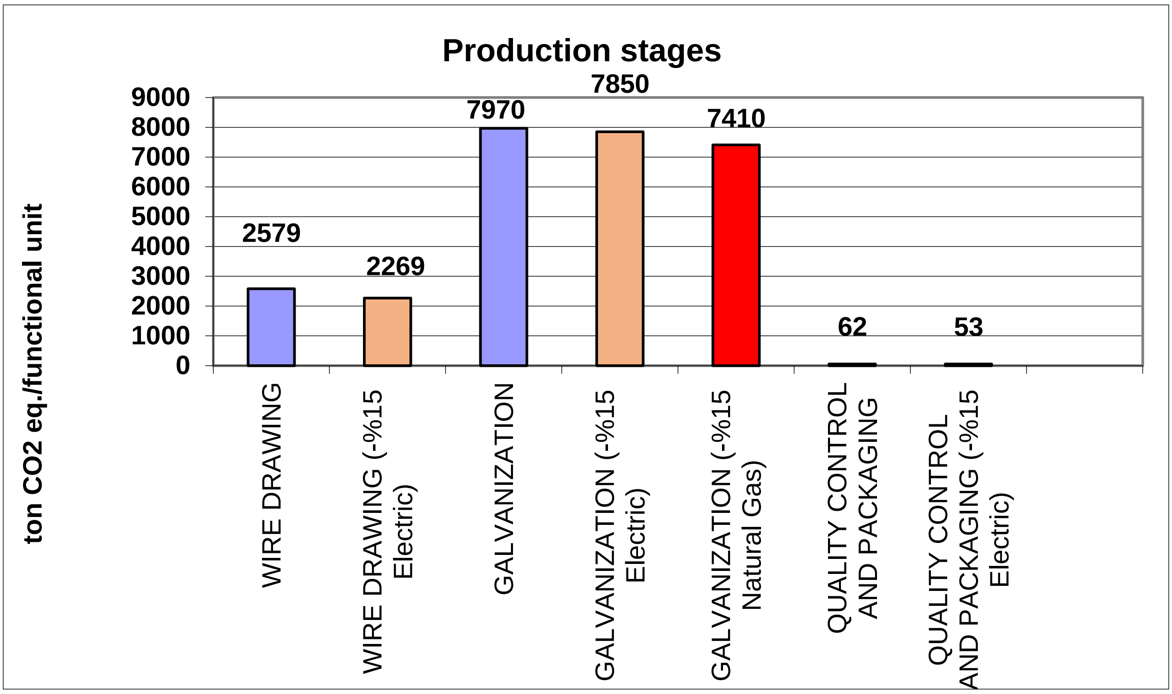


Figure 4.29. The carbon footprint of the production stages (NACE: 25.61.01)

4.3.2. Calculation of the Environmental Gains of IS Model

In accordance with the defined potential matches and symbiotic relations in Section 4.1., possible gains at the end of the IS are summarized in Table 4.26 and compared with the IS models mentioned in the literature review part of this thesis. In Table 4.27, on the other hand, emission factors of the energy and materials that are subjected to saving are defined, and their references are shared in detail. Emissions factors are multiplied by the savings amount. In the end, annual carbon emission savings and energy, water savings, and waste reductions are identified. In the assumption part of the table, the fate of the material and energy consumption before the IS application is written.

Table 4.26. IS Achievements in the Literature and AOIZ

OIZ Subjected to IS Project	**CO_2 Emission Save (tCO_2/year)**	**Annual Energy Save**	**Raw Material Save (tons/year)**	**Water Save (m^3/year)**	**# of Facility Involved in the Symbiosis**
Industrial Symbiosis in Iskenderun Bay (2010-2014)	38,680	33581155 kWh	276,253	6500	264
Eskisehir Industrial Symbiosis (IS) Possibilities Research Project (2020)	118,505	3-30%	129,312	-	50
Konya OIZ (2018)	4,420	$804,000 energy cost saving	-	-	-
Industrial Symbiosis and Eco-efficiency Project in Antalya Organized Industrial Zone (2015-2017)	3,800	-	91,600	75,000	-
Industrial Symbiosis Project in İzmir Region	63,892	151,840,000 kWh	16,000	1,152,032	57
SINP In Columbia	1126	619,500 kWh	7207	146,000	36
AOIZ	119259 tCO_2/year	14790219 kWh 241616 m^3 natural gas	189,367	303489	24

Table 4.27. Detailed Calculation of the Gains of the IS

Edges	Saving	Amount	Unit	Emission Factor (CO$_2$ eq kg/kg material)	Resource	Annual Emission Save (kgCO$_2$eq/year)	Assumption
1-1	Water	250,000	m^3	5,76e-4	European Reference Life Cycle Database, 2005	144	Drinking water save (groundwater)
1-28	Fruit Pulp	23,788	tons	3,108e-2	Ecoinvent Data v2.2 (2010)	739000,00	Animal feed
1-29							
1-11							
2-28 2-29	Tea Dust	23	tons	0,739	(Freitas de Alvarenta et al., 2010)	16997	Chicken feed
2-24	Plastic waste	5	tons	0,01	Ecoinvent Data v2.2 (2010)	201	Final disposal
3-3	electricity	4,401,791	kWh	439,00	MoIT, 2024	1932039	Reduction in energy consumption
3-27	textile waste	2601,00	tons	0,15	Ecoinvent Data v2.2 (2010)	379600	the disposal to municipal incineration
4-4	water	53,489	m3	5,76e-4	European Reference Life Cycle Database, 2005	30,9	Drinking water save (groundwater)
	electricity	8,979,667	kWh	0,439	MoIT, 2024	3941781	the disposal to municipal incineration
4-27	textile waste	4,710	tons	0,15	Ecoinvent Data v2.2 (2010)	706500	the disposal to municipal incineration
5-27	textile waste	491,00	tons	0,15	Ecoinvent Data v2.2 (2010)	73650	the disposal to municipal incineration
5-24	plastic waste	24,00	tons	0,01	Ecoinvent Data v2.2 (2010)	240	final disposal

(cont. on next page)

Table 4.27 (cont.)

Edges	Saving	Amount	Unit	Emission Factor (CO_2 eq kg/kg material)	Resource	Annual Emission Save ($kgCO_2eq/year$)	Assumption
6-27	textile waste	180,00	tons	0,15	Ecoinvent Data v2.2 (2010)	27000	saving from the disposal to municipal incineration
6-30	metal waste	76	tons	0,01	Ecoinvent Data v2.2 (2010)	764	final disposal
6-24	plastic waste	83	tons	0,01	Ecoinvent Data v2.2 (2010)	830	final disposal
6-10	paper and cardboard	406	tons	0,03	Ecoinvent Data v2.2 (2010)	12180	disposal, packaging paper, municipal incineration
7-10	paper and cardboard	80	tons	0,03	Ecoinvent Data v2.2 (2010)	2400	disposal, packaging paper, municipal incineration
7-27	textile waste	38	tons	0,15	Ecoinvent Data v2.2 (2010)		saving from the disposal to municipal incineration
8-8 8-26	plastic waste	820	tons	0,01	Ecoinvent Data v2.2 (2010)	8200	final disposal
9-9	biowaste (chips)	75,861	tons	1,45	European Reference Life Cycle Database, 2005	110074,311	landfill wooden product
9-10	paper and cardboard	347	tons	0,03	Ecoinvent Data v2.2 (2010)	8550	disposal, packaging paper, municipal incineration
9-25	waste ash	8,676	tons	0,02	Ecoinvent Data v2.2 (2010)	199,548	
10-24	plastic waste	243	tons	0,01	Ecoinvent Data v2.2 (2010)	2430	final disposal

(cont. on next page)

Table 4.27 (cont.)

Edges	Saving	Amount	Unit	Emission Factor (CO_2 eq kg/kg material)	Resource	Annual Emission Save (kgCO_2eq/year)	Assumption
10-25	waste ash	25,036	tons	0,02	Ecoinvent Data v2.2 (2010)	575,828	
11-9 11-29	by-product (DDGS)	25,517	tons	0,9	Ecoinvent Data v2.2 (2010)	23700000	reduction in material consumption
12-11	Same firm	Information Share Potential					
12-25	gypsyum	48,000	tons	0,01	Ecoinvent Data v2.2 (2010)	336	inert material landfill
13-8	pp-non woven	Information Share Potential					
14-10	paper and cardboard	176	tons	0,03	Ecoinvent Data v2.2 (2010)	4400	disposal, packaging paper, municipal incineration
14-24 14-14	plastic waste	1801	tons	0,01	Ecoinvent Data v2.2 (2010)	18010	final disposal
15-10	paper and cardboard	91	tons	0,03	Ecoinvent Data v2.2 (2010)	2275	disposal, packaging paper, municipal incineration
15-24	plastic waste	610	tons	0,01	Ecoinvent Data v2.2 (2010)	6100	final disposal
16-10	paper and cardboard	15	tons	0,03	Ecoinvent Data v2.2 (2010)	375	disposal, packaging paper, municipal incineration
16-15	Same firm	Information Share Potential					
16-24	plastic waste	18	tons	0,01	Ecoinvent Data v2.2 (2010)	180	final disposal

(cont. on next page)

Table 4.27 (cont.)

Edges	Saving	Amount	Unit	Emission Factor (CO$_2$ eq kg/kg material)	Resource	Annual Emission Save (kgCO$_2$eq/year)	Assumption
17-30	metal waste	590	tons	0,01	Ecoinvent Data v2.2 (2010)	5900	final disposal
18-18	acid reduction	45	tons	2,59	Ecoinvent Data v2.2 (2010)	116550	reduction in material consumption
	electricity	909261,00	kWh	0,439	MoIT, 2024	3636	Reduction in energy consumption
	natural gas	241615,00	m3	0,07	Ecoinvent Data v2.2 (2010)	16913,05	Reduction in energy consumption
18-25	waste ash	273	tons	0,02	Ecoinvent Data v2.2 (2010)	6279	final disposal
19-30	metal waste	492	tons	0,01	Ecoinvent Data v2.2 (2010)	4920	final disposal
20-30	metal waste	908	tons	0,01	Ecoinvent Data v2.2 (2010)	9080	final disposal
20-24	PE extruder	Information Share Potential					
21-25	metal waste	265	tons				
21-30				0,01	Ecoinvent Data v2.2 (2010)	2650	final disposal
22-27	textile waste	1	tons	0,15	Ecoinvent Data v2.2 (2010)	146	saving from the disposal to municipal incineration
23-30	metal waste	249	tons	0,01	Ecoinvent Data v2.2 (2010)	2490	final disposal
24-25	mixed waste	2100	tons	0,02	(metal +paper and cardboard packaging) Ecoinvent Data v2.2 (2010)	42000	final disposal

CHAPTER 5

CONCLUSION

This thesis presents the development of an industrial symbiosis model for 24 facilities belonging to 22 firms in the AOIZ-organized industrial zone. The facilities were coded using NACE codes, and potential symbiosis alternatives were examined both between the firms and within the factory processes. Potential matches were identified, and the environmental benefits of symbiosis were quantified, including reductions in emissions, electricity, natural gas consumption, and waste production. Similarly, the study found that the firms with the highest potential for interactions within the IS system are recycling/recovery firms and those producing primarily organic content. In this context, the matches, information, and data from this Project could be useful when evaluating the symbiotic conditions of newly established eco-industrial parks.

The main barrier to industrial symbiosis is organizational challenges. These challenges include insufficient support and commitment from top management, financial restraints, and a lack of new organizational policies for adapting industrial symbiosis (Taqi et al., 2022). In addition, the cooperation and sharing required for industrial symbiosis may not be economically sustainable for all actors involved. When modifications or new constructions are necessary to create connections between companies, the economic benefits might not justify the investment. Initial investments and equitable cost and benefit sharing are significant concerns (Menato et al., 2017).

The final destination of by-products, whether they are sent to landfills, require pretreatment or are used directly in other networks, and the classification of by-products as hazardous or non-hazardous, and inert or non-inert are the main concerns regarding the material exchange in industrial symbiosis. The frequency and severity of potential barriers or difficulties related to waste management and business operations is another concern regarding IS (Marinelli et al., 2021).

Focusing on creating local symbiotic relationships within industrial parks or clusters can minimize transportation costs and enhance the feasibility of by-product exchanges. Encouraging collaborative projects among industries, academia, and government to explore new avenues for by-product utilization and resource efficiency is also important. Investing in research and development for technologies that can efficiently process by-products and waste materials into valuable resources will further support the development of industrial symbiosis (Akhtar et.al., 2022).

In the symbiosis evaluation process, after identifying symbiotic relationships, it is important to model these relationships and evaluate and weigh all other possible matches related to NACE codes using this model. Similarly, conducting LCA analyses for all facilities during the analysis of the results is crucial for weighing symbiosis alternatives and in decision-making processes. Additionally, value stream maps (VSM) in these studies simplify complex processes, allowing for better visibility of every detail. Having value stream maps for all facilities in an eco-industrial park in the same format can benefit all lean production model activities, especially symbiosis. However, the importance of data collection should be emphasized before all of these steps. The accuracy and adequacy of data provided by firms are decisive factors in establishing symbiosis. In this context, it is critical to establish a team responsible for this task for each organized industrial zone.

To enhance industrial symbiosis practices in organized industrial zones, it is recommended that dedicated teams be established to manage and provide data for symbiosis activities. As part of the journey towards becoming a Green OIZ, one of the performance parameters could be the carbon savings achieved per firm involved in the symbiosis. In this study, the number is 4969 tCO_2/year. Under the scope of lean production, it is crucial to collect, process, and continuously improve data across all industrial zones. This task could be managed by a team within each OIZ.

Considering that AOIZ has a total of 440 firms and 22 of them are now part of a symbiosis, achieving this represents a 5% improvement. This would qualify AOIZ to gain 2 points towards the Green OIZ certificate issued by TSE. More facilities must participate in symbiosis activities to become a green organized industrial zone (OIZ). Increasing the number of participating facilities in future studies will help an OIZ progress towards becoming an eco-industrial park. Additionally, as the number of facilities increases, the opportunities for symbiosis will also increase, leading to significant environmental gains. A system where all symbiosis activities are recorded and formalized will significantly contribute to ensuring the sustainability of these efforts.

REFERENCES

Akgün, A. C. 2020. Türkiye'de Yöresel Çayların Markalaşma Süreci: Çaykur 42 Numaralı Tirebolu Çayı Örneği. Uluslararası Halkla İlişkiler ve Reklam Çalışmaları Dergisi, 3(2), 131-155.

Akhtar, N., Bokhari, S. A., Martin, M. A., Saqib, Z., Khan, M. I., Mahmud, A., Zaman-ul-Haq, M., & Amir, S. (2022). Uncovering Barriers for Industrial Symbiosis: Assessing Prospects for Eco-Industrialization through Small and Medium-Sized Enterprises in Developing Regions. *Sustainability, 14*(6898).

Akinlabi, S. A., Mashinini, P. M., Abima, C. S., Fatoba, O. S., & Akinlabi, E. T. (2021). TIG & MIG hybrid welded steel joint: A review. Proceedings of the International Conference on Industrial Engineering and Operations Management, Toronto, Canada, October 23-25, 2019.

Ali, A. K., Wang, Y., & Alvarado, J. L. (2019). Facilitating industrial symbiosis to achieve circular economy using value-added by design: A case study in transforming the automobile industry sheet metal waste-flow into Voronoi facade systems. Journal of Cleaner Production, 234, 1033-1044

Alkaya, E., & Demirer, G. N. (2015). Water recycling and reuse in soft drink/beverage industry: A case study for sustainable industrial water management in Turkey. Resources, Conservation and Recycling, 104, 172-180.

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.

Almahdawi, M. 2018. Using tea waste as a source of protein in the ration and its impact on productive performance, growth, and some blood parameters of Awassi lambs. Advances in Animal and Veterinary Sciences, 6(11), 499-508.

Alvar-Beltrán, J., Napoli, M., Dao, A., Ouattara, A., Verdi, L., Orlandini, S., ve Marta, A.D. 2021. Nitrogen, phosphorus and potassium mass balances in an irrigated quinoa field, Italian Journal of Agronomy, 16,1788.

Ammenberg, J., Baas, L., Eklund, M., Feiz, R., Helgstrand, A., & Marshall, R. P. (2015). Improving the co2 performance of cement, part iii: the relevance of industrial symbiosis and how to measure its impact. Journal of Cleaner Production, 98, 145-155. https://doi.org/10.1016/j.jclepro.2014.01.086

Antalya OSB , TTGV (2015), Antalya Organize Sanayi Bölgesinde Endüstriyel Simbiyoz ve Eko-Verimlilik Projesi, Antalya.

Arzoumanidis, I., D'Eusanio, M., Raggi, A., & Petti, L. (2020). Functional unit definition criteria in life cycle assessment and social life cycle assessment: a discussion. In Perspectives on Social LCA: Contributions from the 6th International Conference (pp. 1-10). Springer International Publishing.

Awasthi, M. K., Sindhu, R., Sirohi, R., Kumar, V., Ahluwalia, V., Binod, P. & Pandey, A. (2022). Agricultural waste biorefinery development towards circular bioeconomy. Renewable and Sustainable Energy Reviews, 158, 112122.

Ažman Momirski, L., Mušič, B., & Cotič, B. (2021). Urban strategies enabling industrial and urban symbiosis: The case of slovenia. Sustainability, 13(9), 4616.

Baldassarre, B., Schepers, M., Bocken, N., Cuppen, E., Korevaar, G., & Calabretta, G. (2019). Industrial symbiosis: towards a design process for eco-industrial clusters by integrating circular economy and industrial ecology perspectives. Journal of Cleaner Production, 216, 446-460. https://doi.org/10.1016/j.jclepro.2019.01.091

Bevilacqua, M., Ciarapica, F. E., Mazzuto, G., & Paciarotti, C. (2014). Environmental analysis of a cotton yarn supply chain. *Journal of Cleaner Production, 82*, 154-165.

Bocken, N. M. P., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. Journal of Industrial and Production Engineering, 33(5), 308-320. https://doi.org/10.1080/21681015.2016.1172124

Briga-Sá, A., Nascimento, D., Teixeira, N., Pinto, J., Caldeira, F., Varum, H., Paiva, A. 2013. Textile waste as an alternative thermal insulation building material solution, Construction and Building Materials,38,155-160.

Budihardjo, R., Hadipuro, W. 2022. “Green value stream mapping: a tool for increasing green productivity”, Journal of Management and Business Environment, 4(1), 1-19.

Bull, M., Zerdin, K., Howe, E., Goicoechea, D., Paramanandhan, P., Stockman, R., Stewart, C. 2004. The effect of high pressure processing on the microbial, physical and chemical properties of valencia and navel orange juice. Innovative Food Science & Emerging Technologies, 5(2), 135-149.

C. Stocks, Wood, J., Guy, S. 2005. “Minimisation and recycling of spent acid wastes from galvanizing plants”, Resources, Conservation and Recycling, 44(2), 153-166.

Cáceres, C. R., Törnroth, S., Vesterlund, M., Johansson, A., & Sandberg, M. (2022). Data-Center Farming: Exploring the Potential of Industrial Symbiosis in a Subarctic Region. Sustainability, 14(5), 2774.

Campos, D.A., Gómez-García, R., Vilas-Boas, A.A., Madureira, A.R., Pintado, M.M. 2020, Management of Fruit Industrial By-Products—A Case Study on Circular Economy Approach. Molecules, 25, 320.

Chandara, H., Sunjoto, Sarto. 2015. “Plastic Recycling in Indonesia by Converting Plastic Wastes (PET, HDPE, LDPE, and PP) into Plastic Pellets”. ASEAN Journal of Systems Engineering, 3(2), 65-72.

Chertow, M. 2007. Industrial symbiosis. Encyclopedia of Earth.

Chertow, M. and Lombardi, D. (2005). Quantifying economic and environmental benefits of co-located firms. Environmental Science & Technology, 39(17), 6535-6541.

Chertow, M. R. (2007). Uncovering Industrial Symbiosis. Journal of Industrial Ecology, 11(1), 11-30.

Chertow, M. R., Ashton, W. S., Espinosa, J. C. 2008. Industrial Symbiosis in Puerto Rico: Environmentally Related Agglomeration Economies. Regional Studies, 42(10), 1299–1312.

Chertow, M.; Ashton, W.; Kuppalli, R. 2004. “The Industrial Symbiosis Research Symposium at Yale: Advancing the Study of Industry and Environment”, Yale School of the Environment Publications Series, 23

Chopra, S. S., & Khanna, V. (2014). Understanding resilience in industrial symbiosis networks: Insights from network analysis. Journal of environmental management, 141, 86-94.

Christofi A., Tsipiras D., Malamis D., Moustakas D., Mai S., Barampouti.M, 2022, Biofuels production from orange juice industrial waste within a circular economy vision, Journal of Water Process Engineering, Volume 49, 103028,

Cui, H., Liu, C., & Liu, W. (2018). Understanding the evolution of industrial symbiosis with a system dynamics model: a case study of hai hua industrial symbiosis, china. Sustainability, 10(11), 3873. https://doi.org/10.3390/su10113873

Dadashnejad, A., Valmohammadi, C. 2018. “Investigating the effect of value stream mapping on operational losses: a case study”, Journal of Engineering Design and Technology, 16(3), 478-500.

De Monte, M., Padoano, E., Pozzetto, D. 2005. Alternative coffee packaging: an analysis from a life cycle point of view. Journal of Food Engineering, 66(4), 405-411.

Debnath, B., Haldar, D., & Purkait, M. K. 2021. Potential and sustainable utilization of tea waste: A review on present status and future trends. Journal of Environmental Chemical Engineering, 9(5), 106179.

Dolgen D, Alpaslan MN (2020) Eco-Industrial Parks: Experiences from Turkey. Glob J Ecol 5(1): 030-032. DOI: https://dx.doi.org/10.17352/gje.000016

Dolgova, O., & Nikitaeva, A. (2023). Industrial Symbiosis as a Way to Solve Environmental Problems in Regions (on the Example of the Russian Black Sea

Area). BIO Web of Conferences, 63, 03007. https://doi.org/10.1051/bioconf/20236303007

Dong, J., Tang, Y., Nzihou, A., Chi, Y., Weiss-Hortala, E., Ni, M. 2018. Life cycle assessment of pyrolysis, gasification and incineration waste-to-energy technologies: Theoretical analysis and case study of commercial plants. Science of The Total Environment, 626, 744-753.

Dönmez, E. T., Turker, E. 2022. Thermal and Sound Insulation Performances of Building Panels Produced by Recycling Waste Fibres of Yarn Factories. Textile and Apparel, 32(1), 9-23.

EC (European Commission). 2020. Circular economy plan.

Ehrenfeld, J. R., & Gertler, N. (1997). Industrial Ecology in Practice: The Evolution of Interdependence at Kalundborg. Journal of Industrial Ecology, 1(1), 67-79.

Eissa, M., Ahmed, A., El-Fawkhry, M. 2015. "Conversion of mill scale waste into valuable products via carbothermic reduction". Journal of Metallurgy.

Elomaa, H., Sinisalo, P., Rintala, L., Aromaa, J., Lundström, M. 2019. Process simulation and gate-to-gate life cycle assessment of hydrometallurgical refractory gold concentrate processing. The International Journal of Life Cycle Assessment, 25(3), 456-477.

Eom, H., Kim, J., Nam, I., & Bae, S. 2021. Recycling Black Tea Waste Biomass as Activated Porous Carbon for Long Life Cycle Supercapacitor Electrodes. Materials, 14(21), 6592.

EPA (Environmental Protection Agency). 2013. "Lean and environmental toolkit", EPA, EPAROSTAT / EUROPEAN COMMISION. 2018. NACE Rev. 2 Statistical classification of economic activities in the European Community.

EPA. (2013). Lean and Environment Toolkit. Environmental Protection Agency.

Erdumlu, N., Ozipek, B., Oztuna, A.S. and Cetinkaya, S. 2009 Investigation of Vortex Spun Yarn Properties in Comparison with Conventional Ring and Open-end Rotor Spun Yarns, Textile Research Journal. 79, 585- 595.

Ersoy Mirici, M., & Berberoğlu, S. (2022). Türkiye Perspektifinde Yeşil Mutabakat ve Karbon Ayak İzi: Tehdit Mi? Fırsat Mı?. Doğal Afetler Ve Çevre Dergisi, 8(1), 156-164. https://doi.org/10.21324/dacd.982396

Ersöz, T., Tenbeli, R., & Ersöz, F. (2021). Visual analysis of Turkey's textile sector with Gephi complex network. Proceedings of the 11th International Symposium on Intelligent Manufacturing and Service Systems (IMSS'21), Sakarya University, 519-529. Retrieved from

European Commission. (2019). The European Green Deal. Brussels.

European Commission. (2021). Fit for 55: delivering the EU's 2030 Climate Target on the way to climate neutrality. Brussels.

Eurostat / European Commission. 2023. Glossary: Statistical classification of products by activity (CPA).

Favi, C., Germani, M., Mandolini, M., & Marconi, M. (2016). PLANTLCA: a lifecycle approach to map and characterize resource consumptions and environmental impacts of manufacturing plants. Procedia CIRP, 48, 146-151.

Fernandes, P. R. B., Contin, B., Siqueira, M. U., Ruschel-Soares, R., & Baruque-Ramos, J. (2021). Biocomposites from Cotton Denim Waste for Footwear Components. Materials Circular Economy, 3(29), 1-10.

Ferrández, D., Zaragoza-Benzal, A., Santos, P., Durães, L. 2023. "Characterisation of new sustainable gypsum composites with low-density polyethylene waste from single-use bags". Journal of Building Engineering, 80, 108103.

Fidan, F. Ş., Aydoğan, E. K., & Uzal, N. (2021). An integrated life cycle assessment approach for denim fabric production using recycled cotton fibers and combined heat and power plant. Journal of Cleaner Production, 287, 125439. https://doi.org/10.1016/j.jclepro.2020.125439

Finnveden, G., Hauschild, M. Z., Ekvall, T., Guinee, J., Heijungs, R., Hellweg, S., & Suh, S. (2009). Recent developments in Life Cycle Assessment. Journal of Environmental Management, 91(1), 1-21.

Fraccascia, L., Yazdanpanah, V., van Capelleveen, G. et al. Energy-based industrial symbiosis: a literature review for circular energy transition. Environ Dev Sustain 23, 4791–4825 (2021). https://doi.org/10.1007/s10668-020-00840-9

Garcés-Ayerbe, C., Rivera-Torres, P., Suárez-Perales, I., & Leyva-de la Hiz, D. I. (2019). Is It Possible to Change from a Linear to a Circular Economy? An Overview of Opportunities and Barriers for European Small and Medium-Sized Enterprise Companies. International Journal of Environmental Research and Public Health, 16(851). https://doi.org/10.3390/ijerph16050851

Garza-Reyes, J., Romero, J., Govindan, K., Cherrafi, A., Ramanathan, U. 2018. “A pdca-based approach to environmental value stream mapping (e-vsm)”, Journal of Cleaner Production, 180, 335-348.

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? Journal of Cleaner Production, 143, 757-768. https://doi.org/10.1016/j.jclepro.2016.12.048

Geng, Y., Tsuyoshi, F., & Chen, X. (2012). Evaluation of innovative municipal solid waste management through urban symbiosis: a case study of Kawasaki. Journal of Cleaner Production, 18(10-11), 993-1000.

Groen, E. A., Heijungs, R., Bokkers, E. A. M., & de Boer, I. J. M. (2015). Sensitivity analysis in life cycle assessment. In Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector.

GTE. (2024) “İzmir’de Eko-Endüstriyel Park Dönüşümü: Yeşil İAOIZ Projesi” Tamamlandı!. Retrieved June 29, 2024, from https://gte.com.tr/eco-industrial-park-transition-in-izmir-green-iaoiz-project-has-been-completed/

GTE. (2024) Exploring Eskisehir Industrial Symbiosis (ES) possibilities. Retrieved June 29, 2024, from https://gte.com.tr/en/exploring-eskisehir-industrial-symbiosis-es-possibilities/

Hakeem, F., & Kim, J. (2020). Cradle-to-Cradle Denim: Fringed Dress and Poncho Design. ITAA Proceedings, 77.

Harfeldt-Berg, L., & Harfeldt-Berg, M. (2023). Connecting organizational context to environmental sustainability initiatives and industrial symbiosis: Empirical results and case analysis. Sustainable Production and Consumption, 40, 210-219. https://doi.org/10.1016/j.spc.2023.06.023

Hein, A. M., Jankovic, M., Feng, W., Farel, R., Yune, J. H., & Yannou, B. (2017). Stakeholder power in industrial symbioses: A stakeholder value network approach. Journal of cleaner production, 148, 923-933.

Henriques J, Ferrão P, Castro R, Azevedo J. Industrial Symbiosis: A Sectoral Analysis on Enablers and Barriers. Sustainability. 2021; 13(4):1723. https://doi.org/10.3390/su13041723

Herczeg, G., Akkerman, R., & Hauschild, M. (2018). Supply chain collaboration in industrial symbiosis networks. Journal of Cleaner Production, 171, 1058-1067. https://doi.org/10.1016/j.jclepro.2017.10.046

Holgado, M., Aminoff, A., & Tenhunen, J. (2018). Value stream mapping as a tool for identifying improvement potentials in sustainable supply chains. International Journal of Production Research, 56(1-2), 88-105.

Holgado, M., Benedetti, M., Evans, S., Baptista, A. J., Lourenço, E. J. 2018. "Industrial symbiosis implementation by leveraging on process efficiency methodologies", Procedia CIRP, 69, 872–877.

Hopewell, J., Dvorak, R., Kosior, E. 2009. "Plastics recycling: challenges and opportunities." Philos Trans R Soc Lond B Biol Sci., 364(1526):2115-2126.

International Synergies Ltd. (2019). A roadmap for a national industrial symbiosis programme for Turkey. International Synergies Ltd.

Ismail, Y. 2020. “Potential Benefit of Industrial Symbiosis using Life Cycle Assessment”, J. Phys.: Conf. Ser., 1625 (012054)

Istrate, I.-R., Juan, R., Martin-Gamboa, M., Domínguez, C., García-Muñoz, R. A., & Dufour, J. (2021). Environmental life cycle assessment of the incorporation of recycled high-density polyethylene to polyethylene pipe grade resins. Journal of Cleaner Production, 319, 128580. https://doi.org/10.1016/j.jclepro.2021.128580

Jacobsen, N. (2006). Industrial symbiosis in kalundborg, denmark: a quantitative assessment of economic and environmental aspects. Journal of Industrial Ecology, 10(1-2), 239-255.

Jacobsen, N. (2006). Industrial symbiosis in kalundborg, denmark: a quantitative assessment of economic and environmental aspects. Journal of Industrial Ecology, 10(1-2), 239-255.

Jafari, A., & Sadeghian, P. (2022, May). Applications of Recycled Gypsum from Waste Drywalls in the Construction Industry: A Review. In Canadian Society of Civil Engineering Annual Conference (pp. 817-832). Cham: Springer Nature Switzerland.

Kalumba, D., Chebet, F.C. 2023. “Utilisation of polyethylene (plastic) shopping bags waste for soil improvement in sandy soils”, 18th International Conference on Soil Mechanics and Geotechnical Engineering (Paris), 3223-3226.

Kandemir, K., Piskin, E., Xiao, J., Tomaş, M., & Capanoglu, E. 2022. Fruit juice industry wastes as a source of bioactives. Journal of Agricultural and Food Chemistry, 70(23), 6805-6832

Khan, J. G., Gadekar, S. S., Dalu, R. S. 2014. “Defects in Extrusion Process and Their Impact on Product Quality”. International Journal of Mechanical Engineering & Robotics Research, 3(3), 187-194.

Kılıçaslan, İ., Kaya, D., Sapmaz, S. 2012. “Waste heat recovery in galvanizing industry”, JESTECH, 15(3), 135-139.

Kim, J., Park, K., Hwang, Y., & Park, I. (2009). Sustainable manufacturing: a case study of the forklift painting process. International Journal of Production Research, 48(10), 3061–3078. https://doi.org/10.1080/00207540902791785

Kim, Y., Mosier, N. S., Hendrickson, R., Ezeji, T., Blaschek, H., Dien, B. & Ladisch, M. R. (2008). Composition of corn dry-grind ethanol by-products: DDGS, wet cake, and thin stillage. Bioresource Technology, 99(12), 5165-5176. doi:10.1016/j.biortech.2007.09.028.

Kooduvalli, K., Vaidya, U., Ozcan, S. 2020. Life Cycle Assessment of Compostable Coffee Pods: A US University Based Case Study. Scientific Reports, 10, Article 9158.

Kozak M, (2010)" Tekstil Atıkların Yapı Malzemesi Olarak Kullanım Alanlarının Araştırılması" Yapı Teknolojileri Elektronik Dergisi, 6(1) 62-70

Lawal, M., Wan Alwi, S. R., Manan, Z. A., & Ho, W. S. (2021). Industrial symbiosis tools—a review. Journal of Cleaner Production, 280, 124327. https://doi.org/10.1016/j.jclepro.2020.124327

Lee, Y. J., Kim, S. D., Hong, J. P., Cho, H. G., & Yoon, S. M. (2016). Industrial network analysis using inter-firm transaction data. Indian Journal of Science and Technology, 9(26).

Leigh, M. and Xiao-hong, L. (2015). Industrial ecology, industrial symbiosis and supply chain environmental sustainability: a case study of a large uk distributor. Journal of Cleaner Production, 106, 632-643. https://doi.org/10.1016/j.jclepro.2014.09.022

Li, R., Miao, C., Wei, T. 2020. "Experimental study on corrosion behaviour of galvanized steel wires under stress", Corrosion Engineering Science and Technology the International Journal of Corrosion Processes and Corrosion Control, 55(8), 622-633.

Liu, K., Wang, X., & Yan, Y. (2022). Network analysis of industrial symbiosis in chemical industrial parks: a case study of nanjing jiangbei new materials high-tech park. Sustainability, 14(3), 1381. https://doi.org/10.3390/su14031381

Liu, Z., Hansen, D. W., & Chen, Z. (2023). Leveraging digital twins to support industrial symbiosis networks: A case study in the norwegian wood supply chain collaboration. Sustainability, 15(3), 2647.

Lombardi, D.R. Laybourn, P. 2012. Redefining Industrial Symbiosis. Journal of Industrial Ecology, 16, 28-37.

Mahmood, A. 2020. “Smart lean in ring spinning—a case study to improve performance of yarn manufacturing process”, The Journal of The Textile Institute, 111:11, 1681-1696,

Marconi, M., Gregori, F., Germani, M., Papetti, A.,and Favi, C. (2018). An approach to favor industrial symbiosis: the case of waste electrical and electronic equipment. Procedia Manufacturing, 21, 502-509.

Marinelli, S., Butturi, M. A., Rimini, B., Gamberini, R., & Sellitto, M. A. (2021). Estimating the Circularity Performance of an Emerging Industrial Symbiosis Network: The Case of Recycled Plastic Fibers in Reinforced Concrete. *Sustainability*, *13*(18), 10257. https://doi.org/10.3390/su131810257

Maspul, K. A., & Moga, K. N. 2021. Biodegradable Coffee Bag Use in Increasing the Coffee Roastery Sustainability in the United Arab Emirates. Academia Letters, Article 3826.

Mila G., Primasari, B., Aziz, R. 2021 Application of life cycle assessment (LCA) on green tea product (case study in the X company), IOP Conference Series: Materials Science and Engineering, vol. 1041, no. (article no: 012025).

Mısır, A., & Arıkan, O. (2022). Avrupa Birliği (AB) ve Türkiye’de Döngüsel Ekonomi ve Sıfır Atık Yönetimi. Çevre İklim Ve Sürdürülebilirlik, 23(1), 69-78.

Mısır, G., & Arıkan, Y. (2022). Implementation of the European Green Deal in Turkey: Opportunities and Challenges. Journal of Environmental Policy & Planning, 24(3), 389-402.

Morales, M. and Diemer, A. (2019). Industrial symbiosis dynamics, a strategy to accomplish complex analysis: the dunkirk case study. Sustainability, 11(7), 1971. https://doi.org/10.3390/su11071971

Mulrow, J. S., Derrible, S., Ashton, W. S., Chopra, S. S. 2017. "Industrial Symbiosis at the Facility Scale." Journal of Industrial Ecology, 21(3), 559-571

Muñoz-Villamizar, A., Santos, J., García-Sabater, J., Lleó, Á., Grau, P. 2019. "Green value stream mapping approach to improving productivity and environmental performance", International Journal of Productivity and Performance Management, 68(3), 608-625.

Nagy, A., & Kuti, R. 2016. "The Environmental Impact of Plastic Waste Incineration." Academic and Applied Research in Military and Public Management Science, 15(3), 231-237

Neves A, Godina R, G. Azevedo S, Pimentel C, C.O. Matias J. (2019). The Potential of Industrial Symbiosis: Case Analysis and Main Drivers and Barriers to Its Implementation. Sustainability.11(24):7095.

Ongondo, F. O., Williams, I. D., & Cherrett, T. J. (2021). A review of circular economy studies in developed countries and its potential adoption in developing countries. Waste Management, 119, 2-9. https://doi.org/10.1016/j.wasman.2021.05.040

OSBÜK (Organize Sanayi Bölgeleri Üst Kuruluşu). (2024) Yeşil OSB Sertifikasyonu İlk Kez OSBÜK Tarafından Verilecek. OSBÜK. Retrieved June 29, 2024, from https://osbuk.org/view/haber/goster.php?Guid=2821a6d8-3552-11ef-a1d3-0050568cba34

Park, J., Duque-Hernández, J., & Díaz-Posada, N. (2018). Facilitating business collaborations for industrial symbiosis: the pilot experience of the sustainable industrial network program in colombia. Sustainability, 10(10), 3637.

Parvathikumar, G., Babu Balachandran, G., Sahadevan, B. 2023. "Performance of green concrete paving block imbibed with industrial scrap steel mill scale for sustainable construction", Materials Research Express, 10(3), 035505.

Patricio, J., Kalmykova, Y., Rosado, L., Cohen, J., Westin, A., & Gil, J. (2022). Method for identifying industrial symbiosis opportunities. Resources, Conservation and Recycling, 185, 106437. https://doi.org/10.1016/j.resconrec.2022.106437

Patricio, J., Kalmykova, Y., Rosado, L., Cohen, J., Westin, A., Gil, J. 2022. “Method for identifying industrial symbiosis opportunities”, Resources, Conservation and Recycling, 185, 106437.

Paul, R. (2015). Denim and jeans: an overview. In Denim. Hohenstein Institut für Textilinnovation gGmbH, Boennigheim, Germany. https://doi.org/10.1016/B978-0-85709-843-6.00001-9

Paula, F., Guiné, R., Cruz-Lopes, L., Duarte, A., Fragata, A., & Reis, M. 2015. Effects of pre- and post-harvest factors on the selected elements contents in fruit juices. Czech Journal of Food Sciences, 33(4), 384-391.

Pawar, S., Siddheshwar, R. 2017. “Waste Heat Recovery on Hot Dip Galvanizing Furnace Waste Heat Recovery on Hot Dip Galvanizing Furnace (Design & Manufacturing)”, International Engineering Research Journal, Special Edition PGCON-MECH-2.

Pekşen, A., & Yakupoğlu, G. 2009. Tea waste as a supplement for the cultivation of Ganoderma lucidum. World Journal of Microbiology and Biotechnology, 25(4), 611-618.

Rentería Núñez, G., & Perez-Castillo, D. (2023). Business models for industrial symbiosis: A literature review. Sustainability, 15(9142). https://doi.org/10.3390/su15129142

Ruban, A., 2012. “Life Cycle Assessment of Plastic Bag Production”. Master thesis in Sustainable Development at Uppsala University.

Ruggeri, R. (2022). AB Üye Devlet Politikaları ve Döngüsel Ekonomiyi İlerletme Önlemleri: İtalya’da Döngüsel Ekonomi Stratejisinin Geliştirilmesi. Sardunya Bölgesel Çevre Koruma Ajansı (İTALYA). Türkiye'nin Döngüsel Ekonomiye Geçiş Potansiyelinin Değerlendirilmesi için Teknik Destek.

Rujnic-Sokele, M., Baric, G. 2014. “Life Cycle of Polyethylene Bag”, Annals of Faculty Engineering Hunedoara” 12(1), 41-48.

S. Menato, S. Carimati, E. Montini, P. Innocenti, L. Canetta and M. Sorlini, "Challenges for the adoption of industrial symbiosis approaches within industrial agglomerations," 2017 International Conference on Engineering, Technology and Innovation (ICE/ITMC), Madeira, Portugal, 2017, pp. 1293-1299,

Sangwan, K. S., & Bhakar, V. (2017). Life cycle analysis of HDPE Pipe Manufacturing – A Case Study from an Indian Industry. Procedia CIRP, 61, 738-743. https://doi.org/10.1016/j.procir.2016.11.193

Schlüter, L., Mortensen, L., Drustrup, R., Gjerding, A., Kørnøv, L., & Lyhne, I. (2022). Uncovering the role of the industrial symbiosis facilitator in literature and practice in nordic countries: an action-skill framework. Journal of Cleaner Production, 379, 134652. https://doi.org/10.1016/j.jclepro.2022.134652

Sonel, S. A., Gürel, B., & Demirci, M. (2023). Enhancing Industrial Symbiosis in Turkey: Policy and Practice. Sustainability, 15(5), 2450.

Song, X., Geng, Y., Dong, H., & Chen, W. (2018). Social network analysis on industrial symbiosis: A case of Gujiao eco-industrial park. Journal of Cleaner Production, 193, 414-423.

Steven, E., Chin, J., Nadlifatin, R. 2022. Implementation of Lead Time Improvement in the Cutting Production Process using Clustering Data Mining and Lean Manufacturing. KnE Social Sciences, 7(10), 382-391.

Steven, M., et al. (2022). Lean Production and Value Stream Mapping. Journal of Industrial Engineering, 45(2), 122-134.

Sukdeo, N., Ramdass, K., & Petja, G. (2020). Application of 7S methodology: A systematic approach in a bucket manufacturing organisation. South African Journal of Industrial Engineering, 31(4), 178-193.

Suzuki LL, Cunha ILC, Teixeira CE, Kulay L, dos Santos MT. 2023; The Modeling and Simulation of Waste Recovery Processes Applied to the Orange Juice Industry. Sustainability. 15(21):15225.

Tagne, R. F. T., Tchuifon, D. R. T., Ateba, F. R., & Azambou, I. C. 2023. Environmental sustainability of Cameroon tea production: an LCA study. Sustainable Food Technology, 1, 116-125.

Takacova, Z., Hluchánová, B.,Trpčevská, J. 2010. “Leaching of zinc from zinc ash originating from hot-dip galvanizing”, Metall., 64, 600-602.

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.

Tirsan/Kässbohrer. (2016). Power & Free Conveyor for Semi-Trailer Production. JOT International Surface Technology, 1, 50-51.

United Nations Industrial Development Organization. (2024) Eco-industrial parks. Retrieved June 29, 2024, from https://www.unido.org/our-focus-safeguarding-environment-resource-efficient-and-low-carbon-industrial-production/eco-industrial-parks

United Nations. (2024)Sustainable Development Goals. Retrieved June 29, 2024, from https://sdgs.un.org/goals

Ute, T. B., Celik, P., & Uzumcu, M. B. (2019). Utilization of cotton spinning mill wastes in yarn production. Textile industry and environment, 85, 13-7.

Vareltzis, P., Gargali, I., Kiroglou, S., & Zeleskidou, M. 2020. Production of instant coffee from cold brewed coffee; process characteristics and optimization. Food Science and Applied Biotechnology, 3(1), 39-46

Wahrlich, J., & Simioni, F. J. (2019). Industrial symbiosis in the forestry sector: A case study in southern Brazil. Journal of Industrial Ecology, 23(6), 1470-1482

Wang, R., & Haller, P. (2022). Applications of wood ash as a construction material in civil engineering: A review. Biomass Conversion and Biorefinery. https://doi.org/10.1007/s13399-022-03580-0

Wei, W., Larrey-Lassalle, P., Faure, T., Dumoulin, N., Roux, P., & Mathias, J.-D. (2015). How to conduct a proper sensitivity analysis in life cycle assessment: Taking into account correlations within LCI data and interactions within the LCA calculation model. Environmental Science & Technology, 49(1), 377-385. https://doi.org/10.1021/es502128k

World Bank. (2021). Circular Economy in Industrial Parks: Technologies for Competitiveness. International Bank for Reconstruction and Development / The World Bank.

World Bank. (2021). Circular Economy in Industrial Parks: Technologies for Competitiveness. International Bank for Reconstruction and Development / The World Bank. https://openknowledge.worldbank.org/handle/10986/35110

Xiong, S., Huang, X., Xu, W., Guo, X., Liu, S. 2021. "Corrosion and protection of galvanized steel in vegetation-growing concrete (II): Coating protection", Asia-Pac J Chem Eng., 16, e2702.

Xu, L., Zhang, W., & Zhao, X. (2023). Improved eco-friendly packaging for sustainable tea products. Journal of Material Cycles and Waste Management.

Xu, Q., Hu, K., Wang, X., Wang, D., & Knudsen, M. T. 2019. Carbon footprint and primary energy demand of organic tea in China using a life cycle assessment approach. Journal of Cleaner Production, 233, 782-792.

Yang, M., Chen, L., Wang, J., Msigwa, G., Osman, A. I., Fawzy, S., Rooney, D. W., & Yap, P.-S. (2023). Circular economy strategies for combating climate change and other environmental issues. Environmental Chemistry Letters, 21(1), 55-80. https://doi.org/10.1007/s10311-022-01499-6

Yeldan E., (2021), European Green Deal and Turkey, https://pmrturkiye.csb.gov.tr/wp-content/uploads/2021/02/The-European-Green-Deal-and-Turkey-Erinc-Yeldan.pdf

Yılmaz, F. (2022). Enerji Yönetimi ve Türkiye: Avrupa Yeşil Mutabakatı Çerçevesinde Bir Değerlendirme. Akademia Doğa Ve İnsan Bilimleri Dergisi, 8(1), 19-37.

Zhang, Y., Duan, S., Li, J., Shao, S., Wang, W., & Zhang, S. (2017). Life cycle assessment of industrial symbiosis in Songmudao chemical industrial park, Dalian, China. Journal of Cleaner Production, 158, 192–199. https://doi.org/10.1016/j.jclepro.2017.04.119

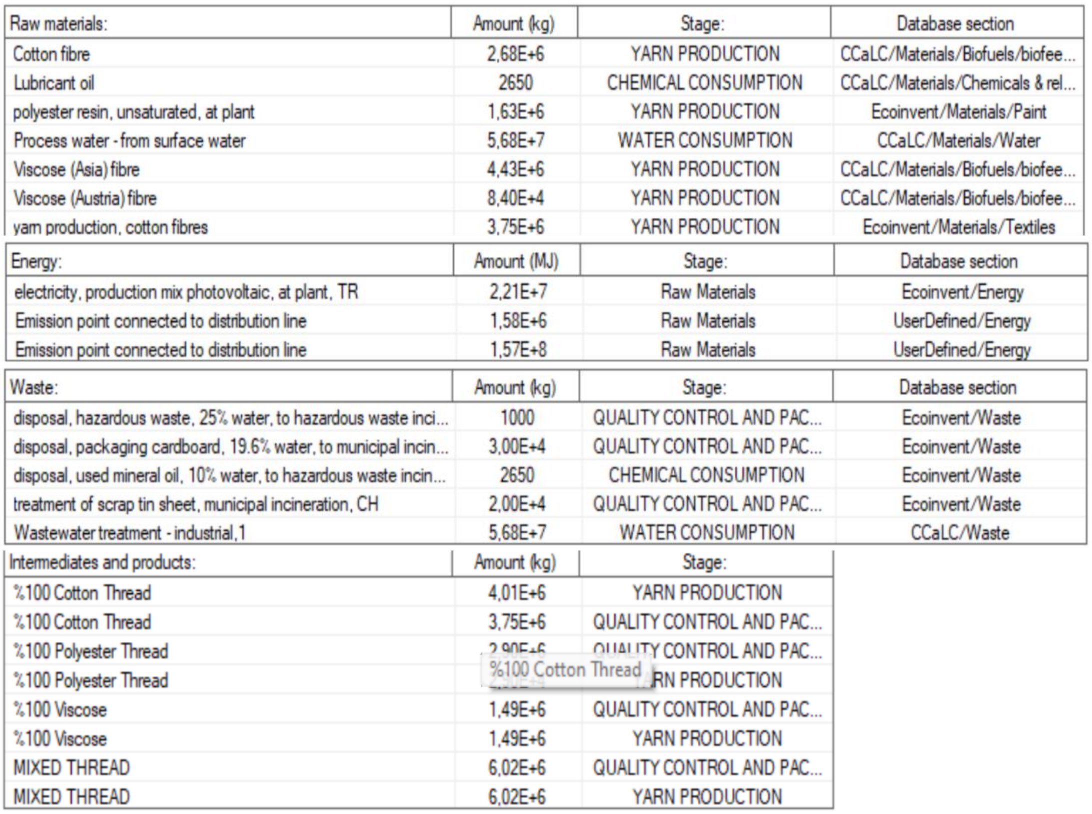
Zhang, Y., Zheng, H., Chen, B., Su, M., & Liu, G. (2014). A review of industrial symbiosis research: Theory and methodology. Frontiers of Earth Science, 9(1), 91-104.

Zhao, Y., Su, B., Fan, X., Yuan, Y., Zhu, Y. 2023. “Corrosion fatigue degradation characteristics of galvanized and galfan high-strength steel wire”, Materials, 16, 708.

APPENDIX A

LIFE CYCLE INVENTORY AND MULTIPLE ENVIRONMENTAL IMPACT OF THE FACILITY (NACE: 25.61.01)

Table A.1. Life Cycle Inventory of the Facility (NACE: 25.61.01)



Raw materials:	Amount (kg)	Stage:	Database section
Cotton fibre	2,68E+6	YARN PRODUCTION	CCaLC/Materials/Biofuels/biofee...
Lubricant oil	2650	CHEMICAL CONSUMPTION	CCaLC/Materials/Chemicals & rel...
polyester resin, unsaturated, at plant	1,63E+6	YARN PRODUCTION	Ecoinvent/Materials/Paint
Process water - from surface water	5,68E+7	WATER CONSUMPTION	CCaLC/Materials/Water
Viscose (Asia) fibre	4,43E+6	YARN PRODUCTION	CCaLC/Materials/Biofuels/biofee...
Viscose (Austria) fibre	8,40E+4	YARN PRODUCTION	CCaLC/Materials/Biofuels/biofee...
yarn production, cotton fibres	3,75E+6	YARN PRODUCTION	Ecoinvent/Materials/Textiles

Energy:	Amount (MJ)	Stage:	Database section
electricity, production mix photovoltaic, at plant, TR	2,21E+7	Raw Materials	Ecoinvent/Energy
Emission point connected to distribution line	1,58E+6	Raw Materials	UserDefined/Energy
Emission point connected to distribution line	1,57E+8	Raw Materials	UserDefined/Energy

Waste:	Amount (kg)	Stage:	Database section
disposal, hazardous waste, 25% water, to hazardous waste inci...	1000	QUALITY CONTROL AND PAC...	Ecoinvent/Waste
disposal, packaging cardboard, 19.6% water, to municipal incin...	3,00E+4	QUALITY CONTROL AND PAC...	Ecoinvent/Waste
disposal, used mineral oil, 10% water, to hazardous waste incin...	2650	CHEMICAL CONSUMPTION	Ecoinvent/Waste
treatment of scrap tin sheet, municipal incineration, CH	2,00E+4	QUALITY CONTROL AND PAC...	Ecoinvent/Waste
Wastewater treatment - industrial,1	5,68E+7	WATER CONSUMPTION	CCaLC/Waste

Intermediates and products:	Amount (kg)	Stage:
%100 Cotton Thread	4,01E+6	YARN PRODUCTION
%100 Cotton Thread	3,75E+6	QUALITY CONTROL AND PAC...
%100 Polyester Thread	2,90E+6	QUALITY CONTROL AND PAC...
%100 Polyester Thread	[illegible]	RN PRODUCTION
%100 Viscose	1,49E+6	QUALITY CONTROL AND PAC...
%100 Viscose	1,49E+6	YARN PRODUCTION
MIXED THREAD	6,02E+6	QUALITY CONTROL AND PAC...
MIXED THREAD	6,02E+6	YARN PRODUCTION

%100 Cotton Thread

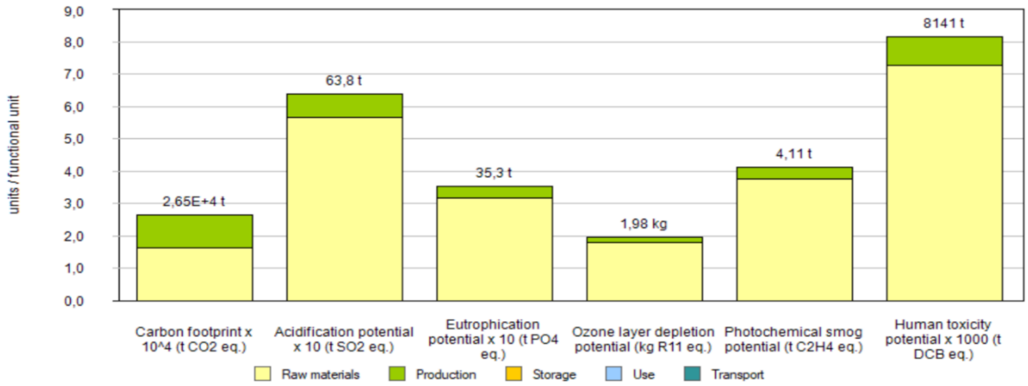
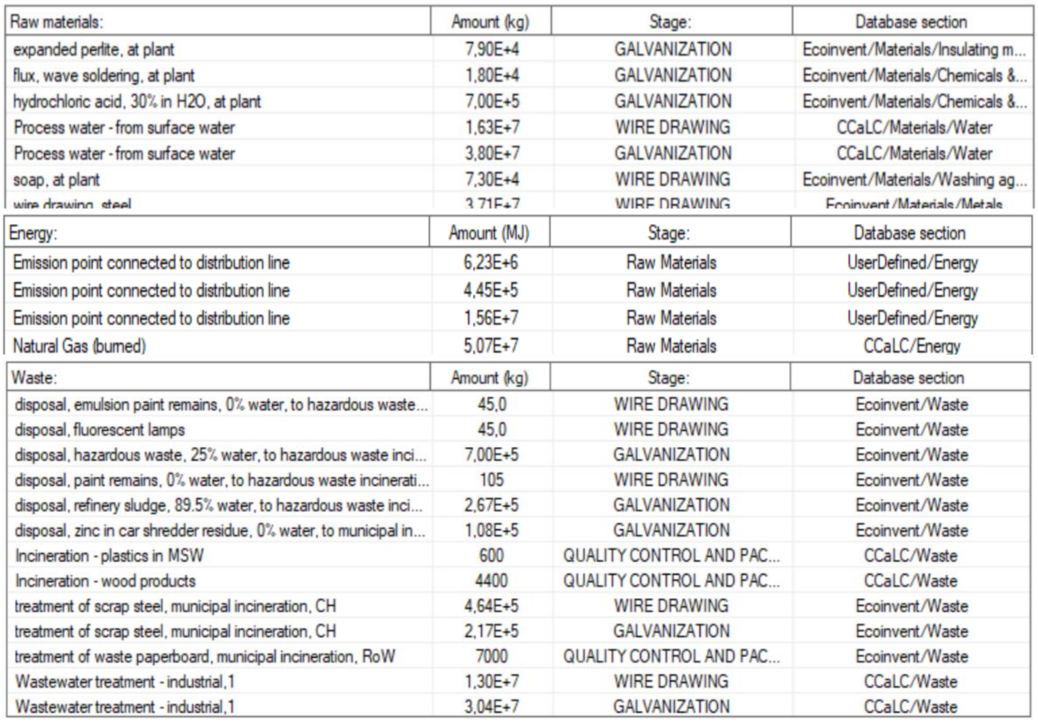


Figure A.1. Multiple Environmental Impact of the Facility (NACE: 25.61.01)

APPENDIX B

LIFE CYCLE INVENTORY AND MULTIPLE ENVIRONMENTAL IMPACT OF THE FACILITY (NACE: 13.10.05)

Table A.2. Life Cycle Inventory of the Facility (NACE: 13.10.05)



Raw materials:	Amount (kg)	Stage:	Database section
expanded perlite, at plant	7,90E+4	GALVANIZATION	Ecoinvent/Materials/Insulating m...
flux, wave soldering, at plant	1,80E+4	GALVANIZATION	Ecoinvent/Materials/Chemicals &...
hydrochloric acid, 30% in H2O, at plant	7,00E+5	GALVANIZATION	Ecoinvent/Materials/Chemicals &...
Process water - from surface water	1,63E+7	WIRE DRAWING	CCaLC/Materials/Water
Process water - from surface water	3,80E+7	GALVANIZATION	CCaLC/Materials/Water
soap, at plant	7,30E+4	WIRE DRAWING	Ecoinvent/Materials/Washing ag...
wire drawing, steel	3,71E+7	WIRE DRAWING	Ecoinvent/Materials/Metals

Energy:	Amount (MJ)	Stage:	Database section
Emission point connected to distribution line	6,23E+6	Raw Materials	UserDefined/Energy
Emission point connected to distribution line	4,45E+5	Raw Materials	UserDefined/Energy
Emission point connected to distribution line	1,56E+7	Raw Materials	UserDefined/Energy
Natural Gas (burned)	5,07E+7	Raw Materials	CCaLC/Energy

Waste:	Amount (kg)	Stage:	Database section
disposal, emulsion paint remains, 0% water, to hazardous waste...	45,0	WIRE DRAWING	Ecoinvent/Waste
disposal, fluorescent lamps	45,0	WIRE DRAWING	Ecoinvent/Waste
disposal, hazardous waste, 25% water, to hazardous waste inci...	7,00E+5	GALVANIZATION	Ecoinvent/Waste
disposal, paint remains, 0% water, to hazardous waste incinerati...	105	WIRE DRAWING	Ecoinvent/Waste
disposal, refinery sludge, 89.5% water, to hazardous waste inci...	2,67E+5	GALVANIZATION	Ecoinvent/Waste
disposal, zinc in car shredder residue, 0% water, to municipal in...	1,08E+5	GALVANIZATION	Ecoinvent/Waste
Incineration - plastics in MSW	600	QUALITY CONTROL AND PAC...	CCaLC/Waste
Incineration - wood products	4400	QUALITY CONTROL AND PAC...	CCaLC/Waste
treatment of scrap steel, municipal incineration, CH	4,64E+5	WIRE DRAWING	Ecoinvent/Waste
treatment of scrap steel, municipal incineration, CH	2,17E+5	GALVANIZATION	Ecoinvent/Waste
treatment of waste paperboard, municipal incineration, RoW	7000	QUALITY CONTROL AND PAC...	Ecoinvent/Waste
Wastewater treatment - industrial, 1	1,30E+7	WIRE DRAWING	CCaLC/Waste
Wastewater treatment - industrial, 1	3,04E+7	GALVANIZATION	CCaLC/Waste

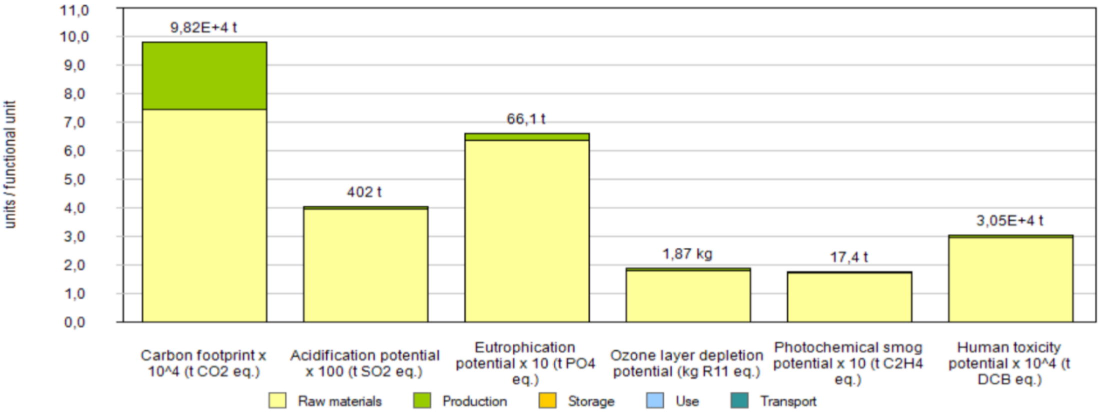


Figure A.1. Multiple Environmental Impact of the Facility (NACE: 13.10.05)