REPUBLIC OF TURKEY
ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY

INSTITUTE OF GRADUATE STUDIES
DEPARTMENT OF INDUSTRIAL ENGINEERING

PROCESS IMPROVEMENT WITHIN THE SCOPE OF GREEN INDUSTRY COMPLIANCE IN DYEING PROCESS IN TEXTILE FACTORIES

KÜBRA YILMAZ
MASTER OF SCIENCE

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ABSTRACT

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The textile industry, a substantial component of the global economy, holds significant importance due to its environmental impacts. Particularly, the use of water and chemicals during dyeing processes raises concerns in the context of climate change and environmental sustainability. Hence, it is crucial from both environmental and economic standpoints for textile factories to adopt green industry standards, particularly in their dyeing operations. Adapting to the green industry aims to reduce water and energy consumption in textile dyeing processes, minimize waste, and decrease the carbon footprint. This approach has become crucial in achieving sustainability in textiles following the signing of the Paris Climate Agreement. Important elements of this transformation include the reuse of washing waters used in the dyeing process, the recycling of wastewater, and the enhancement of energy efficiency through necessary methodological and equipment changes.

This study analyzes the energy, labor, production, and consumption data, maintained in Excel format since 2011, for a textile factory with four branches located in the Adana Organized Industrial Zone. Among these factories, the one designated as UT1, which has the highest average energy and water consumption compared to the other three branches, was selected. In recent years, the use of artificial intelligence and machine learning technologies in predicting industrial processes has been increasingly observed. The data were analyzed using LSTM (Long Short-Term Memory) and ANN (Artificial Neural Networks) forecasting methods. Particularly, the LSTM algorithms, which provided the most accurate results, enabled advanced forecasting of electricity consumption in dyeing processes for future years. The electricity consumption forecasting results have been an essential guide in planning strategic initiatives to enhance factory efficiency. Following improvement efforts aimed at reducing energy consumption and lowering the carbon footprint, significant optimizations in processes and layouts have been made at specific bottleneck points within the facility. These improvements have led to savings in labor, time, and space, and have reduced unit production costs. Additionally, the likelihood of workplace accidents has been reduced to a preventable level.

Key Words: Carbon Footprint, Climate Change, LSTM, Process Improvement, Sustainability

ÖZET

TEKSTİL FABRİKALARINDA BOYAMA PROSESİNDE YEŞİL ENDÜSTRİYE UYUM KAPSAMINDA SÜREÇ İYİLEŞTİRME

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Nisan 2024, 71 Sayfa
Tekstil endüstrisi, küresel ekonominin önemli bir parçası olmakla birlikte, çevresel etkileri bakımından da dikkate değer bir sektördür. Özellikle boyama işlemleri sırasında kullanılan su ve kimyasallar, iklim değişikliği ve çevresel sürdürülebilirlik bağlamında endişeleri artırmaktadır. Bu nedenle, tekstil fabrikalarının özellikle boyama proseslerinde yeşil endüstriye uyum sağlaması, hem çevresel hem de ekonomik anlamda büyük önem taşımaktadır. Yeşil sanayiye uyum, tekstil boyama proseslerinde su ve enerji kullanımını azaltmayı, atık miktarını minimize etmeyi ve karbon ayak izini düşürmeyi hedeflemektedir. Bu yaklaşım, Paris İklim Anlaşmasının imzalanması ile tekstilde sürdürülebilirliğin sağlanması için büyük önem taşımaktadır. Boyama prosesinde kullanılan yıkama sularının tekrar kullanımı, atık suyun arıtılarak yeniden kullanımı ,enerji verimliliğinin gerekli yöntem veya ekipman değişikliği ile artırılması, bu dönüşümün önemli unsurları arasında yer almaktadır.

Bu çalışma Adana Organize Sanayi Bölgesinde yer alan 4 şubesi olan tekstil fabrikasının 2011 yılından bu yana, excel formatı ile tutulan enerji, işçilik, üretim ve tüketim verileri işlenmiştir. Bu fabrikalar arasında, enerji ve su tüketim ortalaması diğer üç şubeye göre en yüksek olan UT1 numaralı fabrika seçilmiştir. Son yıllarda, yapay zeka ve makine öğrenmesi teknolojilerinin endüstriyel süreçlerin tahminlemesinde kullanılmasının giderek arttığı gözlemlenmektedir.Veriler LSTM (Uzun Kısa Süreli Bellek) ve ANN(Yapay Sinir Ağları) tahminleme yöntemi ile analiz edilmiştir. Özellikle, gerçeğe en yakın sonuçları veren LSTM algoritmaları sayesinde, ileri tahminleme yaparak boyama proseslerinde elektrik tüketiminin gelecek yılları tahmin etme yetisi sağlanmıştır. Elektrik tüketimi tahmin sonuçları, fabrikanın verimliliğini artıracak stratejik çalışmaların planlanmasında önemli bir rehber olmuştur. Enerji tüketiminin azaltılması ve karbon ayak izinin düşürülmesine yönelik iyileştirme çalışmaları sonucunda, süreç ve yerleşim optimizasyonu ile tesisin belirli darboğaz noktalarında önemli iyileştirmeler gerçekleştirilmiştir. Bu iyileştirmeler, işçilik, zaman ve alan tasarrufu sağlamış, birim üretim maliyetlerini düşürmüştür. Ayrıca, iş kazalarının meydana gelme olasılığı önlenebilir seviyeye getirilmiştir.

Anahtar Kelimeler: İklim Değişikliği, Süreç İyileştirme, Sürdürülebilirlik, LSTM, Karbon Ayak Izi

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I want to thank my husband and mother for the support they gave me.

LIST OF CONTENT

1. INTRODUCTION

1.1. Climate Change: Its Significance and Impacts on the Textile Industry

Climate change represents one of the most pressing environmental challenges facing our planet, with widespread impacts observed globally. These effects include severe storms, droughts, extreme precipitation, rising sea levels, disruptions in ecosystems, and loss of biodiversity. Extreme weather events can affect agricultural production, jeopardize food security, and diminish water resources. Rising sea levels pose a significant threat, particularly to low-lying islands and coastal areas. Changes in ecosystems impact the habitats of various animal and plant species, leading to a loss of biodiversity. Additionally, climate change has direct and indirect impacts on human health. Heatwaves and air pollution can lead to respiratory issues and other health problems. Alterations in food and water sources can result in nutritional deficiencies and diseases. Moreover, climate change significantly affects social and economic systems, leading to economic losses, migration, security issues, and social inequalities. Therefore, combating climate change is not only an environmental imperative but also a social and economic necessity.

The textile industry is among the sectors most affected by climate change. It influences both production processes and supply chains. The effects of climate change are particularly evident in areas such as raw material production, energy consumption, and waste management. For instance, the production of natural fibers like cotton is dependent on water resources and specific climatic conditions. Droughts and extreme weather events caused by climate change negatively impact the production of these fibers, consequently affecting supply chains. This can lead to fluctuations in raw material prices and issues in supply reliability. Additionally, rising temperatures due to climate change can reduce the quality of fibers, thereby decreasing the overall quality of textile products. The textile sector is known for its intensive energy and water usage. Climate change, by reducing water availability and increasing energy costs, escalates production costs. Considering these factors, global environmental regulations aimed at combating climate change are increasing. This necessitates the industry, including textiles, to shift towards more sustainable production methods and materials. The primary objective of this study was to forecast future electricity consumption using LSTM and ANN methods. In the subsequent phase, efficiency measures were implemented within the factory to optimize electricity usage, thereby promoting the more efficient use of limited energy resources. Specific projects were initiated to reduce the electricity consumption per kilogram of yarn. Consequently, these efforts aim to mitigate the adverse effects of climate change by reducing the consumption of limited energy and water resources..

1.2. The Carbon Emission in the Textile Industry and Its Significance

In Turkey, the carbon and water footprints of the industrial sector are of significant importance in terms of the country's economic growth and sustainability goals. In terms of carbon footprint, Turkey's industrial sector, particularly in energy-intensive industries such as steel, cement, and petrochemicals, is a major contributor to substantial carbon emissions. The combustion of fossil fuels used in these sectors leads to the release of large amounts of carbon dioxide (CO_2) and other greenhouse gasses into the atmosphere. Turkey's participation in international environmental agreements like the Kyoto Protocol and the Paris Climate Agreement necessitates taking significant steps to reduce these emissions. In the sector's fight against climate change, technological innovations that increase energy efficiency and the use of renewable energy sources in production processes are gaining importance. For instance, investing in renewable energy sources like solar and wind energy can reduce the carbon footprint in this area.

Particular industries such as textiles, food processing, and mining, has a notable impact on the country's water footprint due to their high water consumption. In terms of industry, water consumption is of great importance both for the water used in production and for the management of wastewater generated after production. The growing significance of water management strategies is underscored by Türkiye's constrained local water resources and the compounded impacts of climate change

From a sustainability perspective, Turkey's industrial sector must take steps to reduce both its carbon and water footprints. This includes various strategies such as increasing energy efficiency, transitioning to renewable energy sources, using water-saving technologies, and improving wastewater management practices. Additionally, adopting eco-friendly technologies and innovative approaches will contribute to Turkey's continued economic growth and achievement of environmental sustainability goals.

The textile industry often leads to significant carbon footprints due to dyeing and drying processes that typically require high temperatures, as well as substantial water and energy consumption. Dye houses represent one of the most energy-intensive and chemical-consuming stages of textile production. During these processes, significant amounts of carbon emissions are generated from various energy sources (e.g., fossil fuels and electricity) and chemical processes.

Additionally, the production and transportation of chemicals used during dyeing processes also contribute to carbon emissions. For instance, the energy and raw materials utilized in the production of synthetic dyes can lead to increased carbon footprint. The transportation and storage of these chemicals further result in additional emissions.

Therefore, reducing the carbon footprint is of critical importance for sustainability.In this context, utilizing renewable energy sources and implementing energy efficiency projects are crucial for reducing the carbon footprint of textile dyeing factories. Additionally,There is also a need for technological projects to enable reuse of water and waste. Moreover, using alternative dyeing methods and biodegradable dyes that are less harmful to the environment is important in this process. Additionally, optimizing production processes to reduce energy consumption, establishing systems to recycle and reuse water, and treating wastewater for possible reuse is of great significance for the textile industry. In this process, training necessary employees, specializing in this area, and conducting necessary project and improvement works are required. In this period, producing high-value, sustainable products and using recycled raw materials in production are preferred by customers. Furthermore, changing climate conditions also push producers in this direction. Collaborating with universities and relevant companies specialized in this field can yield more effective results in sustainability.

Climate change also has significant impacts on the textile sector's waste management and product life cycle. Textile wastes often contain dyes and processed fibers with harmful chemicals. Proper management of these wastes can contribute to the environment and, consequently, to climate change. In this context, the adoption of sustainable waste management practices by the textile sector, and the development of recycling and reuse strategies, are important Hence, it is possible to reduce waste volume while ensuring a more efficient utilization of resources.

As sustainability and environmental awareness increase, such practices become critical for the future of the textile sector. The international community has made agreements like the Paris Climate Agreement and set sustainable development goals to tackle this global issue. Strategies to combat climate change include transitioning to renewable energy sources, increasing energy efficiency, conserving forests, and reducing greenhouse gas emissions. Every individual, community, and government plays a significant role in tackling this global issue.

1.3. Yarn Production and Dyeing Process in Textiles

The history of the yarn industry is considered a part of humanity's quest to produce clothing and express itself, with the foundations of yarn production being laid in prehistoric times. People created materials for protection using plant fibers, animal hairs, and even tree bark. This is acknowledged as the initial phase of yarn and textile production.

In ancient times, yarn production was predominantly manual, utilizing simple tools. During this period, yarn spinning was a vital skill for communities, and textile products often played significant roles in religious, social, and economic life. In Egypt, linen production, in India, cotton, and in China, silk production and processing were developed, each evolving unique techniques for handling these materials.

The emergence of trade routes such as the Silk Road enabled the interchange of yarn and textile products among various cultures, thereby transforming these commodities into highly prized trade goods. In this era, textile served not merely for practical applications but also functioned as indicators of luxury and prestige.

The Industrial Revolution was one of the most significant turning points in the transformation of the yarn sector. Beginning in the late 18th century in England, this period ushered in the mechanization of yarn and textile production. John Kay's invention of the 'flying shuttle' enabled faster weaving, while James Hargreaves' 'Spinning Jenny', Samuel Crompton's 'Spinning Mule', and Richard Arkwright's water-powered frames significantly increased the speed and volume of yarn production. These inventions shifted yarn production from homes to factories, transforming it into a large-scale industrial process. This mechanization led to a transformation in labor and production methods, transitioning many workers from manual labor to machine operation. Concurrently, this shift laid the groundwork for the rise of the working class and the formation of trade unions.

Throughout the 19th century, yarn production became an integral part of the economies of industrialized countries worldwide. As factories expanded and the workforce grew, issues of workers' rights and working conditions began to gain prominence. The yarn and textile industries became the driving forces of industrialization and economic growth in many countries.

In the 20th century, the yarn industry underwent a significant transformation with the discovery of synthetic fibers. Materials such as nylon, polyester, and acrylic revolutionized yarn production by providing alternatives to natural fibers. The development of these new materials during and after World War II became crucial for both civilian and military purposes.

In modern times, the yarn industry is shaped by high technology and innovation. The development of new materials like microfibers, nanotechnology, and bio-based fibers has led to more advanced and specialized products. Automation in production, sustainability, and recycling techniques have become more crucial, transforming global supply chains, production, and distribution processes.

Worldwide, the leading countries in yarn production and export are typically those with extensive textile industry infrastructures, rich natural resources, and/or advanced technologies. Certain countries stand out as prominent yarn producers and exporters. China, the global leader in yarn production and export, is renowned for its large-scale production capacity, easy access to raw material resources, and integrated textile industry. It generally leads in nearly every variety of yarn.

India ranks as the second-largest yarn producer and exporter globally, with a rich tradition in cotton yarn production and a significant history in textiles. The term 'Fabrics of India' originates from this notable heritage. Turkey, strategically located close to both Europe and Asia, is a strong producer of cotton and synthetic yarns, leveraging its geographical position for a strategic export advantage. The Turkish yarn industry is recognized for its modern and flexible production capacity and is a preferred source for the fast fashion sector due to its proximity to Europe. The United Kingdom has been the birthplace of major textile technologies. The United States holds a significant place in the history and technological advancement of yarn production. 'American Cotton' sets a global standard in cotton production, known for its standard quality and cleanliness. Even today, it remains one of the largest cotton producers. European countries like Italy, Germany, and Spain are recognized for producing high-quality and specialty yarns. Italy has gained worldwide fame for producing luxury yarns for the fashion industry. Germany specializes in technical textiles and functional yarns, while Spain is a strong player in various yarns and regenerated fibers. Beyond these nations, Asia-Pacific countries such as Pakistan, Vietnam, Indonesia, South Korea, and Taiwan also hold significant positions in yarn production and export.

As the textile industry rapidly evolves, yarn manufacturers and exporters are increasingly focusing on sustainable production techniques, innovative product development, and supply chain management. In line with the demands of the global textile market, there is a growing trend towards reducing environmental impact, increasing energy efficiency, and investing in yarns produced from renewable resources. In this context, leading yarn producers and exporters worldwide are continually innovating and improving themselves to meet market needs and maintain a competitive edge.

1.4. Process Improvement in the Field of Fancy Yarn Dyeing

To keep pace with constantly changing and evolving customer needs and to sustain their existence, businesses must innovate in their management systems and operational approaches. This highlights the growing importance of process management and improvement. Continuous improvement is essential for meeting customer expectations and staying competitive in the market. In the modern business world, especially in the manufacturing sector, due to the intensity of global competition, it is necessary for businesses to efficiently organize their facility layouts to keep costs under control. Companies place great emphasis on facility layout planning to manage business processes efficiently and optimize material flow. This is a fundamental strategy for increasing production efficiency and market competitiveness. The primary objective of process improvement is to increase the efficiency of businesses, reduce costs, and maximize customer satisfaction. In this context, the importance of process improvement is growing daily, especially for achieving sustainable competitive advantage in a competitive market (Naik and Kallurkar, 2016). An effective facility design increases the efficiency of business processes while reducing material handling costs, which is critical for businesses. In particular, facility layout arrangements offer significant cost advantages by reducing unnecessary transportation operations. The need for layout design often arises from the necessity of a new facility or the reorganization of an existing one. Insufficient planning can lead to adverse effects on business processes and costs. Businesses develop strategies such as layout optimization to efficiently use production resources and reduce costs. Layout changes evaluated with engineering approaches provide advantages in terms of time, job safety, and cost. These approaches serve as an effective tool in solving capacity issues. An efficient facility design helps increase the effectiveness and efficiency of production processes while reducing material handling costs, which constitute a significant part of operating expenses (Tompkins et al., 1996). Therefore, unnecessary transportation operations due to facility layout are among the primary issues that need to be resolved. Typically, the need for facility layout design arises when there is a necessity for a new facility space or when integrating new equipment within the existing facility (Baykasoğlu et al., 2006). Inadequate or poor facility layout arrangements can lead to excess stock between business processes, unnecessary material handling operations, and a slowdown in workflow (Chiang and Chiang, 1998).

Effective use of production resources and reduction of production costs are of great importance for businesses. Businesses develop various strategies to use limited resources more efficiently, increase capacity and quality, reduce costs and increase overall efficiency. Improvements to existing systems are not only costly but also carry various risks. One of these improvement methods is layout optimization. Reducing material handling costs and strategically positioning workstations and storage areas to provide shorter material handling distances will reduce logistics costs. This will contribute to an overall reduction in operating costs.

Considering the advantages and risks, creating replicas of existing systems and assessing changes with engineering approaches using drawing programs will provide significant convenience for practitioners in terms of time, job safety, continuity of production, and cost. The results obtained will clearly define the deficiencies of current systems and offer the possibility to generate alternative solutions. This method can be effectively used in addressing capacity issues. Thus, businesses can develop potential layout plan projects to improve their production processes1.5 A Comprehensive Analysis of Ulusoy Textile Factory

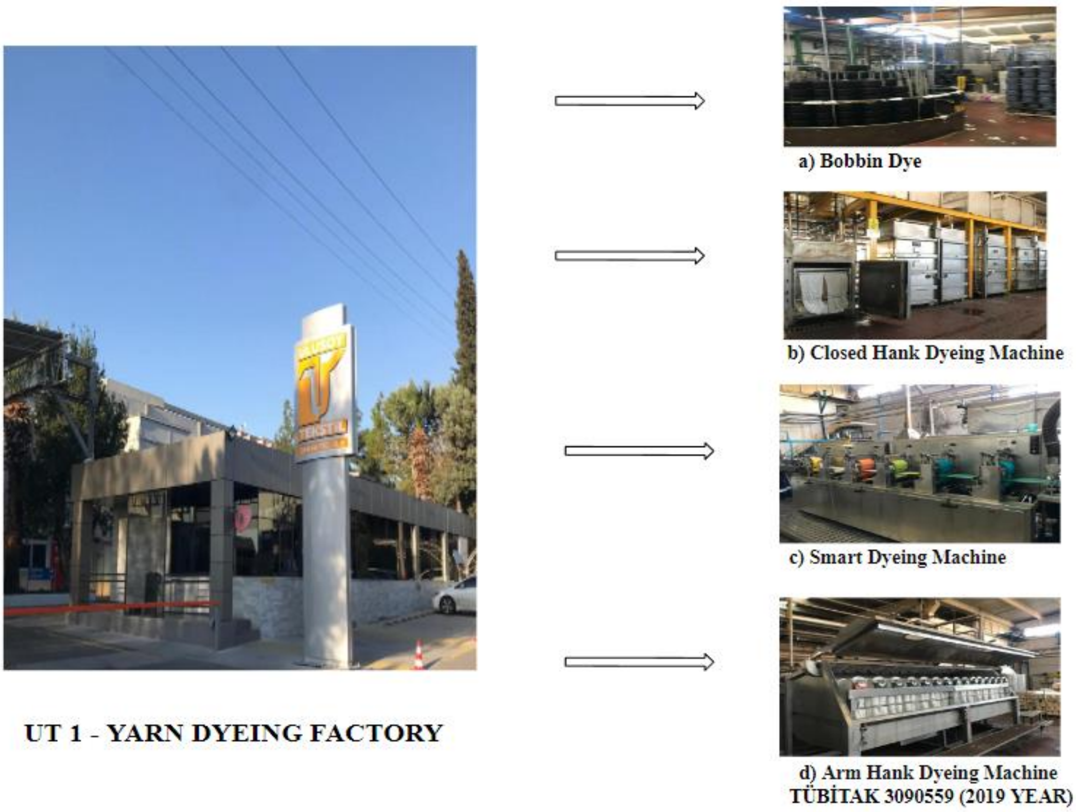

Figure 1. UT 1 Dyeing Processes

In this facility, as shown in Figure 1, four different dyeing methods are employed. These methods are: coil dyeing as seen in Figure 1a, enclosed skein dyeing as seen in Figure 1b, smart dyeing as seen in Figure 1c, and arm skein dyeing as seen in Figure 1d. The dyeing techniques described in Figure 1 are performed in pressurized or non-pressurized environments using chemicals and dyes according to the color requested by customers

a) Bobbin Dyeing (Package Dyeing): Initially, the yarns are gently wound onto perforated bobbins. Each bobbin is wound to the same diameter and placed in the dyeing machine. The dyeing process is carried out under pressure and at a specified temperature. This method is suitable for dyeing fine and less elastic yarns evenly. It is not preferred for delicate and fancy yarns.

b) Closed Hank Dyeing (Skein Dyeing): The yarns, arranged in hank form, are freely hung on the machine's apparatus for dyeing. This is an old and traditional method, ensuring that the natural structure of the yarn is preserved. Generally, dyeing is performed at low pressure and temperature. Hank dyeing is typically used for thick or elastic yarns.

c) Smart Dyeing: Multiple colors are applied simultaneously side by side. This method is ideal for creating multicolored and patterned yarns. It can be performed using techniques such as print dyeing or spray dyeing. Smart dyeing is used for special effects and intricate patterns.

d) Arm Hank Dyeing: This dyeing method is the same as hank dyeing. It is a machine developed by Ulusoy Textile in collaboration with a TÜBİTAK project, with the only difference being that it uses approximately 50% less chemicals and water for the dyeing process.

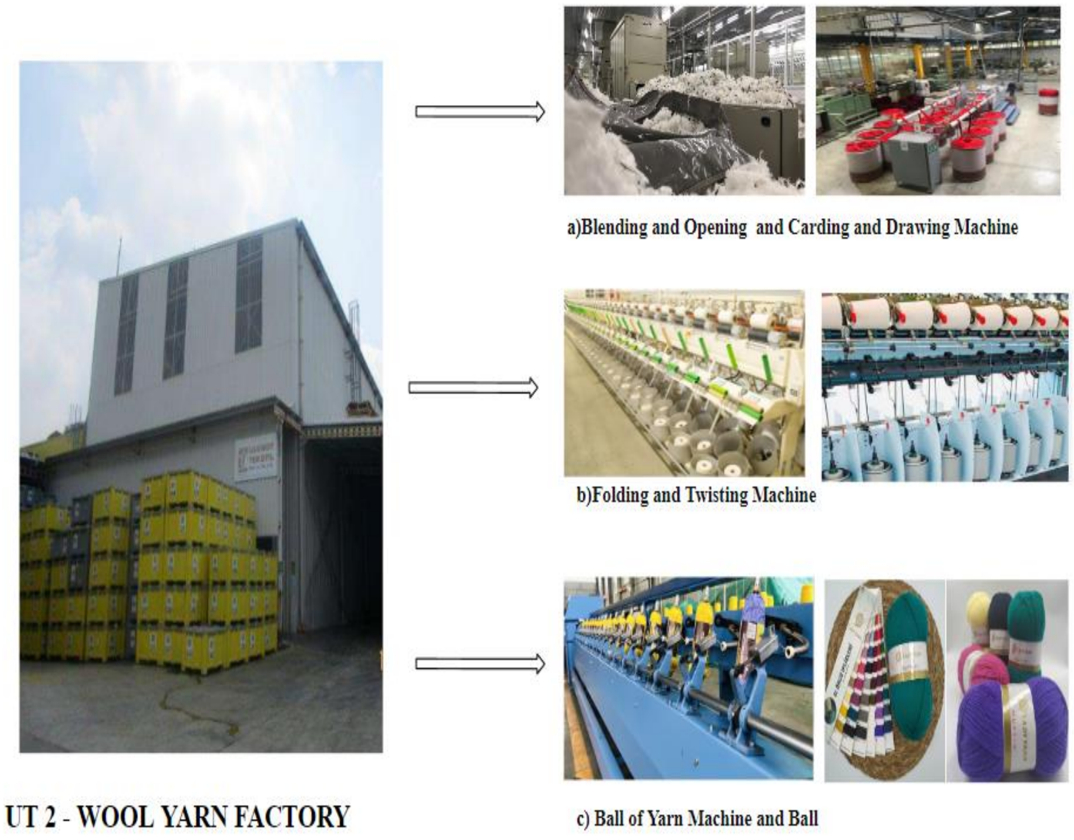

Figure 2. UT2 Spinning Processes

In this facility includes three consecutive processes as shown in Figure 2. These processes are: a) blending, opening, and carding process as seen in Figure 2a, b) folding and twisting process as seen in Figure 2b, and c) balling process as seen in Figure 2c. Based on customer demand, twisted yarn is sold after processes a and b, while yarn is also sold in ball form after process c.

a) Blending, Opening, and Carding Process: The raw material, purchased as fiber, is first processed in the blending and opening machine. Different types and colors of fibers are blended to obtain a homogeneous mixture. In the carding machine, the fibers are combed to become parallel to each other and are arranged into a thin sliver. In the drawing process, these slivers are combined, thinned, and refined to achieve a more uniform structure.

b) Folding and Twisting Process: Single yarns generally do not possess sufficient strength and durability. The combination (folding) of two or more yarns enhances the final product's strength and abrasion resistance. Irregularities and variations in single yarns can be corrected through the folding process, providing a uniform and balanced yarn structure. It also helps to conceal some yarn defects. Folded yarns result in thicker and bulkier yarns, ideal for fuller and heavier fabrics. Folding different colors, types, or textures of yarns creates various visual effects and aesthetic characteristics. Twisting increases the yarn's strength and sometimes its elasticity. The tighter the twist, the stronger the yarn generally is. The amount of twist affects the yarn's texture and perceived quality. Tightly twisted yarns are usually smoother and finer, while less twisted yarns feel softer and fluffier. Twisted yarns help the fabric maintain its shape and resist dimensional changes during washing or use. The twisting process also facilitates the weaving or knitting of the yarn, as it reduces knotting and breakage.

c) Balling Process: This process involves taking yarns from hanks or bobbins and forming them into balls. According to customer demand, balls can be made from 15 grams to 1000 grams. After label and weight control, the balls are packaged and prepared for shipment

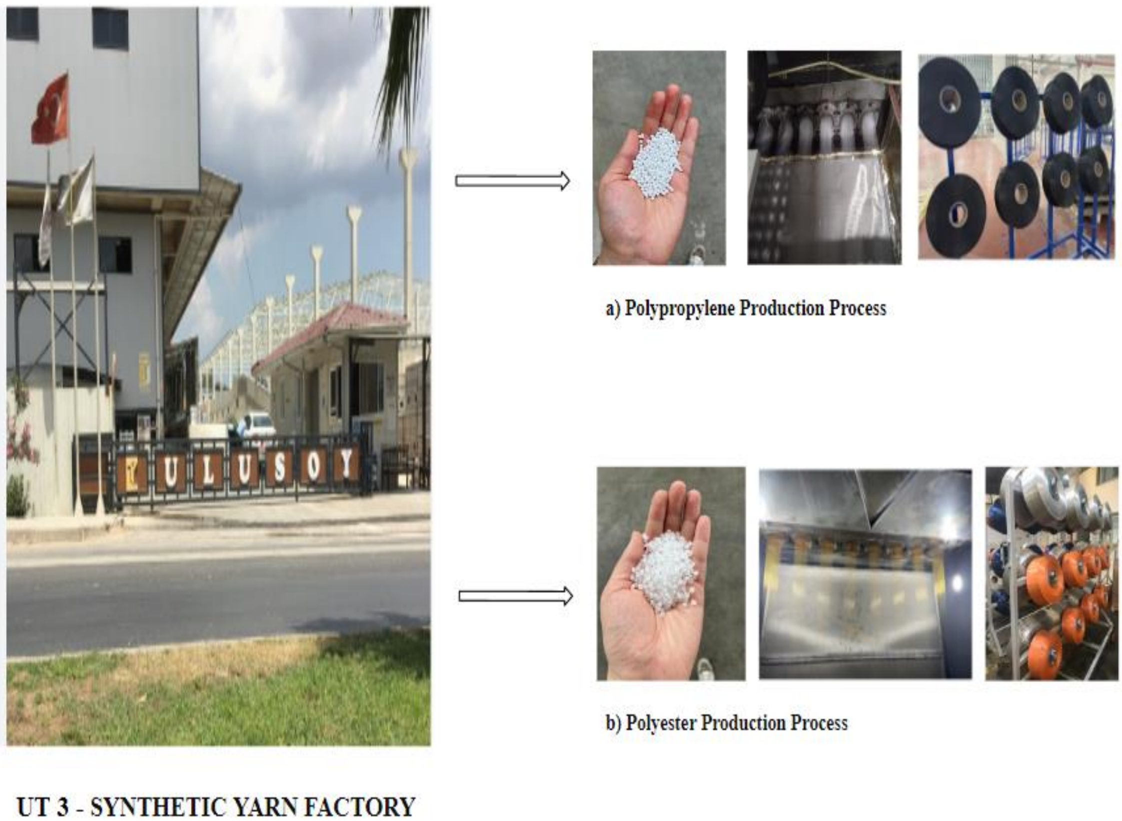

Figure 3. UT 3 Synthetic Yarn Production Processes

In this facility, as shown in Figure 3, synthetic yarn production is carried out. Figure 3a shows the polypropylene (PP) production process, while Figure 3b illustrates the polyester (PES) production process. According to customer demand, dyeing can also be performed during production. Synthetic yarns are dyed during the process of converting chip raw materials into fibers. The polymer, which is the raw material of synthetic fiber, is heated to its melting point and liquefied. Suitable colorants are added to the liquid polymer to achieve the desired color shade. The dyed solution is then passed through fine holes (spinneret). During this process, the molten fibers are solidified by exposure to cold air or water. In this process, fibers are produced to the desired fineness and length. The solidified fibers are then drawn (continuous filament) and, if necessary, cut to obtain the desired properties

a)Polypropylene Production: Polypropylene chips can be easily sourced from petrochemical facilities in our region (Middle East). Although Turkey does not have sufficient production, it is a major consumer. The primary applications are in the sack, carpet, and home textiles sectors. Polypropylene has a lower melting temperature compared to polyester. Due to its low melting point, the melt spinning process is easier. The cost of coloring during melt spinning is also more economical compared to polyester. Its light weight provides a cost advantage in many products. However, its disadvantages compared to polyester include being more difficult to process in subsequent operations, having more volatile chip prices, not being as easy to work with in weaving and knitting, being less heat-resistant, having lower strength, and not being as versatile in transforming into different products.

b)Polyester Production: More than half of the world's fiber consumption is polyester. The production of polyester has increased every year, surpassing cotton first and then becoming more than half of the world's textile consumption. The reasons for polyester's dominance as the leading fiber are its easy and flexible production, easy access to raw materials, low cost, and suitability for technical development. Polyester fibers and filament yarns, which are high-strength, cost-effective, and adaptable to different uses, are gaining market share over spun yarns. Elastic polyesters are replacing nylon, micro polyesters are replacing acrylic, shiny polyesters are replacing rayon, and easy-to-wash, stain-resistant, moisture-wicking polyesters are replacing cotton. Consumers have come to prefer polyester in all products that do not come into direct contact with the skin, especially in non-clothing textiles. Polyester is also increasing its market share in the apparel sector every day.

Figure 4. UT4 Chenille Yarn Production Processes

In this facility, as shown in Figure 4, only chenille yarn production is carried out. Known for its unique and soft texture, chenille yarn is mainly used in decorative and comfortable textile products. The term 'chenille' originates from French, meaning caterpillar; the yarn has a structure similar to the fluffy and soft appearance of a caterpillar. Due to its structure, it is a lightweight material relative to the volume it covers.

a) Chenille Production: Chenille yarn consists of a core thread around which short-cut yarns are tightly wound. The cut yarns are held in place by the twist of two threads in the core. It is also referred to as a yarn version of velvet. The twisted threads in chenille yarn are known by various names such as tie, core, or pile thread. The cut yarns are called pile threads, similar to those in velvet.

The soft and luxurious texture of chenille yarn makes it a popular choice in home textiles (such as blankets, pillows, curtain fabrics, and rugs) and apparel (like sweaters and shawls). It is also frequently used in upholstery fabrics.

The shedding of chenille decreases as its twist increases. However, very high twists can make the chenille yarn stiff, causing difficulties in weaving or knitting. Therefore, an ideal twist is determined for chenille yarns considering their intended use. Generally, chenille yarns used in weaving have higher twists compared to those used in knitting. The height of the pile is also a significant variable defining chenille yarn. As the pile height increases, the volume of the chenille expands, and the yarn becomes softer. On the other hand, it also becomes more prone to shedding. Chenille manufacturers often seek to reduce the pile height for easier handling, but as the pile shortens, the characteristic features of chenille diminish, deviating from its intended use.

As mentioned above, Ulusoy Textile, located in the Adana Organized Industrial Zone and engaged in the production and dyeing of fancy yarns, holds a significant position in the textile industry with its domestic and international sales. To keep pace with the evolving and changing world, stay ahead of competitors, meet customer demands, fulfill the requirements of necessary brands, and gain a competitive edge, Ulusoy Textile is obliged to execute process improvements and innovative projects in the areas of energy, water, and labor. For this purpose, the UT1 Dyeing Plant, the most intensive in terms of energy, labor, chemicals, and dye consumption among its four production facilities, has been addressed. The UT1 facility specializes in dyeing yarn and fiber in bobbin, hank, and degrade formats. The dyeing plant, established about 35 years ago, has changed machinery and production balance in response to shifting demands. There has arisen a need for process and layout improvement in the factory, which aims to maximize production with the existing equipment and space. Additionally, detailed records of energy, labor, chemical, and dye consumption have been meticulously kept since 2011. Analysis has been performed using approximately 4500 data sets over 13 years.

These data have been analyzed to estimate electricity usage in kWh, which is influenced by production-related increases and affects carbon emission values. This estimation was conducted using the LSTM (Long Short-Term Memory) method, and the results have been compared using the ANN (Artificial Neural Network) method. The employed artificial neural network architecture is a 3-input, 1-output forward-fed model. The inputs used are total dyeing quantity, chemical and dyestuff amount, and the quantity of water used per kilogram of yarn. These values were utilized to generate an estimate of electricity usage at the output. The estimated electricity consumption will inform future consumption data and potential improvement projects that can be implemented. In light of the requirements of the Paris Agreement and the need to mitigate the effects of climate change, conducting a current state analysis for the textile sector to manage upcoming tax payments, and facilitating the use of renewable energy are of paramount importance.

2. LITERATURE REVIEW

Aldona et al. (2023) this article emphasizes how the rapid development of digital solutions and technological capabilities aligns with the sustainable development goals under Industry 4.0. The research aims to develop an integrated energy sustainability center encompassing sustainability, Industry 4.0 technologies, and energy efficiency. The study extensively examines processes in a dairy processing plant for energy sustainability assessment. Discussions include strategic, tactical, and operational level implementations related to energy efficiency, change management, and Industry 4.0 technologies. This process includes improving existing processes of energy-intensive technologies and optimizing the overall production process. The energy sustainability framework is evaluated considering economic, environmental, and social impacts using a triple sustainability assessment model (SBM-DEA+LCA-LCC-SLCA). Particularly, this framework is highlighted to significantly contribute to energy efficiency and competitiveness, supporting the ongoing development of Industry 4.0 sustainability. This framework can assist companies adopting energy technologies that support I4.0 components in energy management by providing valuable insights into the impact of these technologies on energy management, aiding their adoption in industrial settings.

Collado et al. (2023) the European Union, in line with the 'European Green Deal,' has identified the Textile and Clothing industry as one of the significant targets to achieve carbon neutrality by 2050. The research aims to analyze the determinants of changes in greenhouse gas emissions in this industry across the EU's 27 member states from 2008-2018 and the extent to which economic growth and emissions are decoupled. The study concludes that the main factors in reducing emissions are intensity and carbonization effects. The textile and clothing industry's relative weight in the EU-27 is noteworthy, playing a significant role in reducing emissions, though this effect is partially offset by the increase in industrial activities. Between 2008-2018, the EU's Textile and Clothing (T&C) industry has become cleaner, with greenhouse gas emissions decreasing by 34%, from 11,252.76 thousand tons of CO_2 equivalent in 2008 to 7,391.12 thousand tons of CO_2 equivalent in 2018. The intensity effect, representing the change in energy consumption relative to industrial output, is the most significant inhibitor of the decrease. However, other factors such as the carbonization effect and structural effect have also contributed to emission reductions. On the other hand, the activity effect, representing economic activity, was the driving force behind the increase in emissions, especially in the final years of the analyzed period. Overall, energy efficiency and consumption in the EU's Textile and Clothing industry have continually improved, aiding in emission reduction

Salihoglu, (2023) this study aims to accurately predict passengers' future destinations in modern transportation industries. Such predictions provide various benefits to companies, including customer satisfaction and targeted marketing. The study's focus is to develop a precise model that captures sequential patterns and dependencies in travel data and accurately predicts individual passengers' future destinations. For this purpose, a new model architecture using the sliding window approach for destination prediction in the transportation industry is proposed. Experimental results demonstrate that the LSTM model achieves satisfactory performance and high scores across different data dimensions and performance metrics. This research advances destination prediction methods, offering companies personalized recommendations and optimizing customer experiences in the dynamic travel environment. It is emphasized that human mobility is a fundamental aspect of our daily lives, and information revealing patterns and trends in how people move provides valuable insights into travel behavior preferences and decision-making processes. This information is vital for city planners, transportation authorities, and policymakers to design and implement effective solutions to address issues such as traffic congestion, transportation infrastructure optimization, and sustainable urban development. In the context of tourism, predicting the next destinations can revolutionize how travel agencies, tour operators, and accommodation providers serve their customers. By anticipating passengers' preferences, these companies can offer personalized services and optimize travel experiences

Albahadılı, (2023) this study presents a multi-stage approach to detecting phishing attacks with a low error rate. Firstly, the dataset is balanced using the GAN (Generative Adversarial Network) deep learning method. Then, features related to web pages' links and codes are extracted using a convolutional neural network (CNN). In the next step, the White Shark Optimization algorithm (WSO) is used to select the main feature. Finally, the selected features are used as input to the LSTM (Long Short-Term Memory) neural network, which classifies fake and real links. Innovations in this study include balancing the dataset with GAN, feature extraction with CNN, introducing the binary version of the White Shark Optimization algorithm, and its practical use in feature selection and phishing attack detection, and presenting a hybrid approach combining CNN, LSTM and swarm intelligence techniquesThe conclusion of the article details a deep learning-based method for detecting phishing URLs based on GAN, CNN, and LSTM networks, and Swarm Intelligence algorithms. The conclusion focuses on feature extraction, feature selection, and the application of these methods in detecting phishing attacks. The White Shark Optimization algorithm (WSO) is used for feature selection, and its use in solving optimization problems with meta-heuristic methods is highlighted. The WSO algorithm, inspired by sharks' hunting behavior, establishes a suitable balance between exploration and exploitation. These results demonstrate how deep learning and swarm intelligence algorithms can be effectively used in detecting phishing attacks

Chinnathai et al. (2023) addresses a digital lifecycle management framework supporting sustainable smart manufacturing for energy-intensive industries (EIIs). The article summarizes the current state of digitalization in such industries, frameworks related to sustainable EIIs, and a literature review. The methodology section details five separate layers: data collection, process management, simulation and modeling, artificial intelligence, and data visualization. These layers provide the technological and managerial tools necessary to improve and optimize sustainable production processes in energy-intensive industries. The article discusses the challenges and potential solutions encountered in the digitalization process of these industries, especially concerning sustainable production and efficiency enhancement.The conclusion section presents a digital lifecycle management framework to support sustainable smart manufacturing in EIIs, comprising five different layers: data collection, process management, simulation and modeling, artificial intelligence, and data visualization. The framework's application in a test case is discussed, along with the challenges faced in digital transformation in EIIs .

Coşgun, (2023) calculates and analyzes the carbon footprint of a textile company operating in the Bursa Organized Industrial Zone, based on the year 2019. The analysis includes direct and indirect greenhouse gas emissions. The total emission amount for 2019 is determined to be 44.71973 tons CO_2 equivalent. The study emphasizes the importance of setting emission reduction targets according to the Absolute Reduction Methodology of the Science-Based Targets Organization (SBTi). Accordingly, an annual reduction of at least 4.2% in scope 1 and 2 emissions should be targeted. These targets support the strategic planning of the textile sector for sustainability and environmental impact management

Işık, (2023) focuses on the increase in natural resource consumption, energy needs, and fossil fuel usage alongside the growing global population and their adverse effects on the natural life cycle. This situation has led to an increase in atmospheric greenhouse gasses and global warming. Global warming has gained importance due to its adverse effects on climate change and natural life. Countries worldwide are conducting various studies to identify, evaluate, and reduce the effects of global warming. These studies include identifying energy-consuming and carbon-emitting activities and calculating carbon emission amounts.

In this research, carbon footprint calculations were conducted using the Tier method at a textile company in Denizli.This methodology was used to calculate greenhouse gas emissions released into the air. The primary objective of the research is to calculate and evaluate the carbon footprint arising from textile production processes. According to the study's findings, the amount of carbon footprint emitted into the atmosphere per ton of product produced at the examined textile company was found to be 1.43 tons of CO2 equivalent. These results underscore the importance of efforts in the textile industry to reduce environmental impacts and carbon emissions.

Partigöç & Soğancı, (2019) global climate change manifests as an inevitable natural disaster, primarily due to rising temperatures and decreasing rainfall worldwide. Drought is characterized as a recurring phenomenon that spans one or more seasons, resulting from reduced precipitation and increased temperatures, impacting all natural resources dependent on water availability. This situation poses significant challenges, particularly in the agricultural sector, leading to decreased soil fertility, limited water access for crops, and the misuse of agricultural lands. Turkey, due to its geographical location, is among the countries most affected by the impacts of climate change. Consequently, developing sustainable disaster management and urban planning policies is of paramount importance. The utilization of Geographic Information Systems (GIS) and Remote Sensing (RS) techniques can contribute to the development of effective strategies for combating drought, thereby mitigating potential environmental problems.

Yüksel, (2022) produced woven fabrics using recycled polyester (r-PET) and cotton (r-CO) fibers and evaluated these fabrics from a sustainability perspective. Seven different blends of yarns were used in the study. The fabrics were buried in soil for 1, 4, and 7 months to examine the biodegradation processes. Additionally, the mechanical and comfort properties of the yarns and fabrics were assessed, and a life cycle analysis was conducted. Biodegradability was determined through weight loss, SEM, FTIR, and DSC analyses. Analyses in various environmental impact categories helped evaluate the effects of using recycled fibers on sustainable textile production. .

Okai- Mensah et al. (2022) presents rich empirical evidence on circularity solutions adopted by major companies in the fast fashion industry. The sustainability reports of six global players were analyzed using a value chain circular model that encompasses eleven stages, from product design to recycled materials. The research demonstrates that major players have developed complex systems to reduce their environmental impact and enforce strict rules in their supply chains.The data source consists of the corporate sustainability reports of the world's largest clothing retailers. These reports detail the strategies and goals adopted in implementing the principle of circularity. A thematic analysis examines how circularity solutions are applied at each stage of the value chain. The research outlines various strategies aimed at reducing the environmental impact of the fast fashion sector and developing more sustainable business models. It highlights the efforts of major players to promote circularity in both supply chains and consumer behaviors.

Şener Fidan, (2022) this article highlights the sustainability issues in the Denim industry and the importance of research in this area. It discusses the development of the concept of sustainability and its integration into the textile industry. The section includes an evaluation of sustainable energy and raw material options used in denim production, considering environmental, economic, and quality dimensions. Alternatives such as recycled and organic cotton, co-generation energy usage, eco-friendly chemicals and dyes, and the replacement of chemicals used in the neutralization process in treatment plants are examined. Methods like Life Cycle Analysis (LCA), TODIM, and Hesitant Fuzzy Analytical Hierarchy Process (HF-AHP) have been used to assess the contributions of these alternatives to denim production. The article demonstrates that all examined sustainability alternatives are more sustainable than conventional denim fabric production. It also discusses the environmental and social impacts, as well as the economic outcomes of these alternatives

Altun Kurtoğlu, (2022) the article emphasizes the importance of transitioning to a circular economy in the textile sector. It specifically points out the steps taken by the European Union in this regard and highlights that misconceptions about the circular economy concept are a significant issue. The study, based on a report published by the Ellen MacArthur Foundation in 2017, examines the advantages and disadvantages of the Turkish textile sector's transition to a circular economy. It mentions gaps in digitalization, raw material production, the production of high-value-added recycled products, and extending the life of materials.The article also discusses various studies aimed at extending the lifespan of textile products, targeting the materials' prolonged economic system presence. The rise of online platforms and stores selling second-hand clothes in Turkey draws attention to the importance of the textile recycling sector. The concept of sustainability in the textile sector has gained prominence, and the circular economy offers a holistic approach to the sector's scattered and complex sustainability goals. The article presents the advantages, disadvantages, and recommendations for the sector's transition to a circular economy, comprehensively addressing the challenges and opportunities faced by the Turkish textile and ready-to-wear sector in this transition and emphasizing its significance.

Tuğaç, (2022) the article "Climate Change Crisis and Cities" discusses the impacts of global climate change on cities and the contributions of cities to climate change. The effects of global warming, such as rising sea levels, extreme weather events, and public health issues, are intensely felt in cities. Various solutions for making cities resilient to climate change are presented. These include impact, vulnerability, and risk analyses; green infrastructure practices in water management; and the need for financing climate actions. Green transformation is economically and socially beneficial, encouraging innovations that can create new employment opportunities. The circular economy plays a significant role in combating climate change by increasing the efficiency of products throughout their lifecycle and reusing waste materials. Strategies like reducing energy from fossil fuels, decreasing natural resource usage, enhancing product lifecycle efficiency, and reusing and recycling waste materials at the source are highlighted. The circular economy is based on the principles of "reduce, reuse, and recycle," and its contribution to the green transformation process is significant in making cities resilient to climate change. The UN's projection that the green transformation will create 6 million new jobs is also mentioned.

Aras Elibüyük et al. (2022) The article examines efficiency improvement efforts conducted in the dyeing section of a textile enterprise. Due to increasing population and global warming, diminishing water resources have increased restrictions on water usage, paving the way for more environmentally friendly and sustainable production processes. In this context, the company's dyeing section, especially in Piece Dyeing, Pad Batch, and HT dyeing processes, aims to reduce energy, water, and chemical usage. The innovations implemented have not caused issues with fabrics compared to old methods and have yielded better efficiency. The results of these efficiency efforts highlight significant savings in water and energy usage in the Pad Batch process. Specifically, water usage in dyed yarn products has been reduced from 20-25 kg to 1 kg per kg of product, saving energy and reducing chemical usage. Similar improvements in polyamide-containing products have also achieved savings in water, time, chemicals, and energy. These improvements have enhanced the company's competitive position in the market and represent a significant step in sustainable production. The original aspect of the article is that these efficiency improvement efforts were applied for the first time within the company and have yielded successful results.

Suleyman et al. (2022) aims to examine the environmental sensitivity and sustainability policies of textile companies in Turkey. The research evaluates the policies of 89 textile companies that produce in different areas and are among the top 500 industrial enterprises announced annually by the Istanbul Chamber of Industry, using the document analysis technique. The findings show that most companies develop policies mainly in the areas of waste, energy, water, and natural resource management. The study concludes with some recommendations considering the scope and content of environmental sensitivity and sustainability policies of textile companies. The operational areas of textile companies, their environmental sensitivity certifications, and their main topics of environmental/sustainability policies are addressed. The original aspect of the study is its comprehensive examination of the environmental sensitivity and sustainability policies of major textile companies in Turkey, highlighting the main elements of policies made in this area. This provides a valuable contribution to understanding sustainability and environmental sensitivity trends in the sector.

Sultan Tuna, (2021) this study aims to examine production problems encountered in the bathrobe garment section of a textile enterprise operating in Denizli. It has been noted that the garment sector faces numerous issues due to product diversity, lack of standard workflows, and variability in raw materials and semi-finished products. These problems are often related to labor-intensive production processes and can lead to common issues in all products, including environmental factors. Using 15 years of production data, the study has developed an order performance score that includes issues like second-quality faulty production and order delays, identifying factors influencing this score. The study concludes that the season significantly affects the production process. Analyzing the factory’s production data, highlights the importance of factors like model type, fabric type, color variety, production quantity, and performance of the sewn model in production, emphasizing the need for improvement efforts on these factors. Experience gained from past problems plays a significant role in reducing potential issues in current-order planning .

Metlioğlu et al. (2021) this study focuses on the development of the concept of sustainability in the textile industry, particularly examining the sustainability strategies of brands such as H&M and ZARA operating in the fast fashion sector. The advancement of technology in the industrial field, the rapid growth of the consumer society, and the economic, ecological, and social problems caused by the ready-to-wear and fashion industries have increased the importance of this issue. The fast fashion sector has chosen to produce in a more environmentally friendly manner, despite high costs, by developing sustainable production methods based on the 4R principle (reduce, reuse, recycle, and repurchase), receiving positive feedback from consumers. The article describes the destructive effects on the environment and ecosystem due to rapid industrialization and mass production in textile production post the Industrial Revolution, including the use of synthetic dyes and machinery, and the inability of natural raw materials to meet needs. The fast fashion sector has increased consumption by triggering a continuous desire to purchase, adversely affecting nature and the ecosystem. Since the 1970s, ecological concerns and a return to nature have started to influence textile production.These brands aim to counter the trend of clothing production doubling between 2000 and 2015, while garments are worn a third less, leading to increased waste.

Ecer et al. (2021) the article discusses the European Union's Green Deal as the new growth strategy and the radical transformation needed in the economy. The EU's goal to become climate-neutral by 2050 requires new regulations and policies for trade partners like Turkey. As Turkey needs to make the necessary adjustments to maintain its trade relations with the EU, this deal significantly impacts Turkey's economic and environmental policies. Turkey needs to consider the border carbon mechanism and circular economy practices to adapt to this new situation. The financial cost of this process for the Turkish economy and its significant impact on economic policies are emphasized. In conclusion, the article discusses the necessity for Turkey to align with the EU's Green Deal and the potential impacts on the Turkish economy. It emphasizes the need for Turkey to develop and implement the necessary policies and strategies for this adaptation.

Coşkun & Doğan, (2021) this study evaluates the carbon footprint amounts resulting from the annual production activities in the garment, fabric dyeing, printing, and yarn dyeing sections of a textile factory in 2018. When comparing the carbon footprint amounts among the produced sections, the garment section has the highest value with 2439 kg CO_2e/kg of product. This section is followed by the fabric dyeing, printing, and yarn dyeing sections. The main causes of carbon footprint formation have been identified as the use of natural gas, coal, and diesel. The study's findings indicate that the dyeing process and energy consumption, especially the re-dyeing of products damaged after the dyeing process, increase the carbon footprint, with the chemicals and dyes used in the printing section being the most significant contributors to the carbon footprint. The coal and diesel used in the factory have been determined as the primary sources of the carbon footprint. Proposed solutions include using worn-out fabrics as raw materials again, regular maintenance of machines in the enterprises, and insulating hot water tanks for sustainable practices. The study concludes with suggestions to promote the use of renewable energy sources, encourage single-color and printless clothing over colored and printed fabrics, and highlight the importance of zero-waste management to reduce production costs and, consequently, carbon footprint amounts. The study compares its findings with research conducted in different countries, emphasizing that carbon footprint amounts vary per enterprise due to process differences.

Özgen Keleş, (2023) This article highlights the potential of coffee waste as eco-friendly and reusable materials and its transformation into textile products to reduce environmental pollution and create a sustainable material cycle. It also focuses on the properties of fibers derived from coffee waste and how these fibers can be used in textile products, pointing to the potential of this innovative approach in moving the fashion and textile industry towards greater sustainability. The unique aspect of the article is its focus on the use of coffee waste in the textile industry, offering an innovative perspective on waste material revaluation and sustainable fashion practices Transforming coffee waste into reusable fibers without harming the environment significantly reduces environmental pollution and creates a sustainable material cycle

Balbay et al. (2021) explore Turkey's shift towards a circular economy, highlighting the challenges and strategies involved. It emphasizes the importance of raising awareness, building infrastructure, and implementing policies that promote circular economic practices. The article also discusses the potential economic, environmental, and social benefits of this transition, including waste reduction, increased resource efficiency, and a reduced ecological footprint. What sets this document apart is its comprehensive and detailed focus on Turkey's unique situation, as well as the impacts of the circular economy on the country's political, economic, and environmental landscapes. This makes it an invaluable resource for understanding and evaluating Turkey's progress towards sustainable development goals. Furthermore, the article addresses the incorporation of the European Union's Green Deal in Turkey under this framework. Çelebi Gürsoy & Yıldız . (2021) presents a case study on process improvement using the lean Six Sigma methodology in a textile enterprise. The primary aim of this study is to identify wastes and errors in textile sector processes through the lean Six Sigma methodology. The research model includes the define, measure, analysis, improve, and control criteria of Lean Six Sigma. The study was conducted using observation techniques between September 2019 and August 2020, applying lean production techniques. The hypothesis is that the application of lean Six Sigma methodology has a statistically significant positive impact on production flow time, process time, error rate per unit, setup time, first-time efficiency, and overall equipment effectiveness. The results show that the successful implementation of Lean Six Sigma significantly reduced waste and defective products in the enterprise. The study observed significant reductions in production flow time, process time, and setup time, with increases in error rate per unit, first-time efficiency, and overall equipment effectivenessLean Six Sigma.

Başoğul et al. (2022)focuses on the evaluation of the carbon footprint of a textile factory operating in Adiyaman. The carbon footprint, an important parameter for examining the environmental impact of increasing greenhouse gasses, is especially significant for textile factories. The study used the Tier-1 method to calculate the factory's service vehicle/diesel consumption, natural gas consumption, electricity consumption, and wastewater-based factors, determining the factory's annual carbon footprint as 297343 tons of CO2. Electricity consumption had the greatest impact on the factory's carbon footprint, while wastewater had the least.

Ahmad et al. (2020) investigates the role of Business Intelligence Systems (BIS) in the Textile and Apparel (T&A) industry during the era of Industry 4.0 and how these systems can solve sustainability issues. Previous studies focused on the use of big data in Industry 4.0 but neglected the role of BIS, especially in the T&A industry. This research employs a qualitative approach with 14 semi-structured in-depth interviews from leading T&A companies worldwide. The findings reveal the sustainability challenges faced by T&A companies in adopting BIS, improvements in value creation processes, and challenges of BIS adoption. In particular, economic sustainability plays a key role in the adoption of BIS and Industry 4.0 technologies in clothing retail businesses

Indrayani & Triwiswara, (2020) this study addresses the application of green industry standards in textile manufacturing and products. It emphasizes the importance of industries transitioning from traditional production processes to green industries, which consider economic growth along with environmental sustainability. Green industry characteristics include efficient use of input materials, alternative eco-friendly materials, low energy and water intensity, reduction of both liquid and solid waste, and emission reduction through low carbon technology. Each characteristic is equipped with Green Industry Standard (GIS) criteria applicable to textile and textile product manufacturers. The research method is a qualitative descriptive approach, incorporating technical management requirements and policy and organizational management aspects. The study is conducted through a literature review and analysis of decrees related to the Ministry's Green Industry Standards (GIS) published in 2019

Roy et al. (2020) this study emphasizes the necessity of identifying Critical Environmentally Conscious Manufacturing Indicators (CECMI) for formulating environmental strategies in textile manufacturing due to the significant environmental harms caused by various textile manufacturing processes. A new integrated model combining Environmental Process Mapping (EPM), Decision Making Trial and Evaluation Laboratory (DEMATEL), and Analytic Network Process (ANP) is developed and examined in the context of an Indian textile industry. DEMATEL explains cause-and-effect relationships, while ANP calculates the weights of indicators. Critical indicators such as waste production, Volatile Organic Compound (VOC) emission, and energy consumption are found to be crucial for the textile industry. Technical solutions associated with CECMI are suggested to address environmental issues. The implementation of technical solutions resulted in reductions of waste by 12%, carbon dioxide emissions by 10-11%, nitrogen oxide emissions by 9-10%, and energy consumption by 5%. Additionally, annual reductions of 8% and 3% in respiratory and allergy problems were achieved from a health perspective.

Tandoğan, (2020) this study examines how advancements in production methods contribute to efficiency in the textile sector. In global competitive conditions, businesses manage and strengthen their complex structures to achieve advantageous positions. Performance management plays a significant role in this process. Method development involves analyzing and improving activities to make business processes more economical, less costly, and faster. The study analyzes performance management and strategic management processes, assessing how these concepts contribute to the advancement of production methods in the textile sector. The uniqueness of this work lies in its focus on performance and efficiency management concepts, detailing the critical importance of advancing production methods in the textile sector and the impacts of these methodological advancements on the sector's competitiveness and productivity. The research merges strategic and technical approaches, offering valuable insights and practices on how to improve the overall performance of the sector .

Sabır, (2020) this study explores the complex and challenging process of product development, occurring before production initiation, during order receipt, or collection preparation stages. It utilizes a large-scale textile enterprise specializing in woven fabrics predominantly made of polyester/viscose for outerwear, focusing on the dye-finishing facility. Work study techniques are applied, payment process includes the flow and customer approval stages based on the product sample provided by the customer. This study performs simulation modeling of the product development process in textile dye-finishing enterprises, employing work study techniques and direct observation for workflow and time measurements. The model aims to determine delivery times by evaluating all options in the product development process, focusing on the flow and customer approval stages based on the customer-provided product sample.

Piribauer & Bartl, (2019) this study presents a mini review addressing the global increase in fiber production and the rising amount of textile waste. As textile products evolve from basic human needs to fashion items, their lifespans decrease, and the complexity of material composition increases. The study provides an overview of current textile recycling methods and discusses innovative developments in the textile recycling sector, particularly focusing on biochemical fiber recycling processes as a step towards a circular economy. Due to the high selectivity of biocatalysts, these processes can be used to extract a specific fiber material from multi-component textiles, thus reducing the complexity of textiles and enhancing recyclability. The findings indicate that annual fiber production is expected to exceed 100 million tons in the coming years, and these trends will only intensify unless consumers rethink their consumption habits. An effective textile waste management strategy requires the separate collection of textiles from municipal waste. To achieve the European Union's circular economy targets, end-of-life textiles need to be recycled into new fiber materials with properties similar to the original material. While this is technically feasible for sorted textile waste composed of a single type of fiber material, multi-component textiles pose a problem for recycling purposes. Avoidance of such multi-component textiles and the adoption of a 'design for recycling' approach in the textile and clothing industry are necessary. Biochemical processes, due to their high selectivity and ecological operating conditions, are seen as the most suitable solution for this task.

Khattab et al. (2019) this study investigates the environmental impacts of the textile dyeing industry and ways to mitigate these impacts. The study emphasizes the severe environmental damages caused by the use of synthetic dyes, reactive dyes, heavy metals, and other harmful chemicals in the textile dyeing process. These damages include direct environmental consequences such as water pollution, reduced soil fertility, and inhibition of photosynthesis, as well as adverse effects on human health. The study highlights the importance of discovering eco-friendly alternative technologies in the textile dyeing industry, such as bio-colors, natural mordants, and dyeing without water using supercritical carbon dioxide. The study also addresses the negative impacts of dyes and auxiliary chemicals used in the dyeing process on human health. It discusses health issues caused by dye powders and dyeing chemicals, such as skin irritations, allergic reactions, and asthma. In this context, various measures are suggested to protect workers and reduce the toxic effects of dyes and auxiliary substances. The study also provides information about the ecological problems arising from the discharge of dyeing process wastewater and the methods used for treating this wastewater, including biological treatment, activated carbon adsorption, and chemical oxidation.

Çınar, (2019) this study analyzes the factors affecting students' final academic success using time series models integrated with deep learning. For this purpose, the records of 200 students from a computer engineering program were examined using deep learning models such as Recurrent Neural Network (RNN), Long Short-Term Memory (LSTM), and Gated Recurrent Unit (GRU). Features like overall grade average, English score, gender, preference order, absenteeism rate, and grades of compulsory courses each semester were used as input parameters for these models. The five-fold cross-validation results showed that RNN, GRU, and LSTM models achieved overall accuracy rates of 81.07%, 85.65%, and 84.41%, respectively. The proposed LSTM model, particularly in identifying at-risk students in the sixth semester, achieved a true negative rate of 87.12%, while the GRU model showed a capacity to predict student success with an 88.71% true positive rate. These methods, providing effective predictions in reducing the risk of failure in any semester, have the potential to enhance students' performance once integrated into a student information system. The originality of this work lies in its approach to predicting students' graduation statuses using deep learning models, evaluating the effectiveness of different deep learning models like RNN, LSTM, and GRU in academic performance prediction, and offering valuable insights for educational advisors and higher education institutions. This approach aims to reduce student failure by strengthening early intervention and support mechanisms.

Pervan, (2019) Under the title "Making Semantic Inferences from Turkish Texts Using Deep Learning Approaches," this study focuses on analyzing Turkish user comments collected from online platforms like social media and e-commerce sites. The study is based on a word2vec model that learns the positive or negative meaning of each word as vector representations while preserving the natural, everyday language of these comments. This model includes deep learning approaches such as LSTM and Dilated Convolutional Neural Networks (D-CNN), along with fundamental methods like Random Forest (RF) for sentiment classification. The study indicates that the LSTM model yields more effective results with fewer parameter calculations, shorter runtime, and higher accuracy compared to the D-CNN model.

Toksöz, (2018) the study examines sustainability practices in the textile sector and their environmental impacts. Using the HIGG materials sustainability index and the life cycle assessment tool, the study conducted a life cycle analysis of four denim woven fabrics made from different types of cotton. In this analysis, only the main input raw material was altered while other parameters were held constant. The study concluded that by changing the main raw material, a significant market share can be obtained with low extra cost. The unique aspect of the thesis is its emphasis on the importance of sustainability practices and life cycle analyses in the textile sector and how these analyses can be an effective way to reduce the environmental impacts of textile products. The study contributes significantly to reporting sustainability activities in the textile industry and educating consumers with ecological labels, making sustainability more actionable. This approach demonstrates how industrial sustainability can balance economic gains with environmental responsibilities.

Türemen et al. (2018) taddresses the increasing consumption of textile products with the rapidly developing fashion industry and the resultant growing need for recycling. It underscores that recycling has gained global importance due to compelling reasons like resource conservation, reducing landfill sites, lowering waste management costs, and the need for cheap raw materials for production. The textile industry plays a significant role in recycling due to the high proportion of recyclable materials.The thesis examines different approaches to recycling. The first approach involves reusing products in their original form, while the second encompasses various methods like mechanical, thermo-mechanical, chemical, and energy recovery. The mechanical method enables waste to be broken down and transformed back into fibers, whereas the thermo-mechanical method involves converting thermoplastic fibers back into granules for use in plastic and fiber production. Chemical methods cover the conversion of waste into raw materials or intermediates through depolymerization. Additionally, the utilization of textile waste as fuel due to its high calorific value is also mentioned as a recycling method.

Kayışkan et al. (2018) the study aims to restructure and improve the supply processes of a dye industry company according to process management techniques, analyzing improvements in supply activities. It involves mapping the firm's current supply processes and designing new processes using process improvement techniques. Results indicate solving existing problems in supply processes and achieving time advantages. Supply chain management encompasses a series of independent operations including raw material and component manufacturers, product assemblers, wholesalers, retailers, and logistics companies, covering material, information, and value flow coordination and optimization from raw material inputs to the final consumer. The originality of the thesis lies in the detailed examination of how supply chain management processes in the dye sector can be improved using process management techniques and highlighting the benefits these improvements bring to organizations. The study shows that effective management of supply processes offers significant cost and time advantages, providing strategic and operational solutions for the sector.

Toprak & Aniş, (2017) the study emphasizes the pressure on the textile industry to produce environmentally friendly products due to increasing societal awareness and public concern for the environment. It notes that many companies and organizations focus on eco-friendly production methods. The main change factors for creating a sustainable textile industry are identified as producing less and harmless waste, recycling, using less energy, water, and chemicals, and ethical concerns in production processes. The article thoroughly addresses the environmental impacts of textile, highlighting opportunities for change in textile processes, and discusses clean production and sustainability concepts. The developments in the textile sector are indicated to play a significant role in increasing environmental problems, with the main environmental impact being the discharge of high amounts of chemicals into the environment. Other major factors include high chemical and water use, energy consumption, air pollution, solid waste, and odor generation. The article examines the environmental issues in the textile and clothing sector and explains that these issues can be addressed within the framework of clean production and sustainability.

Desore & Narula, (2017) The study highlights the significant contribution of the textile industry to environmental pollution compared to other industries, causing various ecological problems like water pollution, waste generation, and air pollution. The textile and clothing industry contributes approximately 1 trillion dollars to the global economy, accounting for about 7% of world exports and employing around 35 million people. The industry is known for its large-scale consumption of water, fuel, and various chemicals. Industrial estimates suggest that over 35% of the chemicals released into the environment come from textile processing and dyeing processes. The textile industry globally consumes about three trillion gallons of fresh water, used to produce 6,000,000 tons of fabric. Particularly in cotton cultivation, about 8500 liters of water are used to grow 1 kilogram of cotton. Considering emerging issues like climate change, resource scarcity, strict regulatory regimes, and increasing demand for sustainable textiles, the environmental damage caused by textile production urgently needs to be addressed.

Öztürk et al. (2016) this study in Denizli, Turkey, focuses on cleaner production assessment in a textile finishing plant, in line with the Integrated Pollution Prevention and Control and Industrial Emissions Directive. It identifies 92 Best Available Techniques (BAT) options, of which 22 have been selected based on technical-economic feasibility. Selected techniques involve practices to optimize water and energy consumption, reduce chemical use, and transition to safer alternatives. The implementation of these techniques is expected to result in significant reductions in water consumption (43-51%), energy consumption (11-26%), chemical use (16-39%), wastewater flow rate (42-52%), chemical oxygen demand load (26-48%), waste gas emissions (12-32%), and solid waste production (8-18%). The payback period of these techniques is estimated between 1 and 26 months. The textile industry, vital for global economic development, is characterized by its heterogeneous nature, complex production chains, and various sub-sectors. Especially in dyeing-finishing operations known for significant water, energy, and chemical consumption, the industry has a resource-intensive structure. Main environmental concerns involve wastewater with high flow rates and significant pollution loads. If inadequately treated, these wastewaters contain surfactants, dyes, pigments, and heavy metals, creating high chemical oxygen demand and environmental risks. The textile industry's high thermal energy needs and intense chemical usage are other pollution sources. Recently, there's been a shift in environmental protection philosophy from reactive "pollution control" to proactive "pollution prevention." This approach addresses inefficiency in resource consumption, and failures in production processes, advocating ecological efficiency, green production, and sustainable manufacturing practices.

Varadarajan & Venkatachalam, (2015) This study states that wastewater in textile dyehouses, characterized by high chemical oxygen demand (COD), biological oxygen demand (BOD), total dissolved solids (TDS), pH, and color, causes serious environmental problems. The various chemicals and volumes of water used for processed fabrics lead to uncorrected dyes and other electrolytes in the wastewater. Current end-point treatment processes are either expensive or inefficient, highlighting the necessity for eco-friendly textile production processes to address this issue. Consequently, the study investigates three potential eco-friendly systems applicable to textile dyeing processes to minimize salt and water consumption: enzymatic processes in fabric preparation, the use of biodegradable organic salts, and surface modifications of cotton.The unique aspect of this article is its comprehensive examination of alternative solutions for reducing water and auxiliary chemical consumption in the textile industry. The approach proposes the application of eco-friendly organic salts and enzymatic processes as alternatives to the inorganic salts commonly used in traditional dyeing processes. These innovative methods aim to reduce the total dissolved solids in wastewater and its environmental impacts, thereby reducing the environmental footprint of the textile industry .

Sabır et al. (2014) this study aims to increase process efficiency in the PES/VIS/LYC fabric production line of a textile finishing plant through the application of method study. The textile finishing process, consisting of a series of operations to turn fabric into finished products, can sometimes lead to inefficiencies due to its multiplicity. Conducted on 1000 meters of fabric, the study used method study techniques to achieve savings in 6 out of 22 operations, freeing up a machine and saving 30 meters in distance and 96 minutes in processing time. The Polyester/Viscose/Lycra® finished fabric was produced under the new system and received customer approval. The uniqueness of this work lies in its focus on optimizing and enhancing the efficiency of textile finishing processes. The reevaluation and integration of traditional processes with innovative approaches have led to significant savings in processing time and costs. This approach presents an effective way to enhance the efficiency of existing systems without the need to renew the machinery park. Additionally, this study demonstrates the successful application of method study techniques in textile finishing plants for increasing efficiency

3. METHODOLOGY

3.1. Data and Characteristics

Ulusoy Textile operates four different facilities within the Adana Organized Industrial Zone, with all dyeing processes conducted at the UT1 facility. As shown in Table 2 and Table 3, the energy and water consumption results indicate that the dyeing facility has higher consumption levels compared to the other facilities. Consequently, the UT1 facility exhibits a higher carbon footprint and water footprint than the other three factories. Notably, in terms of electricity consumption, the UT1 branch alone exceeds the 1000 TOE (Tons of Oil Equivalent) threshold. This necessitates the appointment of an energy manager within the factory. Since 2011, the electricity, water, and natural gas bills, along with the quantities consumed, have been recorded monthly for the yarn dyeing factory.

Against these consumption data, information such as the amount of dyed yarn, reprocessed quantities, consumed chemicals and dyes, and packaged quantities are available. Data on the number of workers employed in that month and the number of days the steam boiler operated are also included. The cost in dollars per 100 kg of yarn produced for energy and labor consumed is specified. The unit costs and consumption quantities of electricity, water, and natural gas used for dyeing 1 kg of yarn for the specified month are also entered. Data on air temperature, one of the most critical parameters affecting production, is available. All these data are easily obtained through invoices and the MRP (Manufacturing Resource Planning) software used in the operation. Invoices arrive in the second week of the following month for each month. The accuracy of the data is ensured by checking the invoices archived in accounting. Leo Textile is used as the MRP software, where daily work orders, planned Gantt charts for production, and monthly, and annual production reports are located. These data are maintained by the person responsible for production. In addition to all these data, the hourly and monthly costs of an employee can be calculated with the maintained energy, water, andproduction data.

Table 1. UT1 2011 – 2023 Data Set

Year	Ay	Bill Amount TL			Consumption				Ges Production	*1.Dyeing Amount*	Reproses Quantity	*Re-proses %*	∑ Dyeing Amount	∑ Packing Quantity
		DG-015	S060	E0060	GasSm3	Wwater m3	W.water Su m3	Electric kW	Electric kW					
2011	1	₺113.760	₺24.166	₺54.001	196.891,5	37.931,0		312.642,0		*283.705 kg*	50.526 kg	*15,1%*	334.231 kg	326.795 kg
2011	2	₺108.012	₺21.028	₺62.621	186.942,6	32.437,0		311.526,0		*306.814 kg*	48.169 kg	*13,6%*	354.983 kg	322.974 kg
2011	3	₺117.004	₺22.130	₺56.619	202.505,5	34.710,0		330.822,0		*366.167 kg*	50.916 kg	*12,2%*	417.083 kg	402.166 kg
2011	4	₺90.682	₺18.797	₺49.592	156.949,0	29.429,0		289.638,0		*282.950 kg*	40.782 kg	*12,6%*	323.732 kg	350.526 kg
2011	5	₺75.074	₺15.741	₺39.773	129.934,4	24.587,0		232.938,0		*190.741 kg*	17.933 kg	*8,6%*	208.674 kg	259.329 kg
2011	6	₺82.555	₺19.720	₺45.306	142.881,9	30.896,0		263.484,0		*244.784 kg*	32.384 kg	*11,7%*	277.168 kg	292.469 kg
2011	7	₺81.788	₺21.870	₺48.939	141.554,8	32.179,0		284.922,0		*235.284 kg*	15.291 kg	*6,1%*	250.575 kg	287.759 kg
2011	8	₺69.950	₺19.632	₺45.205	119.914,4	29.280,0		264.204,0		*257.171 kg*	11.289 kg	*4,2%*	268.460 kg	296.090 kg
2011	9	₺96.609	₺22.936	₺45.326	165.615,5	34.268,0		267.858,0		*261.817 kg*	16.419 kg	*5,9%*	278.236 kg	325.275 kg
2011	10	₺112.226	₺23.638	₺54.322	168.315,2	35.315,0		311.454,0		*306.349 kg*	13.807 kg	*4,3%*	320.156 kg	367.797 kg
2011	11	₺109.496	₺21.946	₺47.541	164.221,4	32.766,0		272.574,0		*273.053 kg*	21.306 kg	*7,2%*	294.359 kg	297.995 kg
2011	12	₺128.221	₺25.883	₺58.952	192.305,3	38.622,0		326.556,0		*315.048 kg*	27.863 kg	*8,1%*	342.911 kg	366.334 kg

Day Steam	Daily Dyeing Quantity	Islandenim Production	Exhange Rate: TL/$	Cost Per 100kg of Yarn($/100kg)			Yarn Consumption per kg (∑Dyeing)			Energy Unit Price			Average Air Temperature
				Energy	**T'siz Energy**	**T'siz Labor**	gas Sm3	Water ton	Electric kW	gas TL/Sm3	Water TL/m3	Elk TL/kW	
28	11.937 kg	13.347 kg	1,5980	$34,55	$40,43		*0,5665*	*0,109*	*0,899*	₺0,58	₺0,64	₺0,17	10 °C
27	13.148 kg	7.119 kg	1,5917	$33,25	$38,36		*0,5163*	*0,090*	*0,860*	₺0,58	₺0,65	₺0,20	11 °C
30	13.903 kg	5.627 kg	1,5352	$30,16	$34,30		*0,4791*	*0,082*	*0,783*	₺0,58	₺0,64	₺0,17	13 °C
24	13.489 kg	5.186 kg	1,5130	$31,96	$36,49		*0,4772*	*0,089*	*0,881*	₺0,58	₺0,64	₺0,17	16 °C
28	7.453 kg	8.346 kg	1,5848	$37,97	$41,39		*0,5987*	*0,113*	*1,073*	₺0,58	₺0,64	₺0,17	20 °C
29	9.558 kg	4.272 kg	1,6146	$32,48	$36,70		*0,5077*	*0,110*	*0,936*	₺0,58	₺0,64	₺0,17	25 °C
29	8.641 kg	12.154 kg	1,6721	$34,74	$36,88		*0,5388*	*0,122*	*1,084*	₺0,58	**₺0,68**	₺0,17	28 °C
28	9.588 kg	10.022 kg	1,7442	$27,75	$28,92		*0,4306*	*0,105*	*0,949*	₺0,58	₺0,67	₺0,17	29 °C
29	9.594 kg	11.217 kg	1,8499	$30,79	$32,64		*0,5722*	*0,118*	*0,925*	₺0,58	₺0,67	₺0,17	27 °C
28	11.434 kg	22.484 kg	1,7446	$31,82	$33,15		*0,4912*	*0,103*	*0,909*	**₺0,67**	₺0,67	₺0,17	21 °C
24	12.265 kg	19.271 kg	1,8396	$31,02	$33,28		*0,5236*	*0,104*	*0,869*	₺0,67	₺0,67	₺0,17	13 °C
29	11.825 kg	16.265 kg	1,8876	$31,43	$34,07		*0,5354*	*0,108*	*0,909*	₺0,67	₺0,67	**₺0,18**	10 °C

The tables 1 provided above exhibit monthly data for the year 2011. Each year encompasses 12 rows of data, with each row consisting of 31 data points. Thus, there is a cumulative total of 4464 data points spanning from 2011 to 2023.These data are crucial for calculating the unit cost per kg. Yearly variations in the unit costs of electricity, water, and natural gas, as well as their impact on production, are observed. Among these data, the variance in electricity consumption relative to monthly production is greater compared to natural gas and water consumption. Among these data, the variance in electricity consumption relative to monthly production is greater compared to natural gas and water consumption. Electricity is predominantly generated from hydroelectric plants and nuclear, and thermal power stations. In Turkey, although some electricity is self-generated, there is a dependency on external sources for the rest. Based on the data on "final energy consumption by sectors" released by the Ministry of Environment and Urbanization, the industrial sector, followed by the service sector, constitutes the highest consumer of electricity.

Archiving and analyzing energy data is of great importance. To be preferred among textile factories, it is essential first to conduct thorough observations and then to monitor production and consumption data. Based on the results of these observations and monitoring, necessary efficiency-enhancing measures should be implemented. As shown in Tables 2 and 3, only the data for the year 2011 are presented as examples. The data from the years 2011 to 2022 are expected to provide insights into future electricity consumption using LSTM and ANN methods. Based on the results of these predictions, the company plans to implement efficiency measures in the field of energy.

3.2 Analysis of Data Using the ANN Method

(ANNs are machine learning models that mimic the neural functioning of the human brain, capable of learning complex patterns and data relationships. Fundamentally developed as an analogy of how neurons in the brain interact with each other, ANNs comprise inputs, outputs, and one or more hidden layers situated between these two. The input layer provides external data to the ANN, which is then transmitted to one or more hidden layers. These hidden layers perform various transformations and calculations on the data, serving the functions of feature extraction and pattern recognition. Each neuron processes the incoming data with weights and a bias value. These weights are continuously adjusted and optimized during the training process.

The outputs of the neurons are generally processed by an activation function (such as sigmoid, or ReLU), ensuring that the output falls within a specific range. The output layer receives processed information from the hidden layers to generate final predictions or classifications. The application of ANNs can vary depending on the dataset and be used for a wide range of problems. In the field of textiles, the ANN method is utilized in numerous areas, which can be outlined as follows:

- **Fabric Defect Detection:** ANNs can be used for detecting defects on fabric surfaces. Utilizing high-resolution images, ANN models are capable of identifying irregularities, stains, or other flaws on the fabric surface and classifying them.
- **Color Matching and Prediction:** Color matching is crucial in dyeing and printing processes. ANNs are used to predict the necessary amounts of dye to achieve a specific color recipe. This is highly effective in ensuring color consistency and reducing production costs.
- **Fabric Properties Prediction:** ANNs can be used to predict the physical and mechanical properties of fabrics, such as durability, flexibility, and water resistance. This aids in material selection and product design processes.
- **Fashion Trend Analysis and Prediction:** In the fashion industry, ANNs are used to analyze consumer preferences and market trends, and to predict future fashion trends. This assists designers and retailers in more effective inventory management and product variety planning.
- **Quality Control and Classification:** In textile product quality control processes, ANNs can be used to automatically classify and evaluate the quality of products. This facilitates the detection of defective products and the improvement of production processes.
- **Optimization of Production Processes:** ANNs can be used to increase the efficiency of textile production processes by optimizing production parameters and reducing energy consumption.
- **Material and Fiber Selection:** In the development of new textile products, ANNs can be used to determine the most suitable material and fiber combinations. This is important for reducing costs and enhancing product performance.

The training of ANNs usually involves methods such as backpropagation and gradient descent. During this process, the weights are updated to minimize the difference between the network's predictions and the actual values. At the end of the training process, the ANN has learned the data relationships for a specific problem and becomes capable of making predictions.

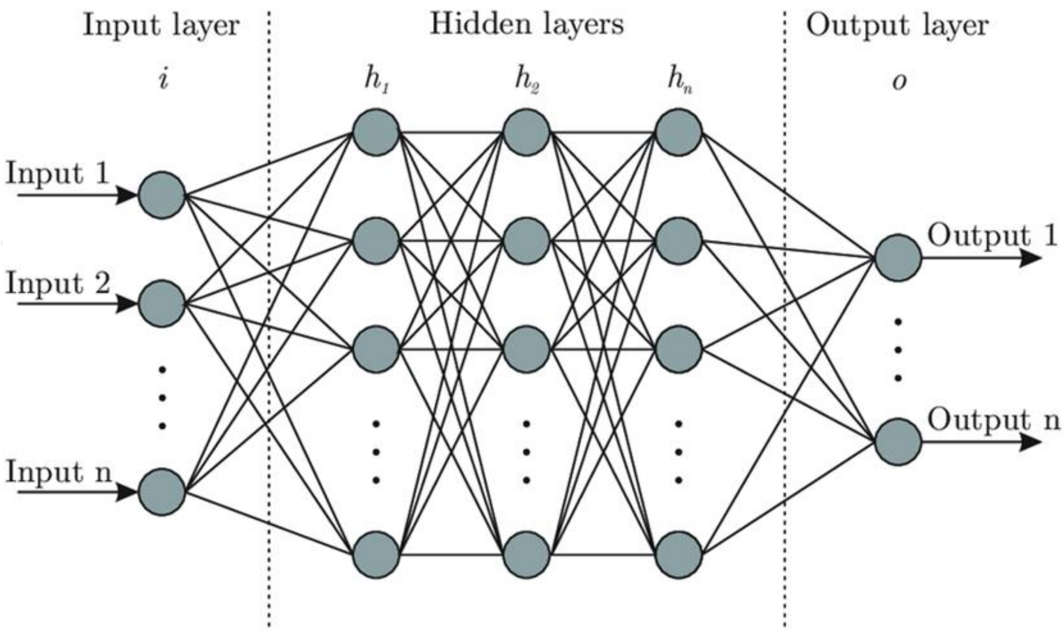

Figure 5. The structure of Artificial Neural Network

The structure of an ANN typically consists of multiple layers as shown in Figure 5, though it can also have a single input and a single output layer. The layers are the input layer, hidden layer, and output layer. The signal from outside is received into the neural network structure through the input layer. It is then transmitted to the output layer via the hidden layer, and as a result of the network, it is conveyed to the external environment through the output layer. The number of neurons in the hidden layer is chosen through trial and error to achieve the best results, while the number of neurons in the input and output layers is selected based on the nature of the problem. In this study, there is one input and one output layer. The input layer uses the previous time period's (t-1) electricity consumption amount, and the output layer uses the electricity consumption amount for the relevant time period (t). The data are monthly electricity consumption figures from the 2015-2021 period, which form the training dataset. The year 2022 constitutes the test dataset.

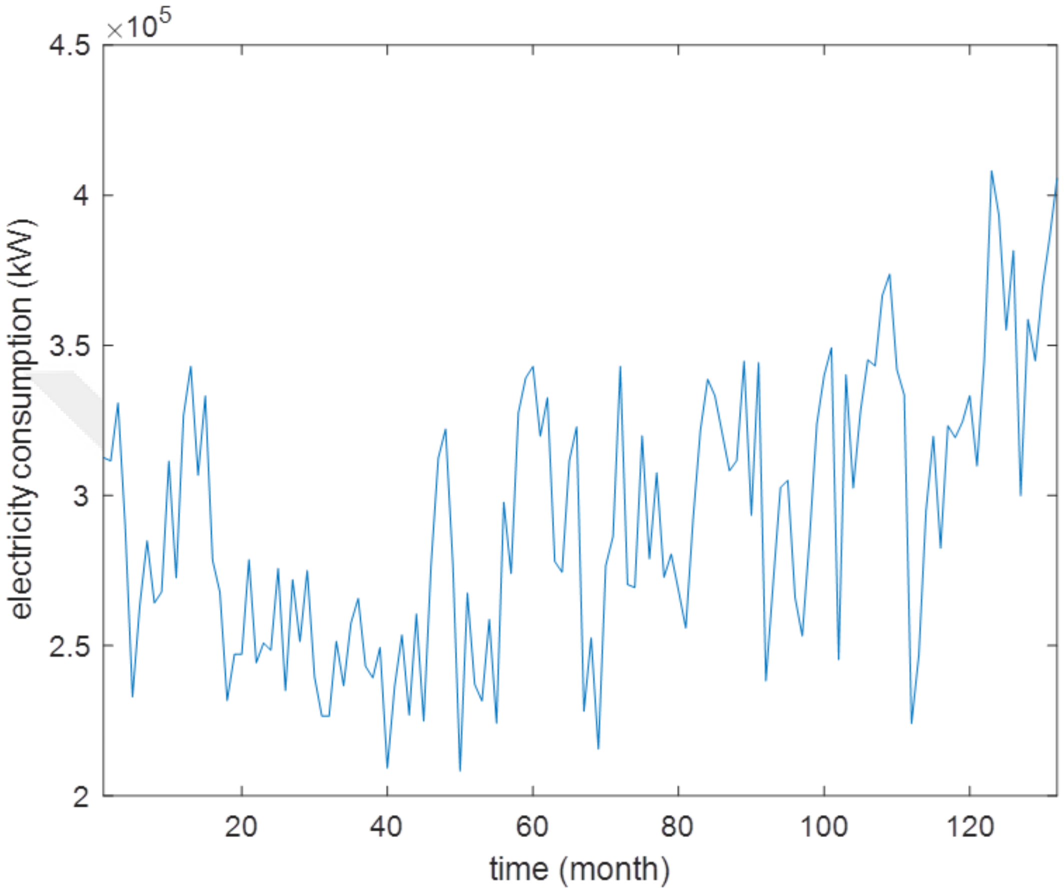

Figure 6. LSTM and ANN traning data

The data used in the training phase are presented in Figure 6. The data illustrated in this diagram have been commonly used in both ANN and LSTM methods. The graph contains monthly electricity consumption data for a period of 120 months. These data are obtained from invoices and have been verified for accuracy

3.3. Analysis of Data Using the LSTM Method

LSTM, proposed by Hochreiter and Schmid Huber for modeling time series, is a member of the Recurrent Neural Networks (RNN) family and is specifically designed for processing sequential data. While the backpropagation mechanism used by RNN structures during computation can cause problems in error backflow, the LSTM method provides long-range dependencies. LSTMs are distinguished by their capacity to learn long-term dependencies within sequential data. This means that LSTM is particularly effective in areas like time series data, natural language processing, and speech recognition. The fundamental idea of LSTM is that the network can retain necessary information for a long time and forget unnecessary information. This feature solves the short-term memory problem encountered by traditional RNNs. LSTM achieves this functionality through its unique cell structure and three different gate mechanisms: the forget gate, the input gate, and the output gate.

- **Forget Gate:** This gate determines which information from the cell's previous state should be forgotten. This is accomplished using a sigmoid function, producing a value between 0 and 1, where 0 means completely forgetting and 1 means completely remembering.
- **Input Gate:** This gate decides which new information needs to be added to the cell state. The new information is generated by a tanh layer and then multiplied by a sigmoid gate, which determines how much of this information should be added to the cell state.
- **Output Gate:** This gate determines the output to be passed to the next layer. It involves passing the cell state through a tanh function and then through a sigmoid gate, which decides how much of this output should be transmitted.

The training of LSTMs is usually carried out through backpropagation using the gradient descent algorithm. LSTMs are critical in many modern machine learning applications due to their ability to learn complex features of time series data and model long-term dependencies in sequential data. Furthermore, LSTMs have an internal memory unit and gate structure to overcome RNN training challenges such as vanishing and exploding gradients. Calculating specific values is critical for the architecture to function. Let's assume the presence of variables f_t for the forget gate, S for the candidate internal state, it for the input gate, ht for the memory cell state, ot for the output gate, and Ct for the internal memory of the unit. Figure 7 illustrates some of these variables

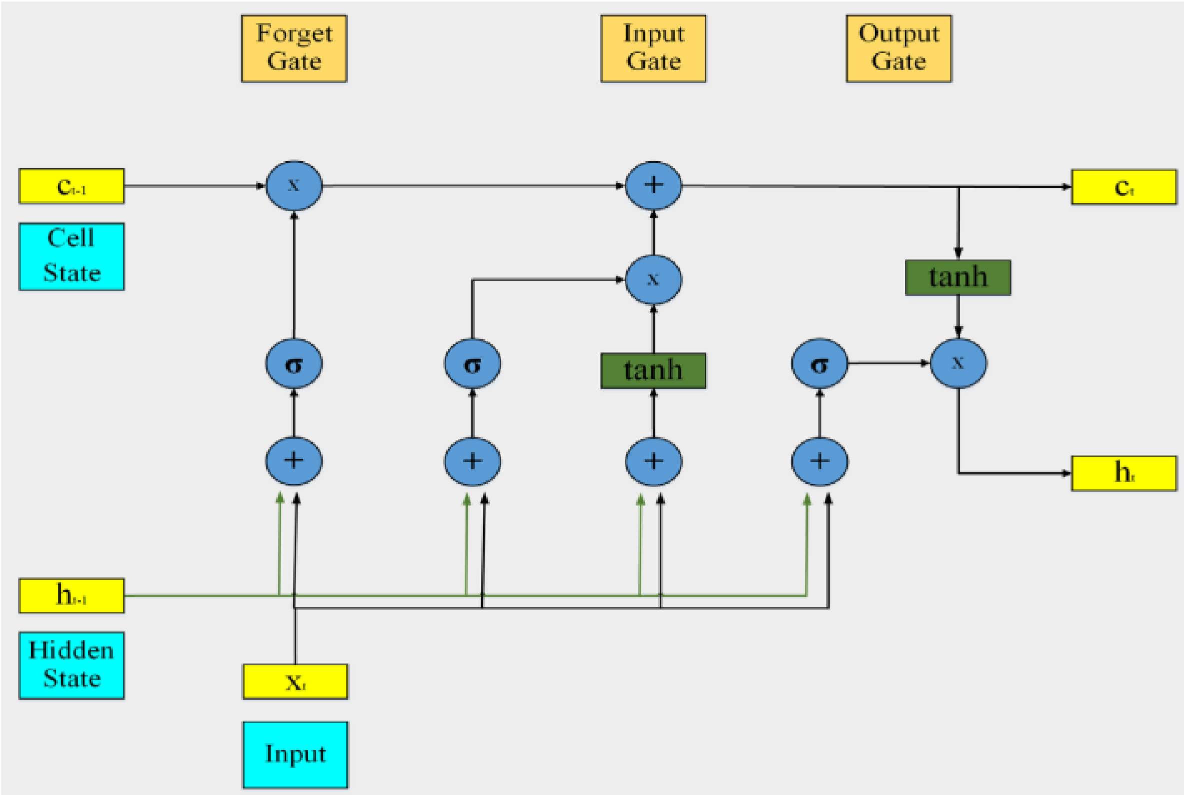

Figure 7. The structure of the LSTM Network method

In this situation, recursive equations of the LSTM method are defined as follows:

$$f_t = \sigma(W_f X_t + U_f h_{t-1} + b_f) \quad (1)$$

$$i_t = \sigma(W_i X_t + U_i h_{t-1} + b_i) \quad (2)$$

$$S = \tanh(W_c X_t + U_c h_{t-1} + b_c) \quad (3)$$

$$C_t = i_t S_t + f_t S_{t-1} \quad (4)$$

$$o_t = \sigma(W_o X_t + U_o h_{t-1} + V_o C_t + b_o) \quad (5)$$

$$h_t = o_t \tanh(C_t) \quad (6)$$

Here:

- σ and tanh are the activation functions,
- X is the memory cell's input vector at time t,
- W_i, W_c, W_o, W_f, U_c, U_i, U_f, U_o, and V_o are weightes of the neural wetwork.
- b_f, b_c, b_i, and b_o are biases.

In addition:

$$\sigma = \frac{1}{1+e^{-X}}$$

The Long Short-Term Memory (LSTM) method is employed in various applications within the textile industry. Some of its applications include:

- **Time Series Prediction:** In the textile industry, LSTM can be used to predict time series data such as raw material prices, demand forecasts, or market trends. This is critically important for improving production planning and inventory management.
- **Production Process Optimization:** LSTM can be used to enhance the efficiency of production processes. For example, production processes can be made more efficient by analyzing time-varying data such as machine performance data, production speeds, and quality control data.
- **Fabric Defect Analysis:** In fabric production, LSTM can detect fabric defects and flaws. In systems where fabric is continuously scanned and the development of defects over time is monitored, LSTM can provide high accuracy in defect detection and classification.
- **Quality Control:** LSTM can analyze process data and quality control test results to evaluate the quality of textile products. This helps in the early detection of faulty products and the improvement of production processes.
- **Demand Forecasting and Inventory Management:** Accurate forecasting of demand for textile products is important for optimizing stock levels. LSTM can provide more accurate demand forecasts by analyzing time series data such as past sales data and market trends.

- **Fashion Trend Analysis**: In the fashion industry, LSTM can be used to predict future fashion trends by analyzing time-varying data such as social media data and sales data.

As seen above, LSTM and ANN methods share many common areas of application. The advantages of the (LSTM) method over (ANN) particularly become evident when working with sequential and time series data.

Learning Long-Term Dependencies: LSTM can learn connections between distant states over time. This is particularly effective in understanding long-term dependencies in sequential data, which is crucial. ANNs often fall short in modeling these kinds of long-term dependencies.

Sequential Data Processing: LSTM is designed to understand the natural flow of any sequential data, such as text, speech, music, or time series data. ANNs are typically more suitable for processing independent data points and are limited in modeling sequential contexts.

Overcoming Gradient Issues: LSTM includes special gate mechanisms to address vanishing gradient and exploding gradient problems, enabling effective learning even in long training sequences. In ANNs, these problems can lead to significant issues, especially in deep network structures.

Flexibility and Adaptability: LSTM can adapt to distinct types and lengths of sequential data, which is important when working with variable-length inputs such as text and speech. ANNs are designed based on fixed-size inputs and can be less flexible with such data.

Retaining Contextual Information: LSTM can process current inputs in light of past information stored in its memory, which is highly valuable in applications like language processing where context matters. ANNs typically process each input independently and have limited capacity to integrate such contextual information.

These advantages demonstrate that LSTM is superior, particularly in processing complex sequential data sets and modeling time-varying dynamics, compared to ANNs. However, both methods have their application areas and advantages, and the choice depends on the specific problem definition and data structure.

3.4. Layout and Process Improvement Analysis

The textile industry holds a significant place in Türkiye's industry in terms of exports and employment. Critical markets within this sector include carpet, home textiles, knitwear, and hand knitting. Continuity in quality and competitiveness in these markets depends on a series of complex processes, one of which is the yarn dyeing process. Yarns are dyed to achieve desired results in terms of appearance and functionality. The yarn dyeing process affects both quality and competitiveness, and the optimization of processes and layouts in facilities plays a significant role. Layout and process optimization in yarn dyeing facilities involve several factors. Firstly, the physical arrangement of the facility should be considered. Different machines and equipment are used during yarn dyeing, bobbin dyeing, and hank dyeing processes. Proper placement of these machines and equipment speeds up the processes and optimizes energy use. Worker safety and ergonomics must also be considered, as a comfortable working environment can increase productivity.

Another critical aspect of layout and process optimization in yarn dyeing facilities is the management of material flow. How yarns are transported before and after dyeing can greatly impact the design of the facility. If material flow is not optimized, processes can be disrupted, and production efficiency can decrease.

Additionally, layout and process optimization in yarn dyeing facilities include creating the necessary infrastructure for workers to work effectively. An appropriate arrangement is required for workers to easily access yarns and effectively communicate with machines. This allows operators to perform their jobs more efficiently. Layout optimization also has the potential to save costs. More efficient material flow and energy usage reduce operating costs while increasing worker productivity, thereby reducing labor costs.

Proper layout and material flow management improve production processes and reduce costs. It also allows to produce higher-quality products by increasing worker efficiency. Therefore, layout optimization should be given significant importance in the design and operation of yarn dyeing facilities. Considering these reasons, a dyeing facility of a factory producing for the four critical markets of the textile sector - carpet, home textiles, knitwear, and hand knitting - has been examined. In this facility, yarns are dyed in bobbin, vat hank, arm hank, and degrade styles, and the workflow created depending on the order and process is shown in Figure 8.

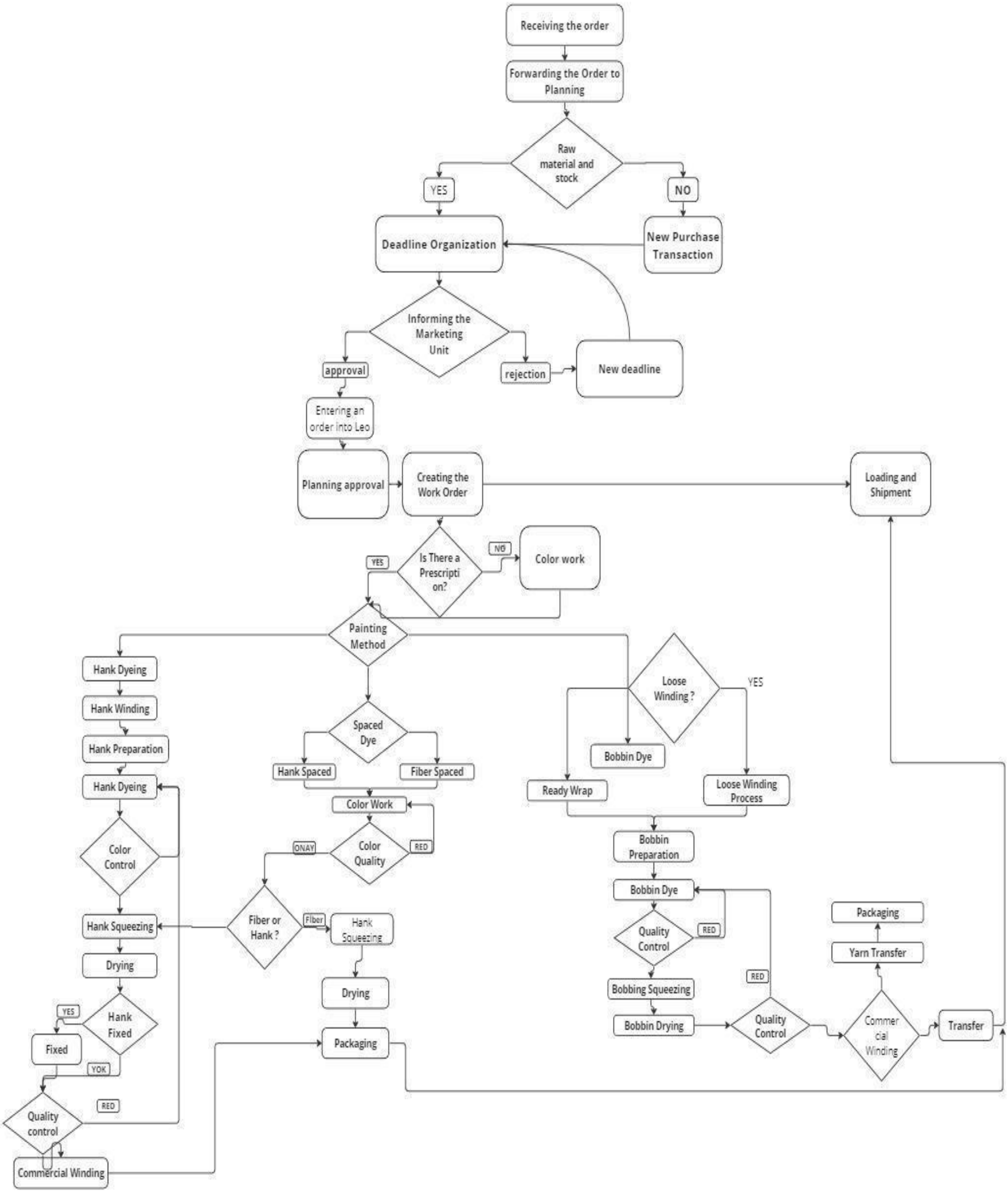

Figure 8. UT1 Workflow Diagram Processes

The workflow diagram that has been created lays the foundation for analyzing the production operations and material flow process of the enterprise. Following the creation of the workflow diagram to enhance efficiency through optimizing the layout plan, the current machine layout plan has been drafted as shown in Figure 9.

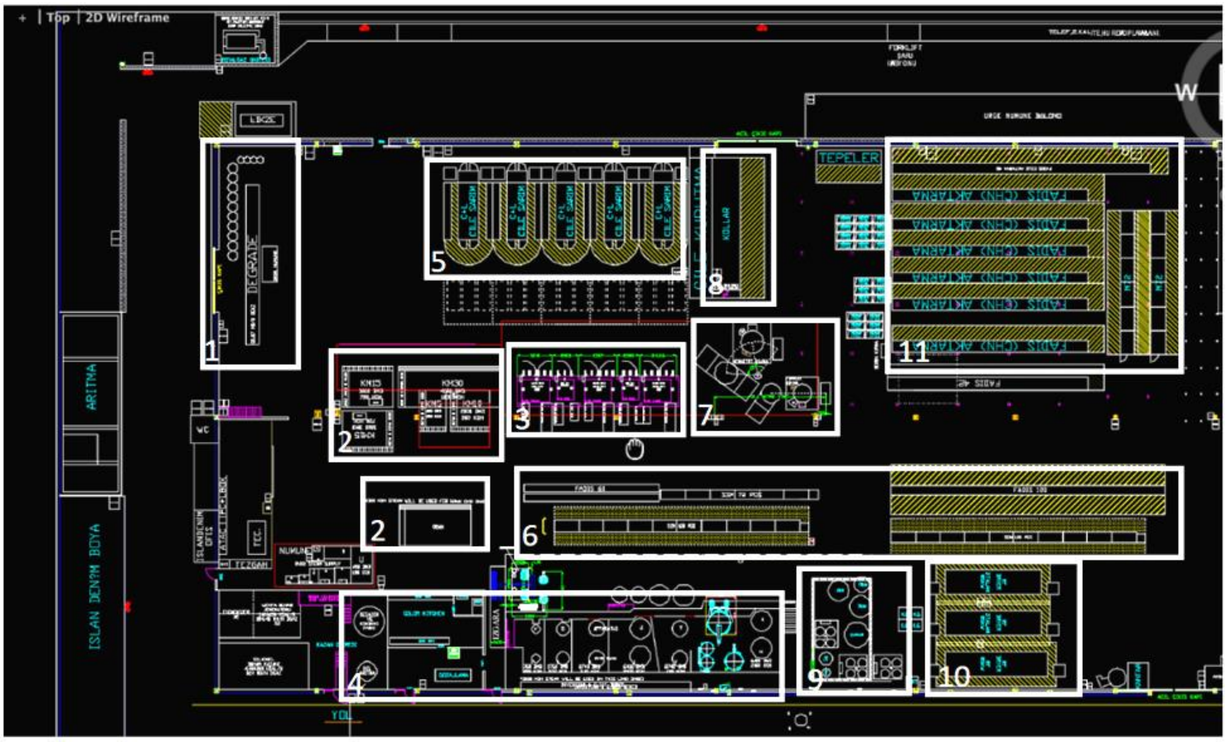

Figure 9. UT1 Current Layout Plan

In the layout plan, the degrade dyeing machine, arm hank dyeing machines, vat hank dyeing machines, bobbin dyeing vats, hank preparation machines, soft winding machines, hank squeezing machines, hank drying machines, bobbin squeezing machines, bobbin drying machines, and commercial winding machines are shown. The corresponding location numbers are given in Table 3.

Table 2. Dyeing Plant Current Layout Plan

NO	LOCATION NAME
1	Spaced Dyeing Machine
2	Hank Dyeing Machine(with arm)
3	Hank Dyeing Machine
4	Bobbin Dyeing Machine
5	Hank Preparation Machines
6	Soft Winding Machines
7	Hank Squeezing Machines
8	Hank Drying Machines:
9	Bobbin Squeezing Machines
10	Bobbin Drying Machines
11	Commercial Winding Machines

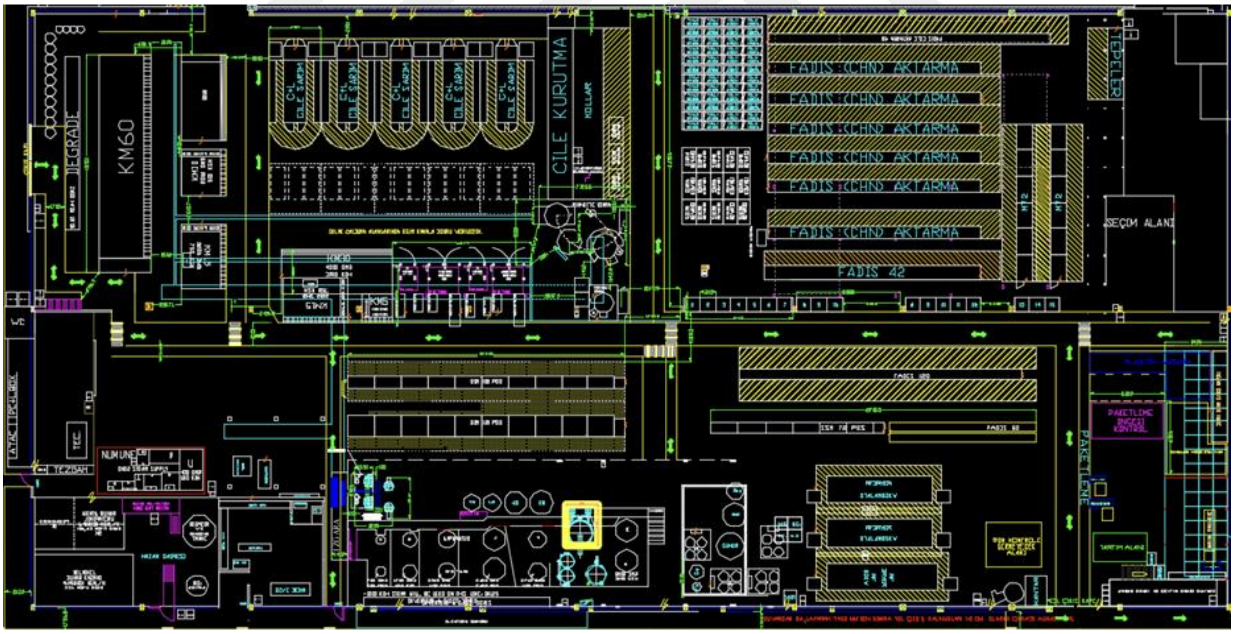

Figure 10. UT1 New Layout Plan

As depicted in Figure 10, a process-oriented Spaghetti diagram was generated through the development of a machine layout plan. This diagram serves to visualize procedures and movements, conduct process analysis, optimize routes, and conceptualize the placement of workers and equipment.The arm hank machines KM10, KM15, and KM20 have been installed parallel to the KM60 machine, consolidating the arm dyeing line in a single area. This has shortened the distance traveled by machine operators along with hank carriers. Space has been made available by relocating the KM20 machine, either for a new machine or for storage purposes. Following the Spaghetti diagram, a new machine, the KM60 arm hank dyeing machine, has been suitably placed in the production line, and the production quantity of arm hank machines has been increased by 70% with the new machine. The hank squeezing machines have been repositioned closer to the hank dyeing line and aligned to ensure continuous and uninterrupted emergency exits. The SMM machines forming the soft winding line have been placed parallel to each other for more effective use. Additionally, the diagram and studies conducted have identified bottlenecks causing delays and extended lead times in the production line. One such bottleneck, the bobbin squeezing line, has been addressed by acquiring a new machine and increasing the number of squeezing arms from 108 to 172, appropriately integrating it into the production line.

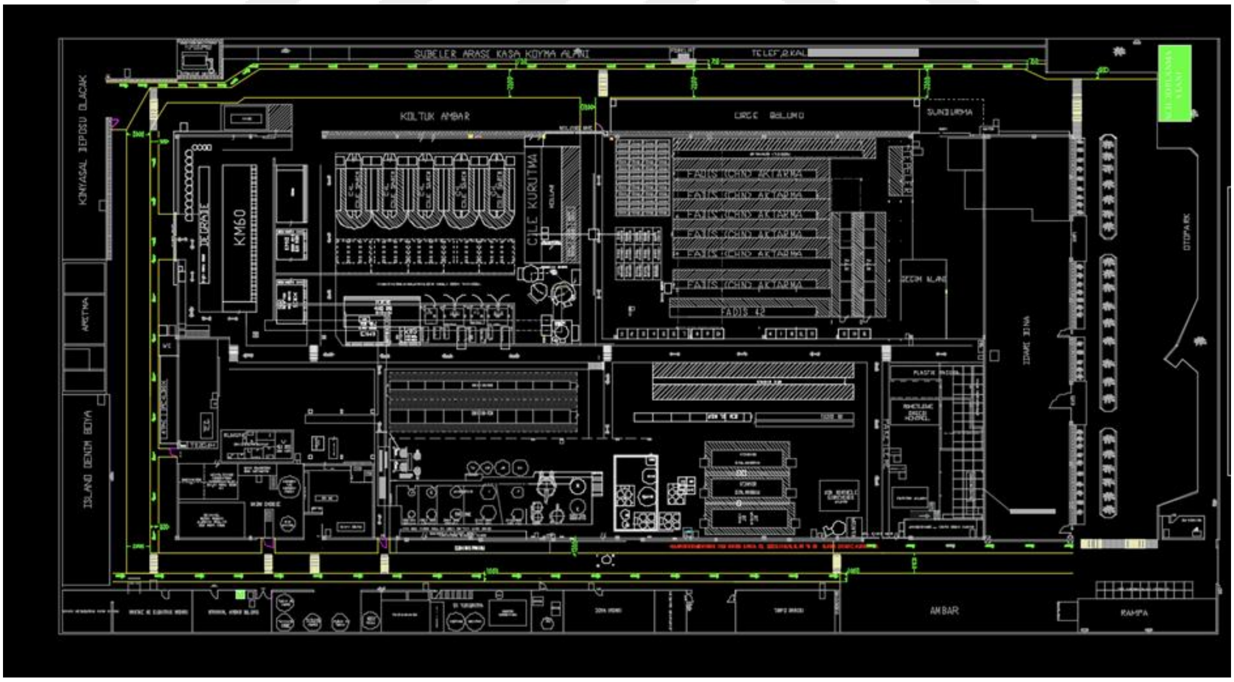

Figure 11. UT1 Production Outer Ring Road Plan

Taking into consideration the production conditions and the working areas of the staff, a layout plan has been developed that includes internal routes directly leading to emergency exits.

Additionally, as shown in Figure 11, external perimeter routes have been established to facilitate the safe evacuation of personnel to the emergency assembly areas marked in green. Storage areas have also been delineated and restricted.

Figure 12. UT1 Packaging Area Before After

Furthermore, as part of the project, a needs assessment was carried out for the packaging section. A platform capable of holding up to 48 pallets, with a stacking capacity of up to 3 meters, was designed and installed. As illustrated in Figure 12, this setup allows the packaging unit's supplies to be conveniently placed in the current location, reducing personnel movement. Additionally, a storage space for supplies was established, resulting in a 60% increase in capacity.4. Analysis and Discussion

In this study, the dataset used was generated in a yarn dyeing factory in the textile sector. The data were recorded monthly from 2011 to 2023. The study includes variables such as consumption of chemical dyes, production in kilograms, and invoice values, while ambient temperature has also been considered for forecasting purposes.

Considering these factors, the rapid changes in electricity consumption, the high unit cost of electricity, and our partial dependence on external sources for electricity production have made electricity the most significant factor affecting competitive strength in the market. When examining the cost per kilogram of yarn, the primary factor in reducing costs has been identified as electricity.

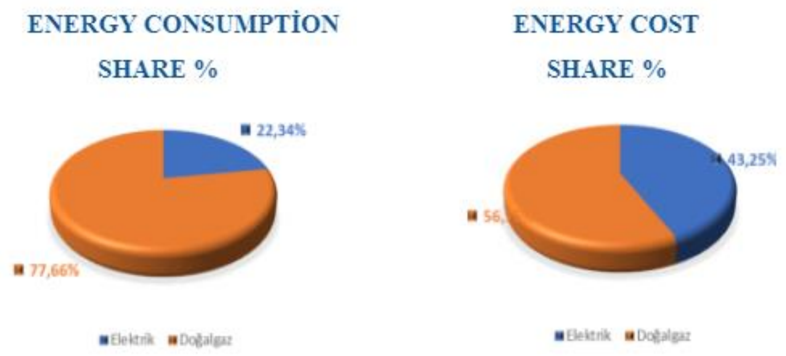

Figure 13. Facility Energy Consumption Shares in 2020

Upon calculating the randomly selected peak data from the year 2020 in the factory, the electricity and natural gas consumption amounts and their costs are as stated above. As seen in Figure 13, electricity consumption constitutes 22.34%, while natural gas consumption accounts for 77.66%. In terms of cost, electricity represents 43.25% and natural gas comprises 56.75%.

Table 3. Energy Consumption and Cost Information in 2020

	Consumption				Cost		Unit Cost
Energy Type	**Quantity**	**Unit**	**TEP**	**% Total**	**TL**	**% Total**	**TL / TEP**
Electricity	3.717.224	kWh	319,7	22,34	1.916.032,6	43,25	5.993,6
Natural gas	1.347.208	Sm3	1.111,4	77,66	2.514.125,0	56,75	2.262,0
Total	-	-	1.431,1	100,0	4.430.157,6	100,0	

Similarly, when looking at the Table 4 average values for the years 2018-2020, electricity accounts for 24% while natural gas is 76%. In terms of cost, the figures are 43% for electricity and 57% for natural gas. As can be seen, in terms of factory costs, electricity is a more significant factor compared to natural gas. As is evident in the literature, the importance of climate change and carbon footprint is increasingly recognized, especially in the industrial sector where energy consumption is most intense. Necessary studies should be conducted in this area. Firms should engage in research and development, execute national and international projects, and collaborate within the university-industry framework, aiming to reduce the per unit electricity consumption. In the textile industry, while purchasing decisions were based on product price and quality in previous years, nowadays, the capability to produce within the framework of social compliance is prioritized. One of the most important aspects of this approach is reducing the amount of energy and water consumed per unit. Additionally, with the signing of the Paris Agreement, the management of the climate change regime and the significance of the carbon footprint have become even more crucial. In our country, as of October 1, 2023, necessary limitations and tax liabilities have been introduced for companies in iron steel, cement, electricity, and hydrogen production. Similar restrictions and tax liabilities are expected in the textile sector in the coming years. Considering all these results, analyzing and forecasting electricity data and conducting improvement studies based on these forecasts are of great importance. Therefore, using Matlab, ANN, and LSTM methods were applied where electricity consumption data from 2015 to 2021 were used as the training set, and the data for 2022 were used as the test set.

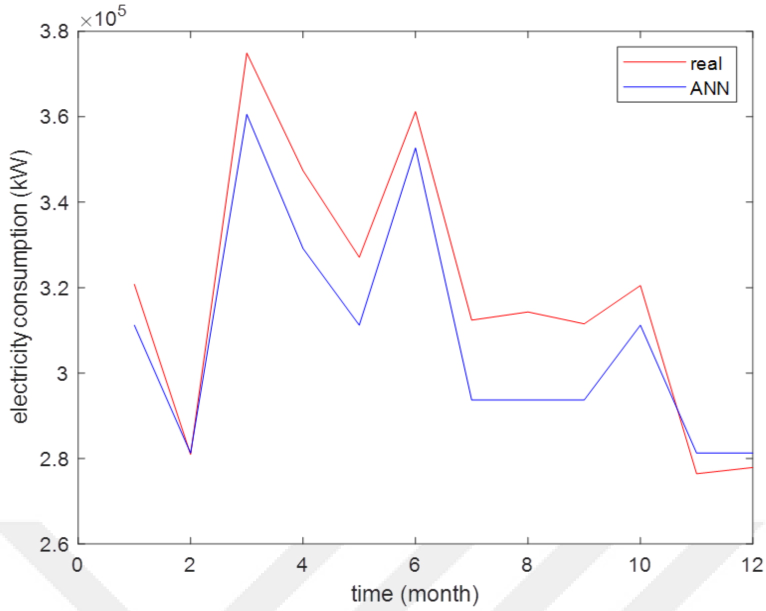

Figure 14. ANN Result

The results obtained from the ANN method are shown in Figure 14. In the graph, the curve represented in red indicates the actual consumption values for the year 2022. The curve depicted in blue represents the predicted values for 2022 as forecasted by the ANN method. Upon examining the results, it is observed that despite the high error value in the first curve, there is a tendency to capture the actual value at peak points.

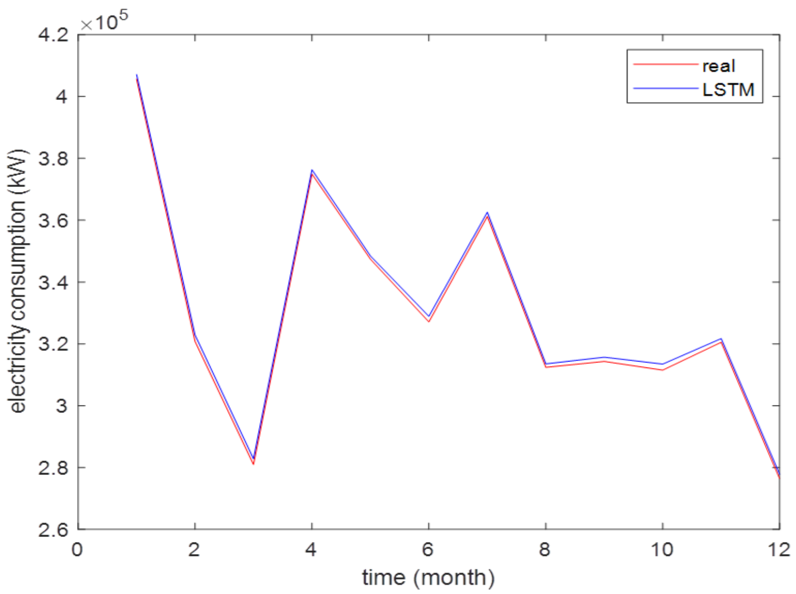

Figure 15. LSTM Result

The graph above displays the results obtained from the LSTM model Figure 15. The curve in red represents the actual values, while the curve in blue illustrates the predicted outcomes. It is evident here that the predictions closely approximate the actual data.

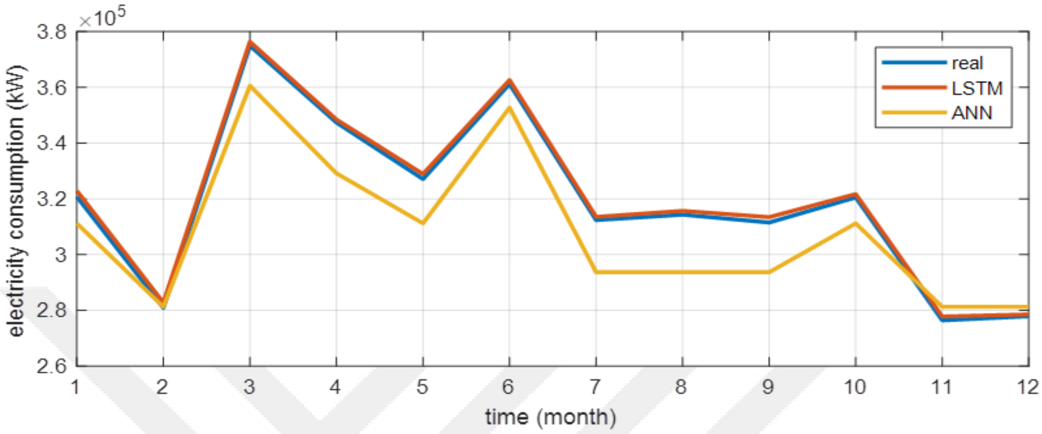

Figure 16. LSTM, ANN, and Real Data Results

In graph 16 above, the graph presents a comparison of the actual data with the prediction results obtained from both the LSTM and ANN models on the same graph. Among the two methods utilized for electricity consumption forecasting, the LSTM has yielded results that are closer to the actual figures.

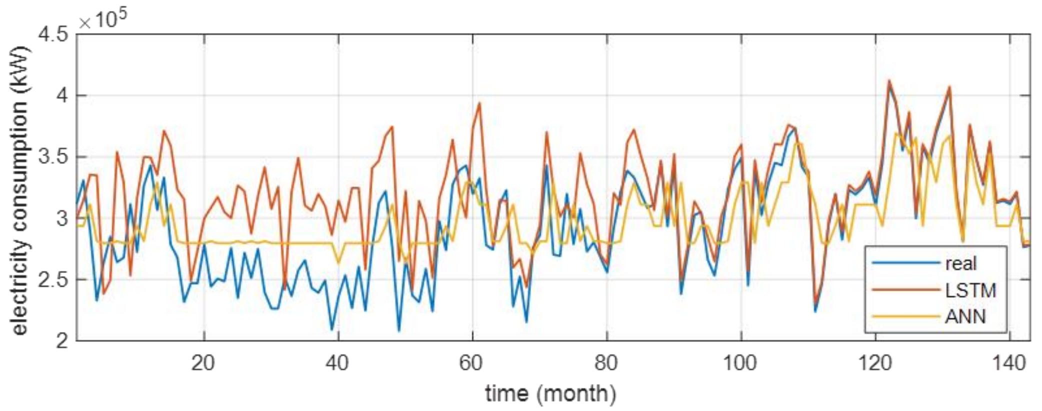

Figure 17. Training and Testing Phase Chart

Predictions are conducted using a Long Short-Term Memory (LSTM) Neural Network, utilizing 84 months of data during the training phase and 12 months of data in the testing phase.

To demonstrate the accuracy of the time series data model, a comparison is made with the Artificial Neural Network (ANN) method. At the end of the study, three distinct error criteria are employed to compare the outcomes derived from both methods.These criteria are Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE), and Theil's Inequality Coefficient (TIC).

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}} \tag{8}$$

$$MAPE = \frac{1}{n}\sum_{i=1}^{n} \vee \frac{X_t - X_g}{X_g} \vee \tag{9}$$

$$TIC = \frac{\sqrt{\frac{1}{n}\sum_{n=1}^{n} \left(X_t - X_g\right)^2}}{\sqrt{\frac{1}{n}\sum_{n=1}^{n} (X_t)^2} + \sqrt{\frac{1}{n}\sum_{n=1}^{n} \left(X_g\right)^2}} \tag{10}$$

Table 5 presents the results of the ANN and LSTM algorithms using error criteria. The linear regression values of the prediction results are also provided in Table 4.

Table 4. Performance results of LSTM and ANN methods

	MAPE	**RMSE**	**TIC**
ANN	8.8081	4.0617e+04	0.0214
LSTM	0.4480	1.4922e+03	0.0023

MAPE: MAPE measures how different the predicted values are from the actual values in percentage terms. A lower MAPE value indicates that the model's predictions are closer to the actual values, typically signaling better model performance. Particularly for LSTM and ANN models, the MAPE value is used to assess the overall accuracy of the models.

RMSE: RMSE is the square root of the average of the squares of the prediction errors and measures how much deviation there is in the model's predictions from the actual values. A lower RMSE value indicates that the predictions are closer to the actual values, thereby suggesting a more accurate model. In LSTM and ANN models, RMSE indicates how well the model captures the variance in the dataset.

TIC: TIC is a statistic that measures how dispersed the model's predictions are about the actual values. As the TIC value approaches zero, the model's predictions become closer to the actual values. This coefficient is particularly useful for comparing data of different scales.

For LSTM and ANN models, these error metrics are utilized to evaluate the prediction performance of the models. Generally, lower values of these three error metrics indicate high accuracy of the model. Comparative analysis of these metrics plays a significant role in determining which model (LSTM or ANN) is more suitable for a specific dataset. If one model's MAPE and RMSE values are significantly lower than the others, it is concluded that this model's predictions are more accurate.

The graphical results of electricity consumption predictions are presented in Figure 21. As can be seen in the figure, the estimation results obtained with LSTM are more consistent with the actual values. Upon examining the results, it is observed that there is a more successful approach with the LSTM method, especially at the peak point. We can also see these results from the outcomes of the formulas.

All these results, along with possible electrical improvements in the factory based on energy audit outcomes, annual savings, and payback amounts, are given in the table.

Table 5. Energy Audit Results and Improvement Points

Precautions		Energy Type	Savings Type				CO2 Reduction Quantity	Investment Cost	Payback Period
			AMOUNT	ORJ. UNIT	TEP/YEAR	TL/YEAR	TON/YEAR	TL	YEAR
1	Air Leakages	Electricity	81.240	kWh/Year	7,0	75.553	48,13	18.000	0,24
2	Replacement of Compressor with a More Efficient Compressor	Electricity	85.050	kWh/ Year	7,3	79.097	50,39	373.000	4,72
3	Condensate Project after Dryer	Electricity	8.551	kWh/ Year	0,7	7.952	5,07	15.000	1,89
4	Replacement of Dryer with a More Efficient Dryer	Electricity	20.250	kWh/ Year	1,7	18.833	12,00	182.780	9,71
5	LED Fixture Conversion	Electricity	6.552	kWh/ Year	0,6	6.093	3,88	112.464	18,46
6	Design of Bobbin Dyeing Vat Circulation Pump Motors as Directly Coupled	Electricity	46.030	kWh/ Year	4,0	42.808	27,27	60.000	1,40
7	Variable Speed Drive Application in Cooling Tower Fan Motor	Electricity	28.599	kWh/ Year	2,5	26.597	16,94	7.786	0,29
8	Replacement of Ulusoy Textile TR-1 Transformer Compensation Panel with Harmonic Reactor Panel	Electricity	66.246	kWh/ Year	5,7	61.609	39,25	40.000	0,65

Following energy audits, the investment budgets of businesses must be considered regarding the projects and recommendations that emerge. Financial models and support should be utilized in implementing these projects. Energy Performance Models and the Efficiency Enhancing Project (EEP) Support financially contribute to the feasibility of these projects for businesses. If no action is taken following energy audits (such as implementing projects or preventing losses and leakages), it will not be possible for businesses to reduce their energy intensity, nor will the energy audits achieve their real objectives.

Our country aims to increase efficiency in all processes from the production to the final consumption of energy by efficiently and environmentally consciously utilizing energy resources. This has been emphasized in the National Energy Efficiency Action Plan, setting action plans to reduce energy intensity in each industrial sub-sector by at least 10%. The Energy Efficiency Law, which came into effect on May 2, 2007, was the first step in energy efficiency in our country, followed by the Regulation on Increasing Efficiency in the Use of Energy Resources and Energy, which came into force on October 27, 2011, and was last updated on January 25, 2020. Under this regulation:

• Industrial establishments with an annual total energy consumption of 1,000 TOE and above are required to conduct an energy audit every four years.

• Buildings in the service sector with a total construction area over 20,000 square meters are required to conduct an energy audit every seven years.

As shown in the table above (Table 6), there are many points of electricity savings in the factory, such as air leakage, replacing compressors with more efficient ones, condensate traps after dryers, replacing dryers with more efficient ones, changing to LED fixtures, implementing speed drives on cooling tower fan motors, and replacing compensation panels with harmonic reactor panels. The table includes investment costs, payback periods, and CO2 reduction amounts. Based on these results and the budget, necessary applications have been started in the factory.

In the study conducted at Ulusoy Textile Dyeing Plant, the aim was to identify existing energy efficiency potentials. The projects identified in the audits conducted at the facility will achieve approximately 342,518 kWh/year of electricity savings and about 318,542 TL in savings annually.

The integration of solar power plants (SPPs) as a renewable energy source in factory environments offers many benefits in line with environmental sustainability and economic efficiency. Firstly, adopting solar energy significantly reduces the carbon footprint of production operations, contributing to global efforts to combat climate change. This transition to renewable sources not only aligns with environmental regulations and green initiatives but also enhances the ecological reputation of the factory among stakeholders. Economically, solar power plants offer a cost-effective energy solution in the long term. Despite the initial investment, the subsequent reduction in energy costs leads to significant savings, making it a financially viable option for factories aiming to minimize operational expenses. Additionally, solar energy provides reliability and energy security, reduces dependency on traditional energy grids, and decreases sensitivity to fluctuations in energy prices. The use of solar energy is also in line with corporate social responsibility strategies, demonstrating a commitment to sustainable practices. This not only appeals to an environmentally conscious consumer base but also positions the factory as a forward-thinking institution in an increasingly eco-aware market. Furthermore, in some regions, factories can benefit from government incentives or subsidies for using renewable energy sources, further enhancing the economic appeal of adopting solar energy.

Table 6. 2023 Monthly Solar Power Plant Gain Table

DATE	GES PRODUCTION (FUSION SOLAR) KW	GES PRODUCTION (FATURA) KW	FACILITY CONSUMPTION (FATURA) KW	TOTAL FACILITY CONSUMPTION KW	ENERJİSA PAYMENT KW	GES PRODUCTION/CONSUMPTION
04/2023	83.619,00	0	234.649,00	318.268,00	-234.649,00	**26,27%**
05/2023	168.618,00	2.649,00	242.445,00	408.414,00	-239.796,00	**41,29%**
06/2023	166.258,00	59.678,00	156.195,00	262.775,00	-96.517,00	**63,27%**
07/2023	178.996,00	50.568,00	176.234,00	304.662,00	-125.666,00	**58,75%**
08/2023	156.538,00	21.158,65	221.581,00	356.960,35	-200.422,35	**43,85%**
09/2023	123.625,00	22.245,30	218.924,37	320.304,07	-196.679,07	**38,60%**
10/2023	105.172,00	17.348,00	211.676,00	299.500,00	-194.328,00	**35,12%**
11/2023	69.403,00	10.519,00	207.656,00	266.540,00	-197.137,00	**26,04%**
12/2023	53.650,00	11.135,00	220.559,00	263.074,00	-209.424,00	**20,39%**

As shown in Table 7, a profit is observed for the UT1 dyeing factory after the completion of the Solar Power Plant (SPP) project. The gain is around 60% during the summer months, while it decreases to about 25% in the winter months. This profit is achieved with 1914 panels, each with a capacity of 545 watts. The setup includes one transformer and eight inverter panels for a single SPP.

Table 7. 2023 Carbon Footprint

Energy Sources	Consumption Amount		Electricity Energy Equivalent	Coefficients	Total	Production	CO2 Amount
	Amount	Units	kWh	$kgCO_2/kWh$	CO2	kg	$kgCO_2/kg$
Electricity	**3.717.224**	**kWh**	**3.717.224**	**0,527**	**1.958.977**	**3.864.176**	**0,50696**
Natural gas	**1.347.208**	**Sm3**	**126.617**	**0,206**	**26.083**	**3.864.176**	**0,00675**
TOPLAM			**3.843.841**		**1.985.060**	**4.013.198**	**0,51371**

Textile factories constitute a significant component of the global carbon footprint, as these facilities often use substantial amounts of electricity and natural gas for energy-intensive processes. As seen in Table 8, the use of electricity and natural gas, primarily sourced from the combustion of fossil fuels, contributes to the increase in carbon dioxide (CO_2) emissions released into the atmosphere, thus exacerbating global warming and climate change. The energy needs of textile production, especially in processes such as heating, drying, dyeing, and printing, are substantial. Since a major portion of the energy used in these processes is derived from fossil fuels, the carbon footprint of the textile sector is considerable. This situation is concerning from an environmental sustainability perspective, necessitating the textile sector to enhance energy efficiency and transition to renewable energy sources as part of the fight against climate change. Moreover, this shift will be beneficial in reducing environmental impact and providing long-term cost savings. Therefore, efforts to reduce the carbon footprint of textile factories contribute not only to environmental but also to economic and social sustainability.

Through all the improvement efforts and the implementation of Solar Power Plants (SPPs), significant savings in electricity consumption per unit have been achieved. These results will serve as a guiding manual for many textile factories.

4. CONCLUSION

Many harmful natural events globally stem from carbon emission-driven climate change. The intensified consumption of fossil fuels to meet increasing energy needs is augmenting the carbon burden on nature. Energy plays a critical role in the sustainability of both the environment and societal living. The rise in greenhouse gas emissions due to human activities and the alterations in natural greenhouse gas levels have turned climate change into a grave issue. Global warming is recognized as the main source of a range of problems, from melting glaciers to changes in climate zones, droughts, and ecosystem alterations. Recently, carbon emission mitigation mechanisms, such as carbon border adjustment mechanisms, have gained attention. Industrialists trading with the EU are particularly focused on this matter. When carbon-based methods are used in production, they may face certain restrictions during export. This situation leads companies to seek alternative, greener, and more environmentally friendly ways to meet their energy needs. Therefore, textile businesses need to analyze their current situation, and carry out necessary layout and process optimizations, to become more competitive. The accuracy of electricity consumption data predictions using ANN and LSTM methods has been demonstrated, with LSTM showing results very close to actual data. The outcomes obtained with this method will be used by the company during production planning, indicating promising results for future year predictions. Key improvement points for electricity consumption, the most crucial energy source, have been identified and savings items have been highlighted. Furthermore, layout optimization, involving the physical arrangement of an existing or proposed facility within a business, has enlarged storage areas, identified bottlenecks, and necessitated the acquisition and relocation of equipment and machinery, thereby reducing worker movement in the process. These layout optimization decisions have directly impacted employee efficiency. Walking and fire paths have been redrawn to always remain clear, reducing the risk of work accidents.

Optimization and forecasting have contributed to significant improvements and productivity increases in production processes, existing work, downtime, bottleneck reduction, and shortening material handling times. Optimization and process improvement activities in the textile sector increase energy efficiency, reducing both costs and environmental impact. Electricity consumption prediction models based on LSTM have accurately analyzed the complex patterns of energy demand in the sector, contributing to the development of energy management strategies. The amalgamation of these approaches plays a critical role in enhancing the sustainability and competitive strength of the textile industry.