

# The Role of Digitalization and Sustainability in the Manufacturing Industry

A Master's Thesis submitted for the degree of  
"Master of Science"

supervised by

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## Affidavit

I, **DAYAS MANJALLY, B.TECH**, hereby declare

1. that I am the sole author of the present Master's Thesis, "THE ROLE OF DIGITALIZATION AND SUSTAINABILITY IN THE MANUFACTURING INDUSTRY", 71 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

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## Abstract

The manufacturing sector, in its current form, is transitioning towards a new era. New industrial technologies and innovative approaches have gained as much importance to the manufacturing sector as the gained awareness and importance of a focus on sustainable practices. This research paper aims to investigate current market trends and will address the research question, “What is the role of Digitalization and Sustainability in the Manufacturing Industry?”. The primary purpose of this research paper is to portray the current status of the evolution of the manufacturing industry and to investigate the challenges surrounding the incorporation of digitalization and sustainability into the contemporary manufacturing business. An in-depth literature review combined with a critical analysis of current market statistics is used to gather a comprehensive view of how to implement a sustainable digitalization strategy. The findings of the research show that modern technologies will allow machines to perform major tasks from monitoring and mitigation to planning and implementing projects in a more efficient manner. It also reveals that although the manufacturing sector is one of the biggest contributors to global sustainability issues, it can also be an integral part of the solution. The concept of sustainable Industry 4.0, where environmentally friendly procedures and technology are central, is very crucial to mitigate any challenges and transform the sector. The findings of this research will contribute to a better understanding of how industrial organizations can become more productive, flexible, and environmentally responsible. Establishing industry-wide standards and recommended practices for digitization and sustainability in manufacturing will facilitate the process of adopting and implementing these strategies. It is of the utmost importance to draw people's attention to the fact that digitalization alone is not a silver bullet capable of ensuring the future economic sustainability of the manufacturing sector. It must be implemented in conjunction with a variety of other policies and practices that promote sustainability.

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# Chapter 1: Introduction

## 1.1 Overview of the Manufacturing Industry

The modern manufacturing system includes various processes involved in the production of goods. Some companies, such as those in the steel and semiconductor industries, use the term "fabrication" instead of "making" (Möller, 2016).

A manufacturing operation is either an assembly or a fabrication process. This type of process involves either removing raw materials from a part or changing its form to obtain a more useful component. Some examples of fabrication include the bending of a flange, plastic injection molding, aluminum extrusion, and steel accessories (Möller, 2016).

The concept of assembly refers to the process of combining multiple components or raw materials to create a more valuable product. Although manufacturing systems can initially fabricate parts, they can also use these components for assembly into finished products. This process involves looking at how materials are transported through the system and how these processes are linked to the intended volume of production. The integrated capabilities of manufacturing engineering, design engineering, and more can help speed up the time it takes to develop new products (Möller, 2016).

The rise of global power has been attributed to the strength of manufacturing. In the 19th century, England became a prominent global power due to its manufacturing sector. Other countries such as Germany, Japan, and the USA also gained significant power due to their strong manufacturing sectors. This is why manufacturing is the key factor that contributes to the development of nations. The long-term growth of a country can only be achieved with the help of its machinery industry. This sector is essential to produce goods and services, as it requires the proper equipment to make their components. Parts that have been produced are then used to make new machine tools, which contribute to the country's economic development. In 2013, the world's trade balance was at about \$18.3 trillion. About 4.3 trillion of this was allocated for commercial services, while merchandise exports made up the rest. This shows that the manufacturing industry is very important to the global economy (Herrmann et al., 2014).

Emerging markets are becoming more sophisticated, which means that a significant portion of the value creation takes place in the local market. Due to the emergence of advanced supply chains and the increasing number of companies outsourcing, China, India, and other low-cost countries are becoming more elongated workbenches. For over a hundred years, the US was regarded as the leading manufacturer. However, due to the financial crisis, it is now neck-and-neck with China. Some Western politicians have started to believe that it's time for the country's manufacturing sectors to return to their original form. Most of the innovations and new products that manufacturers bring to the market are developed in the US. Although manufacturing accounts for only 11% of the country's GDP, it is responsible for over 70% of domestic R&D spending and provides better-paying jobs than service industries. The manufacturing industry is a vital part of the development of countries that are attractive to high-tech sectors. It ensures that their competitiveness is maintained (Herrmann et al., 2014).

The manufacturing industry has a major impact on the country's GDP. It is expected that this sector will continue to grow and contribute to the country's overall economic performance. Due to this, the country's GDP numbers can also measure the contribution of the industrial sector. It is also believed that the increasing number of smart factories and the technological advancements that are happening in the manufacturing industry will help the sector grow and contribute to the nation's GDP. Besides being able to create new products and services, the success of a manufacturing industry depends on the continuous innovation of its various processes (Möller, 2016).

Due to the increasing competition from low-wage countries and the emergence of free market strategies, manufacturing firms have started implementing productivity enhancement measures (Harik et al., 2015). The rapid emergence and evolution of AI and automation technologies have created a paradigm shift in the manufacturing industry. The use of robots and smart machines has become more prevalent (Chin et al., 2019).

Various revolutions and developments have been carried out in the industrial environment to improve its competitiveness. These innovations are based on cutting-edge technologies that can help improve the efficiency of different sectors, such as construction, manufacturing, and service. To maintain its competitive edge, factories need to continuously adapt to the changes brought about by the various technological advancements (Verma et al., 2022).

## 1.2 The Concept of Smart Manufacturing

The concept of smart manufacturing refers to the merging of physical and virtual worlds using cyber-physical systems. It is a new approach to industrial manufacturing that involves the integration of various business processes and technical procedures.

The advantages of smart manufacturing include lower cost of ownership, time and resources, and real-time quality. It is designed to be implemented in a service-oriented manner and is built on a flexible platform that can be used by manufacturing units. This approach also demands the development of adaptable and resilient learning characteristics (Möller, 2016).

Through the use of smart manufacturing technology, various units can be automatically monitored and control the entire manufacturing process. This eliminates the need for manual intervention and allows them to respond in real-time to improve the efficiency of their operations. Using smart manufacturing technology, machines can communicate with each other and provide critical data to help manufacturing organizations make informed decisions. This eliminates the need for manual intervention and allows them to respond in real-time to improve the efficiency of their operations (Möller, 2016).

The fourth industrial revolution in the history of innovation is called smart manufacturing. It involves a bottom-up model that enables companies to create new products and processes with lower costs and more customer-driven innovation. The goal of smart manufacturing is to enable individual manufacturing, enhanced operators, and resilient manufacturing. This concept marks a shift in the way manufacturing is done, with a new level of interaction between the various resources and stakeholders involved. The concept of smart manufacturing revolves around the interconnectedness of various resources, such as robots, manufacturing machines, and storage systems. These will be able to provide a variety of services and solutions (Möller, 2016).

A smart factory is built on the concept of continuous engineering, which involves the use of the physical and cyber worlds in a way that seamlessly connects the various components of a manufacturing process. In terms of Industry 4.0, this concept refers to the exchange of information between different systems and machines (Möller, 2016).



The concept of Industry 4.0 refers to the evolution of the digital manufacturing process. The rise of the Internet of Things and cyber-physical systems has created a framework for the development of smart factories. Through the use of machine-to-machine communication, manufacturers can create an intelligent network that can be used to improve their operations. Using machine-to-machine communication, manufacturing booths can act autonomously, which can reduce the interventions required by humans (Möller, 2016).

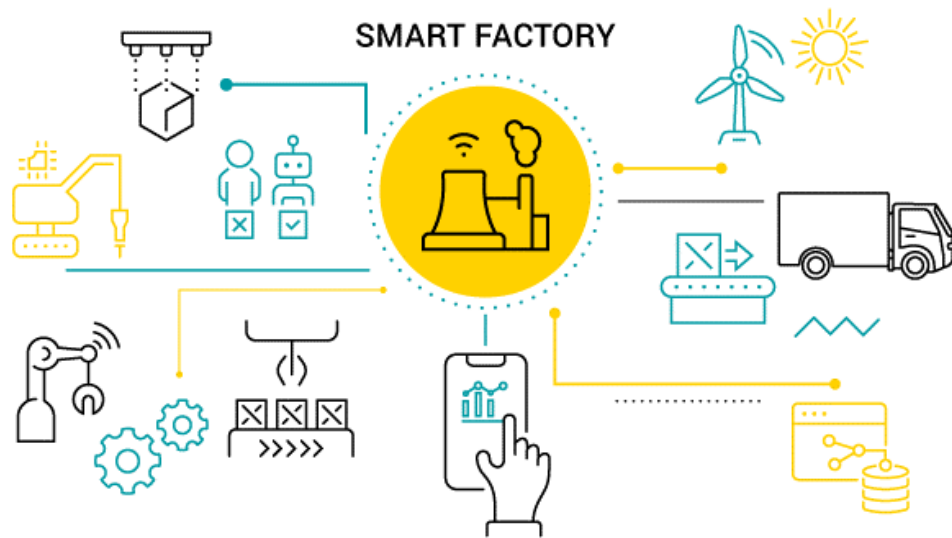


Fig. 1: The impact of factory 4.0 (AVSystem, 2020)

The goal of a smart factory is to allow products to control their manufacturing by sharing their requirements with the machines. This will allow them to identify the necessary steps to complete their production. The concept of a smart factory involves the use of CPS technology, which brings together the physical and virtual worlds. The Internet of Things (IoT) is a framework that enables the gathering of information and controlling objects in the physical world. This is referred to as the synergy between the physical and virtual worlds. The system can be used to integrate various components and software (Möller, 2016).

Through the use of smart manufacturing, factories can improve their efficiency and control their products' flow. This will allow them to adapt their production procedures to meet the needs of their customers. They can also schedule their priorities and keep track of urgent requirements. Using software agents, factories can monitor their processes and ensure that the production rules are followed properly. This will enable them to produce individual products and meet their customers' needs. However, it will

be very challenging to implement this technology due to the presence of multiple machines monitoring the production process. In the case of failure, the agents will automatically perform maintenance procedures (Möller, 2016).

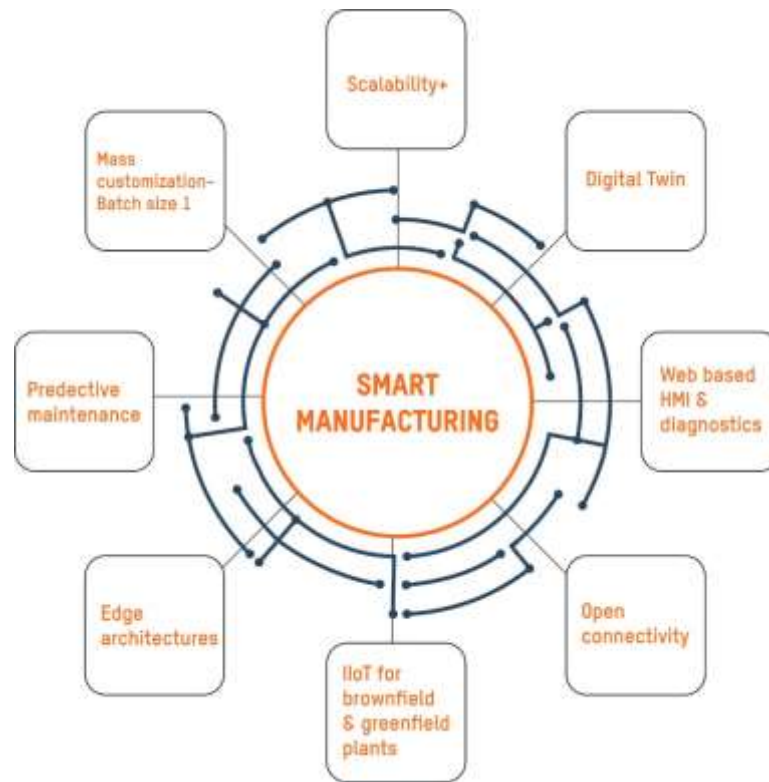


Fig. 2: Smart manufacturing (B&R Industrial Automation GmbH, 2018)

### 1.3 The Importance of Sustainability

The rise of green initiatives has been seen in every sector and continent. They are one of the most lucrative undertakings a company can undertake, and they are a subset of sustainability. Sustainable development aims to meet the needs of the present while ensuring that the future generations can meet their own. To achieve sustainable development, a company must focus on operating more efficiently and effectively. This can be done through the reduction of its waste and improving its performance using lean supply chains. In addition, adopting the 6Rs mindset can help boost market share and improve productivity. The complexity of implementing sustainable development involves many disciplines, such as finance, law, marketing, technology, and risk management. This makes it hard to create a framework that is both profitable and good (Harik et al., 2015).

Due to the increasing awareness about the harmful effects of production, people are more likely to search for products that are made from sustainable materials. This has led to manufacturers adopting various sustainability technologies to maintain their competitive edge. The concept of sustainability 4.0 goes beyond natural resources. It involves incorporating social resources into the production process. This could mean that various components and materials in industrial facilities are equipped with sensors and actuators, which can help improve the efficiency of their operations. This could result in a more flexible and efficient manufacturing process, which would allow machines to adapt to the needs of consumers. In addition, various technologies can help improve the efficiency of machine tools by identifying their optimal paths and reducing their energy consumption (Javaid et al., 2022).



Fig. 3: Three pillars of sustainable manufacturing (Infosys, 2019)

One of the most critical factors that production managers and engineers need to consider is sustainable manufacturing. This is because it is a duty they have to take care of the environment. A product life cycle analysis is a process that can help them determine the impact of their products on the environment. In most cases, the energy requirements of ancillary equipment are different from those of the core process. Through process optimization, we can reduce the environmental impact of our operations while improving the safety and efficiency of our facilities. The concept of

industrial symbiosis refers to the replication of natural cycles in an industrial network. It involves the utilization of resources and waste materials (Javaid et al., 2022).

## 1.4 Scope of Research

This research paper investigates how Digitalization and Sustainability affect the manufacturing industry. It will address the research question, “What is the role of Digitalization and Sustainability in the Manufacturing Industry?”. Furthermore, these sub-questions will aid in the research paper:” How does Industry 4.0 shape the future of the Manufacturing industry?”, “How important is for manufacturing companies to be sustainable?”. Also, it will be examined what the current implementation of Digitalization and Sustainability is in the manufacturing industry. Lastly, the research aims to understand how Industry 4.0 can be implemented while also putting an emphasis on a more sustainable future.

## 1.5 Significance of Research

The manufacturing sector, in its current form, is transitioning towards a new era. There is a strong possibility that in the near future, new industrial technologies and innovative approaches to running businesses may become available. The findings of this research will contribute to a better understanding of how industrial organizations can become more productive, flexible, and environmentally responsible. Manufacturing companies can acquire a better understanding of the environmental impact as well as the amount of digitalization in the product and technology lifecycles by doing research into the relevant literature and gaining a full grasp of the current market condition.

The primary purpose of this research paper is to portray the current status of the evolution of the manufacturing industry and to investigate the challenges surrounding the incorporation of digitalization and sustainability into the contemporary manufacturing business. The purpose of this research study is to shed light on how important it is to implement a sustainable digitalization strategy. When you have a better understanding of the current state of the manufacturing industry, you will have a clearer picture of this topic, which is always evolving, as well as how the sector must adapt to new technologies, while also emphasizing the significance of environmentally responsible practices.

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## 1.6 Research Methodology

The following paper is a literature combined with analysing the current market situation. The first part will contain a systematic literature review mainly based on peer-reviewed articles. Scientific and relevant articles and books were found on the following three databases: EBSCOhost, Science Direct, and SpringerLink. A variety of keywords and different combinations was used to ensure an adequate selection of articles. Examples are “Digitalization in Manufacturing”, “Sustainability in the Manufacturing Industry” and “Industry 4.0”. Further, the results were filtered for peer-reviewed articles from 2000. Furthermore, Google Scholar was also searched for matching literature. Consequently, the potential sources were screened and reduced to a remaining list of content-specific articles. Additionally, relevant reports, newspaper articles, and official government websites were used for further reference and to gather a more comprehensive view. A current market view is included in the research paper to fill the gap of current and relevant statistics in the field and add supporting perspectives to the study's literature.

## 1.7 Limitations

The design of this study, like the designs of the vast majority of other studies, is susceptible to a number of drawbacks. The fact that advancements in technology are continually being made in the manufacturing industry is the key factor that prevents the generality of the findings of this research paper. As a result, some of the assertions made in this research paper may now be considered to be out of date. The second restriction is that it was difficult to obtain access to scholarly articles and journals. This is due to the fact that the research paper relied heavily on papers that were available through the principal databases of the institution. Due to the fact that the research

was conducted at a period that fell within particular time frames established by the educational institution, the study is also subject to time constraints. The lack of previous research on themes such as how the Covid-19 epidemic has brought a change to the tendencies that are addressed in the research paper is another weakness of the study. When compared to the works of more seasoned scholars, the scope and depth of the analyses in the paper are noticeably lacking on a number of different levels.

# Chapter 2: Research Background

## 2.1 Trends in the Manufacturing Industry

The manufacturing industry has undergone various transformations over the past two centuries. From mass production to lean manufacturing, the process has continued to evolve. As the industry continues to adopt new technologies, it is still going through this process.

The concept of craft production was the first paradigm to respond to the needs of a specific customer. It allowed products to be created with a high degree of flexibility and variety. However, due to the lack of manufacturing systems, the cost of production was relatively high (Herrmann et al., 2014).

Through mass production, which involved large-scale manufacturing, products were able to be made at lower prices. However, the exact variety of products was limited. One of the symbols for mass production was Henry Ford's famous statement about cars being painted any colour as long as it is black. Mass production reached its peak following the Second World War due to the high demand for products. This was because the various principles of mass production were able to fully utilize their strengths. One of these is interchangeability, which allows for the random selection of components for assembly. This was very important to facilitate the second principle of mass production, which was the moving assembly line. Henry Ford introduced this system in 1913. Through this process, cars were brought to the workers who were able to perform the same task multiple times (Herrmann et al., 2014).

The third principle of labor is the division of labor. In the moving assembly line, the workers were divided into groups so that they could focus on certain repetitive tasks. After the Second World War, the concept of lean manufacturing emerged as a necessity in Japan due to the country's limited resources. It was developed by Toyota Production System. The philosophy aims to minimize waste and maximize the value of an organization's assets. It is still regarded as a vital part of modern production systems.

Mass customization was introduced during the late 1980s due to the increasing demand for various products. This resulted in an enormous variety of vehicles being created. For instance, BMW claims that there are already 1017 potential combinations for the 7 series. The concept of mass customization is based on three principles. The



first is the family architecture, which allows for the sharing of certain modules. This allows for a high level of customization. The second is the use of manufacturing systems that can be modified to respond to changing demands. The goal of mass customization is to allow engineers to quickly adapt their products to the changes brought about by the rapid emergence and evolution of new technology. One of the most important factors that manufacturers consider when it comes to implementing this strategy is the optimal configuration. Delays in the assembly process can help minimize costs and improve the response time of the system. However, this can also lead to system performance issues due to the complexity of the manufacturing process (Herrmann et al., 2014).

The concept of personalized or mass customization has broadened beyond mass customization. With that in mind, products that are highly personalized may have different cycle times and work steps. This means that they can no longer be limited to static assembly lines. Instead, they can be manufactured using the same production parameters as those utilized in large-scale production facilities.

The rising world population and the need for energy production are two factors that have resulted in the increasing prices of resources and energy. Governments have been working to address these issues by implementing regulations and introducing taxes to reduce emissions. However, a growing number of consumers are demanding products that are made with minimal environmental impact. This is why sustainable manufacturing is becoming a vital component of many companies' operations (Herrmann et al., 2014).

Urbanization and the need for better living conditions are some of the social aspects that have been identified as influencing manufacturing. One of these is the need for factories to be close to their employees and customers. This is because, as human factors, skilled individuals are becoming more important in the manufacturing industry. Besides being able to provide a variety of products and services, factories also have to consider the living conditions of their employees.

The increasing number of computers and communication technologies will continue to affect the manufacturing industry. From the 1950s to the 1960s, the technological advancements in this sector have been noteworthy. One of these is the emergence of the manless factory concept. According to recent studies about the potential of cyber-physical systems, the increasing number of powerful and cheaper ICT components will allow them to enter new areas of production.



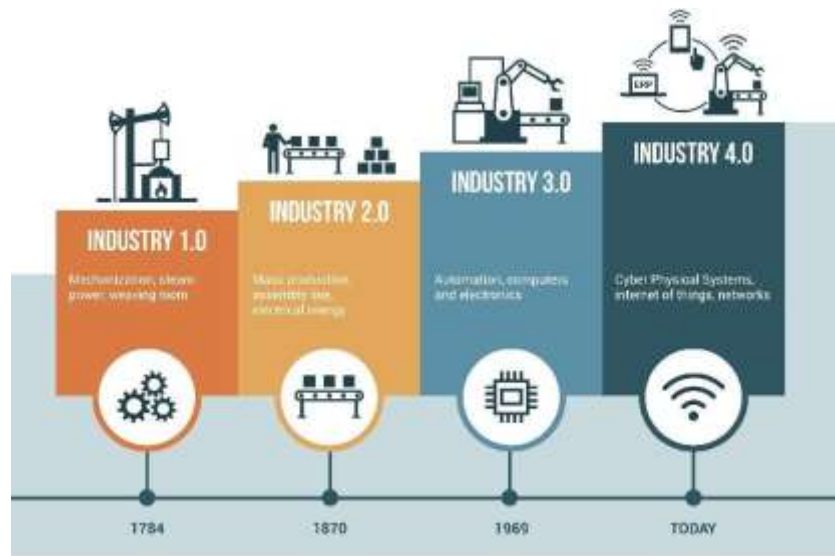


Fig. 4: The four industrial revolutions (IIoT World, 2018)

The spatial context of production allows factories to make a paradigm shift from just reducing their ecological impact to becoming more beneficial to the environment. For instance, they can help in the development of smart grids and the conditioning of waste flows from residential areas. Aside from being able to reduce their environmental impact, factories can also adapt their operations to local conditions. This is why the concept of green manufacturing has been gaining increasing recognition in various academic institutions (Herrmann et al., 2014).

## 2.2 Industry 4.0

The increasing number of AI-driven innovations in the manufacturing industry has shifted the focus of the sector toward the fourth Industrial Revolution, also referred to as Industry 4.0. This new approach can help organizations improve their sustainability by developing new strategies and procedures. AI-based strategies can help improve the efficiency and performance of manufacturing organizations by allowing them to make better decisions and manage their operations. However, they are still not widely adopted due to the lack of skilled and knowledgeable workers. Due to the increasing number of sensors and the complexity of the supply chain, the implementation of AI-based strategies is becoming more challenging. Big data can help manufacturing organizations improve their sustainability and performance. Unfortunately, managing

this information is still a challenge due to the lack of sufficient literature and knowledge (Jamwal et al., 2022).

The increasing number of digital technologies in the manufacturing industry has led to the emergence of new opportunities and the cross-fertilization of various activities in the firm. This can result in significant changes in the way the company creates and captures value. In simple terms, it can be said that the use of digital technologies can help improve the efficiency of a manufacturing organization by increasing the generation of data and the analysis of its information. On the other hand, it can help the company grow by adding value to its customers through the use of new digital platforms (Björkdahl, 2020).

The industrial revolution, which began in the eighteenth century, has transformed manufacturing. It was initially characterized by the use of steam and water for mechanical production. In the 20th century, the industrial revolution was centered on mass production using electrical energy. The Information Technology (IT) and embedded electronics (I&E) revolutions in the 1970s led to the development of Industry 3.0, which was centered on automation. Today, the concept of Industry 4.0 is centered on the use of digital manufacturing systems. These systems combine the physical and digital components of a manufacturing process to create a more efficient and productive environment. To implement Industry 4.0, standards are needed to address the various challenges that engineers and designers face when it comes to designing and implementing complex systems (Möller, 2016).



Fig. 5: Industry 4.0 (DAT4.ZERO, 2019)

The rise of digitalization has had a major impact on politicians and business leaders. It has been regarded as the fourth industrial Revolution following the automation of mass production, the steam engine, and electricity. In Germany, the government has defined Industry 4.0 as the concept of addressing the various challenges and opportunities that manufacturers face in the digital age. This has inspired other countries such as the US, France, Italy, and the Netherlands to develop their own smart manufacturing programs. Although Industry 4.0 mainly focuses on the improvement of manufacturing processes, it has the potential to affect other functions of the industry (Björkdahl, 2020).

Industrial applications will be able to benefit from the various technologies that will be used in the future, such as the ability to control and coordinate multiple processes at the same time. However, it is still important that the various steps in the process are standardized and modular. The concept of the bottom-up manufacturing model is a revolutionary innovation that aims to create a new level of efficiency and cost-effectiveness in the manufacturing industry. It can be achieved using a global network of self-organizational and adaptive manufacturing units (Möller, 2016).

## 2.3 Sustainability Targets

Organizations around the world are facing increasing pressure from customers and stakeholders to adopt sustainable development practices. This has led to a significant shift in the way companies approach their operations and strategies to ensure their long-term sustainability. The concept of sustainability has gained widespread recognition, not just in developed nations, but also in emerging and developing economies where major brands are increasingly present. The manufacturing industry, in particular, has come under scrutiny for its negative impact on the environment, with the International Energy Agency reporting that it accounts for 36% of global greenhouse gas emissions. The industry is also known for its high levels of waste generation and material consumption. In response, an increasing number of companies are committing to improving their operations and adopting sustainable practices. The term "sustainable manufacturing" is gaining recognition, although it does not have a standard definition. Other terms that are used to describe this concept include green manufacturing, environmental conscious manufacturing, and lean manufacturing. To effectively implement sustainable manufacturing practices, it is important to understand the various components involved, such as reducing waste

and material consumption, improving energy efficiency, and promoting the use of environmentally friendly materials. In conclusion, the trend towards sustainable manufacturing is growing, and organizations are increasingly recognizing the importance of rethinking their operations to ensure long-term sustainability. By adopting sustainable practices, companies can improve their environmental impact, reduce waste and material consumption, and ensure their long-term viability (Madan Shankar et al., 2017).

The concept of sustainability refers to multiple systemic pressures that affect various aspects of an organization's operations. These include the environment, social, and economic impacts of business activities. From a regulatory standpoint, there are increasing pressures on companies to account for their environmental and social impacts. The concept of sustainability has gained widespread recognition in academia and mainstream management due to the publication of a report by Brundtland entitled "Our Common Future." This document aims to provide a framework for addressing the various stakeholder groups that are involved in the development of sustainable business practices. In 1992, the UN held an Earth Summit in Brazil. Over 180 governments agreed to address various sustainability policies. A follow-on conference was then held two decades later to develop a set of sustainable development goals. These include ending poverty, protecting the planet, and ensuring that everybody enjoys prosperity. Due to the increasing number of stakeholder groups and media pressure, the scope of reporting requirements for sustainability has also increased. This has resulted in more nuanced and transparent requirements (Mohammad Ebrahimi & Koh, 2021).

Industry 4.0 has created new opportunities for companies to address the challenges related to sustainable manufacturing. The demand for products that are made from sustainable materials has also increased (Zamorano et al., 2021).

Due to the increasing importance of environmental issues, their scholarly attention has been rising in both developed and developing nations. This is because their negative effects on the country's economy and strategies are becoming more apparent. Another issue that has become more serious is preserving natural habitats. This is why it is important that manufacturing firms adopt sustainable practices (Al-Hakimi et al., 2022).

Adopting new projects necessitates the use of cutting-edge technologies, which firms can only use if they receive approval from upper management. The support and

dedication of upper management will boost the implementation of SM by enhancing operational performance with sophisticated technology. The businesses' economic performance can be enhanced by minimizing the wastes connected with their manufacturing operations. By decreasing the costs associated with waste, firms are able to offer higher-quality goods at lower prices, hence increasing customer satisfaction and market share. Government rules play a crucial role in pushing organizations to embrace SM, according to this study. The supportive environmental rules and tax relief might encourage businesses to design recyclable items and raise the percentage of recyclable material in their products. By using green information systems, businesses are able to maintain a continuous flow of information between suppliers, core organizations, and customers. Accessing, monitoring, and reporting actual information between multiple stakeholders can be facilitated via green information systems. In order to enhance operational effectiveness, firms must adhere to worldwide environmental and safety requirements. It will establish a green image for the company and encourage customers to purchase green items.

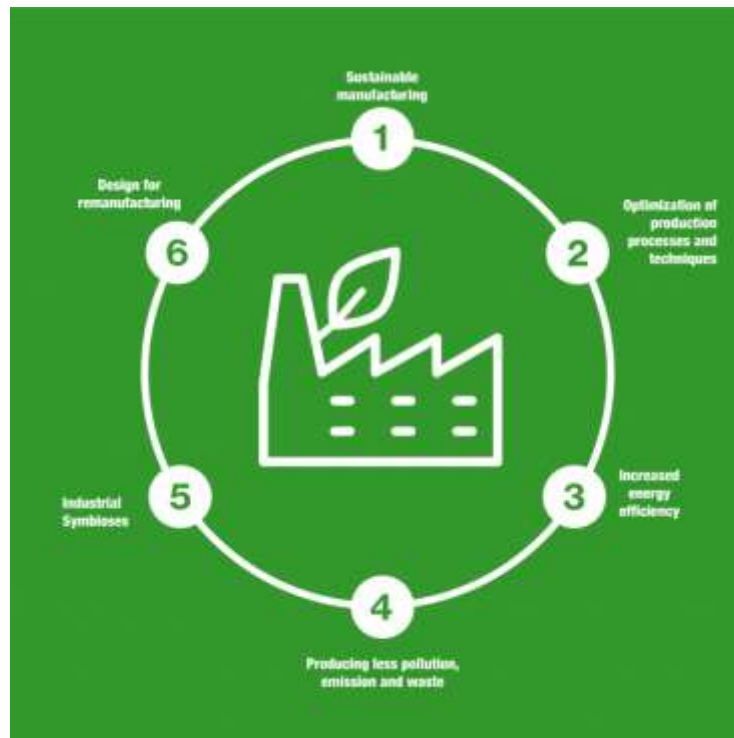


Fig. 6: Learning factory (Sustainability Guide, 2017)

Due to the increasing number of regulations and the need for organizations to align themselves with societal and environmental goals, it is now more important than ever

that they adopt a strategy that focuses on sustainable practices. By adopting a sustainable strategy, organizations can maintain their market position and improve their customer retention rates. It can also encourage their customers to buy more eco-friendly products. If an organization violates the regulations imposed by the government, it can cause its image to deteriorate, lose its competitive edge, and incur costly fines (Malek & Desai, 2022).

The concept of developing a green economy has gained widespread acceptance. It is necessary for the advancement of this concept to ensure that the economy and climate are improved. This is because green innovation can help minimize the effects of conventional innovation on the regular human body. In addition to being more eco-friendly, green innovation can also help prevent the development of mechanical and unnatural shade. Without green innovation, there is no way to achieve sustainable development. This is the reason why the development of new technologies has turned into an inevitable decision. One of the most important factors that can be considered when it comes to improving practical aspects is the difference between extremist and gradual progress. The gradual progress is usually improvements to existing methods and products to increase their variety, quality, and efficiency. On the other hand, extremist advances are the breaking of established cycles and the creation of new items with distinct strategies (Sharma et al., 2022).

## 2.4 Summary

Throughout the previous two centuries, the manufacturing industry has transitioned from Craft Production to Mass Production to Lean Manufacturing to Mass Customization. Researchers argue that several societal factors also have an effect on manufacturing. Highly skilled professionals become even more important in the context of manufacturing as human factors, necessitating that companies facilitate production-related learning and simultaneously consider living conditions (Herrmann et al., 2014).

A closer look at the research suggests that recent advances and breakthroughs in artificial intelligence (AI)-based technologies have moved manufacturing practices towards the fourth industrial revolution, or Industry 4.0. At the system, product, and process levels, manufacturing organizations can observe a favorable influence of AI-based solutions on sustainability. Adoption of AI-based manufacturing solutions enhances decision-making, productivity, and system performance. Despite

sustainability and other benefits, the adoption of AI-based approaches in manufacturing companies is still limited due to the knowledge and digital abilities of employees (Jamwal et al., 2022). Future industrial applications using these essential technologies will enable the real-time, long-distance coordination and control of numerous processes. Nonetheless, this necessitates the standardization and modularization of numerous distinct manufacturing process stages and programming modules of functional models (Möller, 2016).

The consensus view seems to be that keeping pace with digitalization is not the only important focus of the manufacturing industry. Firms are rushing to meet their sustainable development objectives in response to mounting pressures from stakeholders and high-end customers. This dedication to sustainability requires businesses to reevaluate their strategy in order to preserve sustainability in their operations and offerings. Sustainability is a vital strategy not just in industrialized nations, but also in developing and emerging economies, where numerous major brands are headquartered. Consequently, there exists a global effort to implement sustainable business practices, including engineering, design, and production. Concepts, measurements, drivers, obstacles, and indicators are investigated for the effective implementation of sustainable manufacturing (Madan Shankar et al., 2017). Thus, digitalization and sustainability are becoming crucial components of the future of the industrial industry.



## Chapter 3: Current State of Research

### 3.1 Technologies driving Industry 4.0 in Manufacturing

The concept of manufacturing technology involves product innovation, industry model innovation, and manufacturing technology. The use of intelligentization and digitalization brings about a fundamental change in the way production is done in the manufacturing sector. These technologies are the core of the industrial revolution (Zhou, 2013).

Through the use of digitalization, organizations can improve their efficiency and control their operations by implementing more integrated value chains. It can also help them manage their resources more effectively. One of the most important advantages of this technology is the sharing of information between various systems and functions.

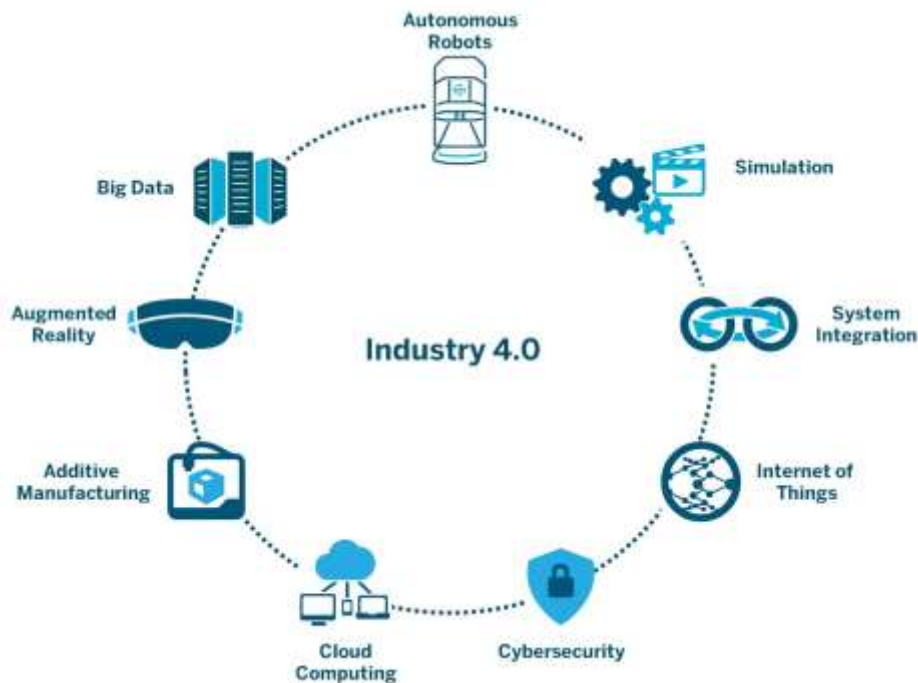


Fig. 7: Technologies driving industry 4.0 (Aethon, 2018)

Due to the vast amount of data that manufacturing firms collect, they are able to share information with their customers and suppliers. Some of the leading firms are now limiting their digital procurement channels to a single digital platform. This change allows them to improve their control over their suppliers and reduce their inventories.



Some firms integrate their supply chain management systems with their customers' production systems. According to one of the sample companies, this method allows them to reduce their time spent communicating with their customers. Through digitalization, a firm can now track the position of its supply chain in relation to its customers' orders. It can also use machine learning to link the data collected from various sources to its end products (Björkdahl, 2020).

### **3.1.1 Deep Learning and Machine Learning**

Machine learning and deep learning are becoming more prevalent in the manufacturing sector, which is expected to help improve the efficiency of organizations by reducing production defects and improving the service they provide. Due to the volume of data generated by various processes in the manufacturing industry, such as the shop floor and supply chain activities, traditional methods are not able to effectively extract important information. With the help of deep learning and artificial intelligence, DL algorithms can perform well in analyzing and extracting data. In data science, DL techniques are often used in predictive modeling and statistical analysis. The ability to analyze and interpret large amounts of information is becoming an emerging area of research in the field of information management. DL's role in manufacturing organizations is crucial (Jamwal et al., 2022).

Compared to AI methods, DL-based systems perform better in various manufacturing-focused applications, such as predictive maintenance and condition monitoring. These systems can process data collected by sensors and sent to the cloud via the Internet. DL-based systems are widely used in Industry 4.0 to provide various benefits to manufacturing organizations. They can help them achieve sustainability by improving their operations. Despite the advantages of DL and AI, there is still a lack of awareness about their applications in the manufacturing sector (Jamwal et al., 2022).

### **3.1.2 Internet of Things (IoT)**

The Internet of Things (IoT) is a rapidly growing technology that has revolutionized the way systems communicate with each other. It leverages big data collection and analysis to enhance the efficiency of supply chains across various industries. The concept of IoT revolves around the idea of connecting objects and devices to each other, enabling them to communicate and exchange information. The use of IoT in

the manufacturing industry has been deemed as smart, as it allows for the monitoring of industrial processes through the use of sensors and communication networks. This enhances the ability of machines to perform specific tasks, reducing the need for human intervention. The integration of IoT in the manufacturing process is achieved through the use of various objects and physical items that are equipped with sensors, processors, and communication capabilities. This allows for seamless intercommunication between these devices and provides real-time information about the status of the industrial process. IoT enables the optimization of various processes, including production, inventory management, and quality control, resulting in a more efficient and cost-effective supply chain. Additionally, IoT provides real-time insights into the performance of machines and helps in identifying potential issues before they cause significant problems. In conclusion, the Internet of Things is playing a significant role in revolutionizing the manufacturing industry. Its ability to connect devices and systems, enhance efficiency, and provide real-time insights is helping manufacturers achieve improved results and remain competitive in an ever-changing landscape. The future of the manufacturing industry is becoming increasingly dependent on IoT technology, and companies that embrace it are poised to experience significant benefits (Onu & Mbohwa, 2021).

### **3.1.3 Autonomous Cyber-Physical systems**

Automated control systems (ACS) are sophisticated tools that help improve the efficiency and accuracy of production processes. They are also useful in reducing costs and enhancing the safety of workers. The system's connection to the virtual and physical world is a key component of industry 4.0. Various advances in artificial intelligence, robotic systems, and the internet of things have led to the development of new kinds of robots. These include cyber-physical and face sensors. Through the use of ACS systems, information and data are transferred seamlessly between the physical and virtual worlds. They allow for a high degree of transparency and control. This technology is commonly utilized in the supply chain, particularly in manufacturing, assembly, and transportation operations. It can help improve the quality and efficiency of a product's assembly process. Industry 4.0 brings together traditional processes with the digital world (Onu & Mbohwa, 2021).

Various manufacturing sectors, such as assembly, maintenance, and production, are now using virtual technologies to improve their operations. These include the use of virtual reality and augmented reality, which allow for the visualization of data. The

concepts of augmented reality and virtual reality are similar in that they allow for the development of new technologies that can improve the efficiency of a manufacturing process. For instance, by using AR, operating instructions can be displayed in the sequential order of a process. In maintenance processes, augmented reality can help provide useful instructions (Onu & Mbohwa, 2021).

### **3.1.4 Big Data Analytics (BDA) and Artificial Intelligence (AI)**

Due to the complexity of the supply chain, it is expected that the amount of data generated will increase. This process will require the management of the massive amount of data that will be collected and stored. Big data analysis (BDA) is focused on identifying what will happen next, instead of what has happened previously. This allows the data to act as a prediction of future events. Due to the increasing number of data sources, the use of big data has shifted from its traditional role of collecting data to analyzing and reporting.

Artificial intelligence (AI) is a concept that aims to facilitate the development of machines that can learn without being programmed. Most of the learning systems that are currently being used in the field are built on neural networks and natural language processing. Currently, a cyber-physical system doesn't have the necessary tools to implement AI. The use of AI allows manufacturing plants to collect and distribute data, which are then used to improve the efficiency of their operations. This process can be carried out through the development of applications that can help improve the efficiency of their facilities. Besides being able to analyze and visualize the data, AI also allows them to create effective and efficient workflows. Through the use of AI, manufacturing plants can also benefit from the development of BDA applications that can help improve their processes and increase their efficiency (Onu & Mbohwa, 2021).

### **3.1.5 Cloud Computing (CC)**

The term CC is an emerging technology in the manufacturing industry that is used to describe various applications. It is the fastest-growing area of focus within the digital economy. It allows businesses to connect to the internet and manage their service. The concept of cloud computing refers to a type of data storage and retrieval system that is easy to use and requires no installation. It enables organizations to access and

manage their data more effectively. In addition, it provides them with the necessary operational and planning convenience (Onu & Mbohwa, 2021).

The rapid spread of technology will allow factories to collect and process information on a higher level, even if decisions are ultimately taken by independent agents. For example, in order to help human workers, CPS will provide them with the necessary live information from the production system (Herrmann et al., 2014).

The amount of data collected by factories in the future will require the creation of a decentralized information pool, which is known as a production cloud. This type of data pool will allow them to process and store all of the information they collect. The data collected by factories will include various details such as the cycle times and productivity of their processes, as well as the energy requirements of their machines and components. They will also be able to analyze the current state of their products and the production conditions. This concept is closely related to the concept of the Internet of Things, which was first introduced in the 1990s. In the IoT, every physical element, such as sensors, processors, and actuators, has a virtual representation that can be accessed and operated through an internet-like structure. This virtual representation can be achieved through the integration of various physical components. A concept known as a Factory of Things is a collection of smart objects that act as their own autonomous system without a hierarchy (Herrmann et al., 2014).

The production cloud can contain various elements that are related to its physical structure. These include a Digital Factory, which is a representation of the real factory that can be used to improve system behavior using simulation techniques. In addition to being able to visualize and simulate the various processes in the factory, this concept also includes a network of digital models. The goal of the production cloud is to provide a comprehensive view of the various processes and resources that are involved in the production of a product. It can also help improve the efficiency of the factory by implementing effective planning and control techniques (Herrmann et al., 2014).

The processing and storage of data in a cloud provides various advantages, such as high degree of transparency and control. It also allows for the creation and management of personalized products through its link to manufacturing services. Through the network, various factories can offer their services to fulfill different requirements. These services can help manufacturers create and manage their supply chains (Herrmann et al., 2014).

### 3.1.6 Additive Manufacturing

In contrast to traditional processes that involve the removal of materials, such as drilling, milling, and cutting, additive manufacturing is a process that involves the use of 3D computer-aided design (CAD) or 3D printing. This technology can help decision-makers improve their efficiency and reduce their inventory by producing prototypes and layers by layers. This process can also help them meet their product customization goals. The advantages of additive manufacturing are designed to improve the competitiveness and performance of SCs. It allows them to create custom and complex structures that are not easily done using traditional methods (Onu & Mbohwa, 2021).

As companies look to maintain their competitive advantage in the face of the emerging technologies, they need to expand their technological capabilities. This concept is not new. Multi-technology firms have been around for a long time. They are able to provide a deeper understanding of their customers' needs by leveraging their technological expertise. The rapid emergence and evolution of digital technologies has created new opportunities for firms to integrate various technology domains and create new business models. At the same time, the increasing competition globally has made digital technologies a strategic imperative for firms. The increasing number of digital platforms has created a conducive environment for the development of new knowledge related to manufacturing processes. This has resulted in improved performance outcomes (Szalavetz, 2022).

Technological diversification is a trend that has been prevalent in various industries. It refers to the degree to which a firm's R&D activities are spread across different technological fields. According to Kook et al., as time goes on, firms will start to prefer to be multi-tech instead of hi-tech (Szalavetz, 2022).

The importance of technological diversification cannot be underestimated, as it allows businesses to explore new business opportunities and develop new strategies. Unfortunately, the exact impact of technological change on performance is still unclear. The presence of dynamic capabilities and complementary assets can help improve performance. These factors are often utilized to integrate new technological resources into a more effective manner (Szalavetz, 2022).

### 3.1.7 Concept of Digital Twin

The rise of intelligent manufacturing has created a new paradigm for improving the quality and productivity of manufacturing. It enables manufacturers to achieve sustainable production by developing new ways to improve their efficiency and reduce their costs. One of the most important factors that manufacturers can consider when it comes to adopting this technology is the digital twin. This technology allows them to analyze and predict the state of their systems in real-time (He & Bai, 2021).

Through the use of the digital twin, manufacturers can monitor and analyze their physical processes. It can also provide them with real-time information about their systems and improve their efficiency. This technology can help them make informed decisions and improve their productivity (He & Bai, 2021).

The continuous improvement of manufacturing has become an essential factor that manufacturers must consider in order to achieve sustainable production. With the help of a digital twin and intelligent manufacturing, they can now produce products that are more intelligent and efficient. It can also monitor and predict the status of their equipment and processes in real time (He & Bai, 2021).

## 3.2 Application of Digitalization in Manufacturing

The concept of digitalization in manufacturing has revolutionized the way the industry works. Through the use of various digital platforms and tools, manufacturers have gained a competitive advantage and increased their efficiency. One of the most significant developments in this area is the implementation of Industry 4.0, which is the integration of artificial intelligence, cloud computing, and the Internet of Things. The Internet of Things (IoT) can help improve the efficiency of production processes by allowing them to collect and analyze real-time data. In addition, it can help prevent unexpected equipment breakdowns by developing predictive maintenance programs. One of the most important areas where the concept of digitalization is having a major impact is supply chain optimization. Through the use of digital tools and platforms, manufacturers can monitor and manage their supply chains in real-time. Another area of innovation is 3D printing. This technology allows them to produce finished products and prototypes quickly. In addition, the use of sensors and cameras in the production process has revolutionized the way quality control is done. Through the use of AI and other advanced technologies, manufacturers can now detect and monitor various defects in real-time, helping them improve their efficiency.

### 3.2.1 Organizational IT Competence

The concept of the productivity paradox emerged during the early stages of research on the use of technology in organizations. It highlighted the lack of a link between productivity gains and the investment in IT systems. These findings prompted studies to identify the factors that can help organizations adopt IT systems. Among the enablers that can help organizations adopt technology are the skills of their employees and the knowledge of their organization's IT department. This is regarded as an essential factor that can help organizations effectively utilize technology. Other factors that can help organizations improve their efficiency include the availability of top management support and the development of systematic approaches to use data (Buer et al., 2021).

The shop floor is becoming the link between physical resources and digital information. The concept of cyber-physical production (CPS) is a vital component of this process, as it allows manufacturers to realize the integration of various physical components and systems into a single digital platform. Through the use of a digital shop floor, sensor and machine data can be collected at the various levels of the value stream. This allows manufacturers to improve the efficiency of their operations by providing actionable insight. In addition, the collected data can be used to make informed decisions. The ability to monitor and control the changes in the status of various processes and components on the shop floor allows manufacturers to improve their operations (Buer et al., 2021).

The concept of vertical integration refers to the process of bringing together various IT systems within a factory, such as those used in the production of sensors and actuators. In addition, horizontal integration is a process that involves the integration of multiple IT systems in the business planning and manufacturing processes. This process can be carried out either internally within a company or across different partners within the value chain. For instance, it can be done in the areas of sales forecasting and production (Buer et al., 2021).

### 3.2.2 Cybersecurity in Digital Manufacturing

The growth of cyberspace is an essential part of society's development. Cybersecurity is a field of knowledge that involves the protection of various technologies and systems from unauthorized access and attack. In 2011, a New York Times article discussed how researchers were able to remotely take over a car's critical systems.



The article noted that the car's communication systems were able to be exploited through Bluetooth wireless technology and cellular connections. Through this technology, a hacker could potentially take over a car's various features, such as its door locks and brakes. He or she could also monitor the vehicle's location and collect other data (Möller, 2016).

The incident shows how cyber can be used to affect the physical processes of manufacturing. In Industry 4.0, if a hacker is able to access a manufacturing facility from a remote location, they can potentially hijack various features of the system. This type of attack can have a tremendous impact on the manufacturing process, such as stopping a whole assembly line or changing the sequence of steps. The incident shows the importance of having a comprehensive cybersecurity strategy when it comes to the operations of a manufacturing facility (Möller, 2016).

One of the biggest issues that cybersecurity professionals face is the rapid evolution of security risks. The conventional approach to protecting against these threats has been to focus on the most critical components of an organization, leaving less important systems vulnerable to less dangerous attacks. The conventional approach to protecting against these threats has failed to address the complexity of the cyber-physical environment. Due to the increasing number of threats, cybersecurity professionals believe that the traditional methods of securing CPS information may no longer be effective. The consolidation of physical and cyber components within CPS creates new vulnerabilities that can be exploited by attackers to take over, disrupt, or even fail the operations of the organization. The main reason for the emergence of this vulnerability is the way that the physical and cyber components are integrated. The cyber component provides a variety of services and tools that are designed to help analyze and monitor the data collected from various sources. The cyber component is also designed to help facilitate the interaction between the various units of a CPS by providing a remote network access. This feature allows the organization to efficiently manage its operations (Möller, 2016).

### **3.2.3 Direct Digital Manufacturing**

Digital Direct Manufacturing (DDM) is a promising technology that can create high-quality personalized products using 3D printing. This could be done through the combination of the advantages of traditional production methods and the digitalisation of skills. The ability to become a manufacturer through basic computer skills can help



people in developing countries earn local value. 3D printers are already being used to bridge educational and technological gaps in developing countries. It is expected that DDM will also be a good candidate to address cultural and technological gaps between developed and developing nations. DDM relies on the prosumer to produce products, which means they can be produced closer to their required time. This eliminates the need for storage space. However, it is still encountering issues due to its lack of contributors and technological maturity (Chen et al., 2015).

Due to the nature of DDM's community, interoperability between its equipment and its designer is often a time-consuming issue. Currently there is no standard that supports this. In addition to physical tests, interoperability also requires calibration. This is why it is important that the hardware is equipped with the necessary tools. Due to the high scrap rate and the time involved in testing and producing products, the costs of materials have increased. With DDM, users can now realize the potential of manufacturing various products. This eliminates the need for manual labor and allows them to produce a batch size product. The increasing use of DDM can lead to an increase in the consumption of materials and environmental issues. Due to its ability to work on smaller scales, DDM's recyclability becomes more challenging. In addition, the unknown environmental and toxicological hazards of DDM need to be studied. This is done to prevent the damaging effects of DDM processes on the ecosystem and human health. It is also beneficial for the development of personalized products as they help address the various social issues that society is experiencing. In addition to environmental issues, the social impacts of DDM processes are also important to be considered. These include waste management, job loss, and logistics. Evaluating the reliability and performance of DDM in the production of goods sold on the open market can be challenging. In Europe, it would be very challenging to establish a conformity for products that are manufactured using DDM. This is due to the complexity of the design process and the unknown who designed the product (Chen et al., 2015).

### **3.2.4 Digitalization in the Supply Chain**

The use of I-based tools, such as ML and DL, is an integral part of sustainable development. These tools help organizations design and implement strategies that will help minimize their carbon emissions and improve their efficiency. Artificial intelligence (AI) is contributing to the sustainability of the supply chain by helping organizations reduce their carbon emissions. Through the use of AI tools, they can

help improve the efficiency of their operations and minimize their impact on the environment. The 2030 United Nations Sustainable Development Agenda has urged organizations to adopt renewable energy as their primary source of energy. However, these sources have various limitations that prevent them from being as efficient as non-renewable sources. Through the utilization of AI-based tools, manufacturing companies can also enhance the efficiency of these energy sources (Jamwal et al., 2022).

### **3.2.5 Digital Innovations**

The use of digital design technology allows for the simultaneous and synergistic development of a product's full life cycle. It can be done through the use of a comprehensive design database that includes multiple features such as virtual reality and computer network. This allows for the product's design to be realistic and improve its performance (Zhou, 2013).

The first innovation in the field of processing technology involves the manufacturing process. Aside from bringing about major advancements in the field of processing, digital technology has also led to various technological innovations. One of these is the material handling technique used in 3D printing. With the help of digital technology, manufacturing techniques can achieve significant improvements in their precision and productivity. This can be achieved through the use of various intelligent and digital technologies such as optimization simulation (Zhou, 2013).

The manufacturing industry is expected to undergo significant changes due to the emergence of digital technology. This will allow companies to respond to the demands of their customers more effectively and efficiently. The increasing number of digital devices and the internet will also enable them to manage their various operations more efficiently. Through the emergence of digital technology, companies will be able to create a new production model that will allow them to adapt to their customers' needs and provide them with the best possible service. This will also allow them to take advantage of their existing resources and improve their efficiency (Zhou, 2013).

## **3.3 Parameters for Sustainability**

The increasing emphasis on the environment and sustainability is becoming a critical topic for business executives and the people who make decisions regarding their

products and services. This has led to the development of imaginative and eco-friendly solutions that have been proposed to buyers. The advancement of technology and the environment are mutually beneficial ways of guaranteeing a successful financial turn-around. While mechanical progress focuses on improving processes and utilizing resources more efficiently, eco-development takes into account the reduction of harmful impacts and the use of renewable energy sources. It is also important to note that developing nations do not have the necessary innovation to address the various natural issues that affect the environment. Instead, they rely on mechanical advancement to address these issues. This could help minimize contamination and improve the global economic situation. The development of new strategies and procedures related to mechanical advancement can help improve the efficiency and practicality of financial transactions (Sharma et al., 2022).

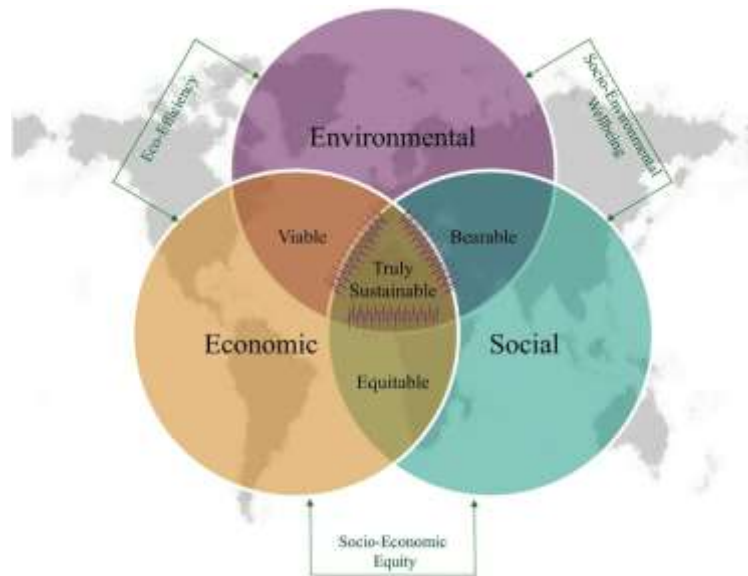


Fig. 8: Sustainability pillars (Tasdemir, Gazo, & Quesada, 2019)

### 3.3.1 Energy Efficiency

One of the most important factors that businesses and organizations consider when it comes to sustainability is energy efficiency. According to the NAM, the manufacturing industry in the US consumes around a third of all energy. This means that a company's sustainability can be affected by how efficiently it uses energy. An energy-efficient strategy can be a lucrative option that can be carried out over time. It can also provide a company with the added benefits of lower energy costs and

increased productivity. The increasing number of manufacturing companies adopting energy-saving techniques is a clear indication that the sector is becoming more sustainable. The IAC database has been used to create the various sub-indices and questions that are related to energy efficiency. One of the most popular software used to estimate a company's energy usage is called "Energex." This program was developed by a group of researchers at West Virginia University. Using the IAC database, they were able to create a comprehensive analysis of 29 factors that affect a company's energy efficiency. The researchers categorized the 29 factors into eight sub-categories. These include air conditioning, lighting, ventilation, and heating, as well as process heat, motors, and cooling towers (Latif et al., 2017).

### **3.3.2 Waste Management**

Sustainable manufacturing practices are critical for long-term success in industries. One key aspect of this is effective waste management. Industries face numerous challenges that impact their financial performance and future growth prospects. These can range from the energy usage of their operations, environmental pollution, to even employee absence. Implementing sustainable waste management strategies can help mitigate these challenges and promote the overall sustainability of industrial operations. The reduction of waste not only reduces environmental impact but also helps optimize resource utilization, improves worker safety and enhances the overall efficiency of operations. Effective waste management should be integrated into the broader sustainability efforts of the industry, encompassing not only the reduction of waste but also recycling, reuse, and recovery. By considering waste management as a crucial aspect of sustainable manufacturing, industries can make meaningful progress towards a more sustainable future (Latif et al., 2017).

### **3.3.3 Workers' health and Safety**

The design and use of workstations play a crucial role in the health and safety of employees in the manufacturing industry. Improper ergonomic design of workstations can lead to an increased risk of injury and can cause chronic or acute health conditions. A recent study highlights the importance of considering the well-being of workers when it comes to designing and manufacturing products. The study emphasizes the need for manufacturers to prioritize the health and safety of employees in their operations. The implementation of ergonomic principles in the

design and use of workstations can significantly reduce the risk of injury and promote a healthy working environment. Additionally, providing education and training on proper posture and techniques to employees can further minimize the risk of injury and promote overall health. By ensuring the safety and well-being of employees, manufacturers can increase productivity, reduce absenteeism, and promote a positive work environment. Ultimately, considering the health and safety of workers should be a top priority in the manufacturing industry (Latif et al., 2017).

### **3.4 Combining Industry 4.0 with Sustainable Manufacturing**

The convergence of sustainability and digitalisation in the production chain is a major theme that has been acknowledged. Both approaches are focused on improving the efficiency of the life cycle management of a product or service by developing new strategies and procedures. For instance, by implementing recycling and disassembly in the life cycle management, the process can reduce the risk of contamination and improve the safety of workers (Machado et al., 2020).

Industry 4.0 is expected to provide various sustainability benefits. These include improving productivity, reducing waste, and enhancing the efficiency of the production system. It is also expected to help companies develop effective collaborations and partnerships with their stakeholders. Besides these, it is also expected to create employment opportunities for the disabled and elderly (Machado et al., 2020).

In addition to supporting sustainable development, Industry 4.0 can also help companies create new business models and provide new product-services. It is expected to help companies develop value networks by developing new strategies and procedures. It is additionally expected to help them implement effective collaborations and partnerships with their stakeholders. Some of the key factors that are expected to influence the development of this concept include the availability of smart data, the establishment of effective training programs for workers, and the use of technology to improve the efficiency of the production system (Machado et al., 2020).

The various sustainability dimensions represent systems that are evolving around the concept of digital value creation. Adopting a solution that is related to one of these systems can have indirect or direct impacts on the other systems. The interactions between various sustainability systems can be categorized into three types: causal

relations, magnitude and scale drivers, and latency and duration dependencies. The effects of a solution depend on its scale and magnitude, while the impacts of an indirect or direct product or service depend on its distribution (Machado et al., 2020).

The concept of sustainability 4.0 allows us to reduce our energy consumption and resources while still achieving the best possible outcome. Some of the emerging technologies that are helping us achieve this are artificial intelligence (AI), the Internet of Things (IoT), and 3D printing. To ensure that the concerns related to data consistency and privacy are addressed in an agile way, these technologies should be used together with agile governance. Some of the promising technologies that are helping us address climate change include carbon capture and storage, wind and solar energy farms, and electric cars. The increasing interest in sustainability 4.0 technology by investors and consumers has led to the development of new business models and the merging of sustainability and technology. These technologies are being used at various scales, such as drones and satellites, and they can be commercially exploited by export-oriented companies. This provides them with an opportunity to expand their reach and improve their efficiency. In addition to being able to commercialize their innovations, these technologies can also help them penetrate international and domestic markets (Javaid et al., 2022).

A sustainable manufacturing process involves using fewer energy-intensive equipment, producing products with low environmental impact, and utilizing renewable resources. It also helps decrease the incidence of waste and harmful emissions. The concept of a green supply chain involves implementing sustainable logistics and supply chain management. This can help companies lower their environmental impact and improve their efficiency. Due to the increasing number of people who are becoming more eco-friendly, manufacturers are required to change their methods in order to align themselves with their customers. Doing so can help them gain a competitive advantage and reach new customers. Through the use of smart manufacturing technology and the Internet of Things (IoT), manufacturers can connect their operations and systems. This can help them improve their efficiency and reduce their costs (Javaid et al., 2022).

Industry 4.0 is the fourth wave of the Industrial Revolution, which is characterized by the emergence of new technologies that are designed to create a more connected and sustainable world. This concept is referred to as Sustainability 4.0, which aims to become a more dominant attitude in addressing environmental, social, and ethical issues. The goal of Sustainable Development is to create a more ethical and

sustainable world by 2030. This concept is made possible through the integration of digital technology into every aspect of an organization. In addition to being able to create value in multiple areas, such as supply chain management and customer service, digitization also allows companies to manage their operations more efficiently. Due to the increasing number of innovations in the Internet of Things (IoT), it is now more important than ever that businesses have the necessary tools and resources to identify and manage their greenhouse gas emissions. In addition to this, sustainability 4.0 also considers other social aspects such as the creation of jobs and a safe work environment (Javaid et al., 2022).

Industry 4.0 is a paradigm that aims to create sustainable value in the industrial sector. It is mainly focused on the contribution of environmental elements to the development of industrial processes. The intelligent cross-linking of value creation tools can help companies realize the efficiency of their resources. With the help of Industry 4.0, companies can realize sustainable value across multiple sustainability dimensions (Stock & Seliger, 2016).

### 3.5 Summary

Innovation in advanced manufacturing technology encompasses product innovation, manufacturing technology innovation and industry model innovation. Digitalization and intelligentization are the generic enabling technologies for product innovation and industrial technology innovation. Digitalization promotes more integrated value chains, which improves the efficacy of diverse business tasks, decreases lead times, and offers more operational control. The exchange of information between systems and functions, such as production and enterprise resource planning, enhances the coordination, visualization, and planning of crucial activities (Zhou, 2013). Utilizing technologies like the Internet of Things, Big Data, Cloud Computing, and Artificial Intelligence, digitalization helps manufacturers to optimize and enhance the effectiveness of their operations.

Sustainability and environmental concerns are swiftly becoming the most important factor in crucial business, manufacturing, and product development decisions. Ecological advancement and technological growth are mutually reliant means of ensuring a feasible economic outcome. Sustainable development is a global concern, although it should be noted that developing nations lack the ingenuity required to combat standard ecological issues and their inherent effects. In this approach,



technological development might serve as the foundation for reducing pollution and the path to a globally feasible economic turnaround. The ensuing techniques for the development of mechanical progress could result in the unmistakable advancement of practical financial outcomes (Sharma et al., 2022).

Sustainability and environmental concerns are rapidly becoming the most important factor influencing crucial business, production, and product development decisions. Ecological progress and technological development are mutually reinforcing strategies for ensuring a viable economic outcome. Sustainable development is a global concern, yet it should be noted that developing nations lack the ingenuity required to combat standard environmental problems and their inherent outcomes. In this approach, technological development might become the basis for reducing pollution and the path to a globally viable economic turnaround. The ensuing ways for the improvement of mechanical development could result in the unmistakable improvement of actual financial outcomes (Javaid et al., 2022).



# Chapter 4: Market Overview

## 4.1 Current Situation

The rapid emergence and evolution of digitization and Industry 4.0 have created a huge opportunity for the manufacturing industry. According to estimates, the smart manufacturing market will grow from around 277.81 billion to over 660 billion dollars by 2029. Many companies have realized that they need to redesign their systems and processes in order to remain competitive. Today's supply chain management challenges are rooted in the demands of consumers. There are many factors that affect the efficiency of a company's operations, such as increasing competition, changing consumer behaviours and technological advancements. Despite the efforts to improve the effectiveness of their supply chains, many companies were forced to restructure their operations due to the pandemic. The rapid emergence and evolution of new consumer behaviours require companies to rethink their supply chain management strategies. The ability to make informed decisions through data is a must in order to improve the efficiency of their operations. Unfortunately, many manufacturers are still not equipped with the necessary digital foundations to implement this process. Due to the increasing number of factors that affect the efficiency of a company's operations, manufacturers are now turning to the cloud to drive their digital transformation and improve their business processes. One of the most critical factors that manufacturers consider when it comes to adopting the cloud is the availability of software-as-a-service (SaaS) solutions (Adapt, 2015).

Digitization in the manufacturing industry is a process that involves the design, development, and implementation of equipment and processes. It is also related to the increasing number of end-users and the improving performance of the supply chain. The government's support for data connectivity is helping the market grow. China's Made in 2025 initiative aims to transform the country's manufacturing industry by increasing the production of high-quality goods and developing new R&D capabilities.

The digital transformation of the manufacturing industry is a process that involves addressing various global issues faced by companies. One of these is the complexity of the supply chain. Through the use of GPS and big data, manufacturers are able to improve their efficiency and manage their supply chains. This allows them to gain a competitive advantage and stay ahead of their competitors. Through a five-year

collaboration, CNH Industrial and its partners will be able to create a global digital hub that will help them develop and launch various digital services. These services will help improve the efficiency and effectiveness of their operations. Using connected vehicles, consumers will be able to benefit from various new services, such as predictive maintenance and green transportation. Manufacturers will also be able to take advantage of the digital capabilities of their products to improve their efficiency and supply chain management. Some of these include Nike's custom shoes and the automotive industry's increasing involvement with consumers. By 2021, it is estimated that there will be around 50 times the digital content. Due to the complexity of analysing and managing Big Data, manufacturers are currently struggling to keep up with the changes in the technology landscape and the increasing number of connected devices. This has made it important for them to move quickly to adopt the digital version of their products and services (Zadjali & Ullah, 2021).

According to Cisco, by 2030, there will be 500 billion devices connected to the Internet. The rise of IoT and other advanced technologies such as SD-WAN and big data analytics is driving the development of new manufacturing processes that are designed to improve the efficiency and quality of their operations. These new tools are helping organizations manage their massive data sets and improve their operations. Big data analytics could have generated around 7% more revenue for German manufacturing firms in 2020, which is an indication that the technology is helping them improve their operations. Also, due to the rapid emergence of 3D printing technology, manufacturers are able to produce goods faster. The rapid prototyping process is a cost-effective way for designers to test and improve their products. Before, the production of various components such as molds and fixtures was usually done by using tooling companies located in other countries. Due to the availability of 3D printing equipment, it has become easier for manufacturers to complete their tooling on-site, which has led to the widespread adoption of the technology in the aerospace and automotive industries. Through the use of secure connections between networks, partners, and customers, organizations are able to drive digital transformation (Adapt, 2015).

A study conducted by Equinix revealed that the private interconnection capacity of the manufacturing industry is expected to grow by over 50% over the next couple of years. This is because the industry's total interconnection bandwidth is expected to reach 1,547 Tbps by 2022. The increasing number of industrial robots has been instrumental in the development of digital manufacturing. They help organizations improve their

efficiency and scheduling by collecting and analyzing data related to their equipment. In addition, they can help prevent unforeseen errors. One of the main advantages of robotization is its ability to help organizations double their turnover. It is also expected that the use of collaborative robots will increase in the manufacturing industry. The global market for industrial robots is expected to grow from about \$13 billion to over \$24 billion by 2025. Workers can easily program intelligent robots to perform tedious tasks and deliver accuracy. According to IFR, the number of industrial robots will increase from 2,408 in 2018 to 3,788 by 2021. Due to the advantages of collaborative robots, such as their ability to work safely in hazardous environments, they are becoming more prevalent in the manufacturing industry. Moreover, various companies are launching mergers and acquisitions to expand their operations.

The emergence of the COVID-19 pandemic led to a shift in manufacturing from traditional to digital. According to a report released by IBM, over 60% of the manufacturers in the country accelerated their digital transformation efforts due to the pandemic, and some of the major technology that they have already adopted include data analytics, cloud computing, and cyber security. Due to the limited workforce, the manufacturers have been compelled to adopt digital technologies to contain the spread of the virus. The need for skilled workforce is also a major challenge that the market faces during the next few years (Deloitte University Press, 2016).

## 4.2 Sustainability in Manufacturing Developing Economies

Due to the continuously changing needs of the market and the limited profit margins, manufacturing organizations are constantly looking for new ways to improve their processes. This can be done using advanced technologies. Even though competing in the international market can be challenging, developing sustainable products can be done. Due to the increasing importance of the environment and the economic considerations, manufacturing organizations are now looking for new technologies that can help them meet their sustainability goals. Some of these include the use of advanced technologies such as the Internet of Things, the Big Data Analytics, and the Cloud Computing (Yadav et al., 2020).

Industry 4.0 is a concept that refers to the next generation of industrial revolution. The manufacturing industry is a vital part of developing nations' economies as it creates jobs and helps build a stronger society. Several multinational companies are currently planning on establishing their operations in these countries due to the low cost of

production and the availability of skilled labor. Due to the increasing need for improving the supply chain management and reducing the overall cost of production, Industry 4.0 has become the most preferred solution for manufacturing companies. However, it is not feasible for small and medium-sized enterprises (SMEs) to fully adopt this concept.

Despite the progress that emerging economies have made in their manufacturing sector, they still have a long way to go in attaining sustainable development (Yadav et al., 2020).

There are only three countries that are among the world's top ten emerging economies when it comes to GDP: China, Brazil, and India. The US, on the other hand, has the highest GDP, but it only uses 14.7 percent of renewable energy resources. Developing nations are not doing well when it comes to the global environment. For instance, China is ranked 120th, India is at 177th, and Brazil is at 69th in the EPI. It is distressing to see that 35 percent of the world's greenhouse gases are generated by these countries. The manufacturing sector is very important to developing nations as it contributes a significant portion of their GDP. It is therefore important that they adopt sustainable strategies and practices in this sector (Yadav et al., 2020).

Developed countries like Germany, the UK, and the US have made significant strides in adopting new technologies to achieve sustainability. Their success is attributed to their well-established infrastructure and advanced manufacturing setups. However, the same advantages that contribute to their success are missing in developing nations. While the potential benefits of Industry 4.0 technologies for sustainability are widely recognized, their practical implementation in developing nations is yet to gain widespread acknowledgement. This paper aims to shed light on the key enabling factors of sustainability that are relevant to developing nations. The authors hope to bridge the gap between the theoretical potential of Industry 4.0 and its practical application in less developed countries. By focusing on the specific challenges and opportunities in these nations, the authors aim to provide valuable insights and recommendations for organizations and governments seeking to promote sustainable development (Yadav et al., 2020).

### 4.3 Challenges Digitalization

Due to the complexity of the technology management process, it will continue to be difficult for organizations to develop green initiatives. Some of the factors that will prevent them from achieving this include cyber security, data protection, and privacy. To address these issues, organizations can develop and implement effective digital operations strategies and solutions. These include establishing data sharing infrastructure, securing networks, adjusting their digital operations procedures, and improving GTI. Through the dissemination of information, organizations can promote the use of advanced technologies and develop low-carbon strategies (Li & Wang, 2022).



Fig. 9: Digital challenges (Xorlogics, 2019)

Most organizations are not able to effectively utilize the data generated by their customers to develop new offerings due to the lack of proper processes and workflows. This is why it is important that they adopt the necessary changes to improve their operations. In addition to improving their processes, it is also important that they are able to identify and develop viable business models (Björkdahl, 2020).

Only a few firms have the central control over all of the data that they collect, which tends to be spread across various market segments, enterprise functions, and geographical locations. This makes it challenging for them to organize their efforts in the digital era. Because of this lack of control, many firms are unable to distribute data

outside of their geographical boundaries. They also lack the necessary skills to analyze and interpret the data to determine how they should be used (Björkdahl, 2020).

Coordination and the hand-over of efforts related to the digitization efforts across different functions can pose problems. A chief digital officer (CDO) is needed to promote growth, but retaining the organization's current structure may not solve the issues. Many firms have a hard time organizing their efforts due to the lack of a culture that supports digital transformation (Björkdahl, 2020).

#### **4.4 Challenges Sustainability**

Even these normative-mimetic drivers are, for the most part, beneficial, there is still a chance that a company's reputation could suffer as a result of their presence. Greenwashing by corporations and other attempts to misrepresent the sustainability profile of a company may give rise to concerns for the appropriate agency, for example. Greenwashing by corporations may also be a violation of the relevant agency's policies. This is owing to the fact that it is easy to take advantage of the fact that the agent's aims and the principal's goals are in direct conflict to one another by using dishonesty and opportunism. This is because the agent's goals and the principal's goals are in direct antagonism to one another. According to the institutional theory, the environment and the social conditions of a particular time and place can have a considerable influence on the formation of the formal structures of a particular company. This is because the environment and the social conditions are intertwined with the history of the company. This concept places an emphasis on the most fundamental components of social structure, such as rules, rituals, and customs, which are the result of the interaction between these various factors. The assumptions made in the vast majority of studies on sustainable development focus on transaction costs and resource bases. Having said that, the inclusion of the sustainability agenda into the workings of a firm can also be impacted by a number of other institutional factors, all of which have the potential to do so. There is a lack of standardization in the sector, there are insufficient resources, and a rising number of novel ideas are being proposed all the time. These are some of the problems that have arisen. The vast majority of companies are unable to account, in a consolidated financial statement, for the full benefits that result from the implementation of sustainable measures that they themselves have taken. Instead, they have a propensity to base

their decisions on transaction costs or assumptions based on resource availability, rather than doing an analysis of the myriad institutional factors that have the potential to impact their work. This is despite the fact that the aforementioned considerations have the potential to have a major impact (Mohammad Ebrahimi & Koh, 2021).

## 4.5 Summary

Industry 4.0 and digitization have increased manufacturing industry growth. The worldwide smart manufacturing market is predicted to rise from USD 277.81 billion in 2022 to USD 658.41 billion in 2029 at a CAGR of 13.1%. During COVID-19, many industrial organizations saw the necessity to change their processes and systems to survive and develop. today's supply chain management, including manufacturing, hinges on the demands of customers. Every aspect of operations and the supply chain is affected by the digitization of the industrial sector. The procedure begins with the design of the equipment. The method is then followed by the optimization of the production process and the monitoring and improvement of the end-user experience.

The fluctuating market demands and slim profit margins have compelled manufacturing companies to reevaluate their present process structures. To improve their entire supply chain and attain sustainability, business managers are always on the lookout for new technologies to embrace. Even to compete in the international market, sustainable product development is required. In addition to the economic consideration, it is now necessary to also take into account the environmental and societal aspects of production. Therefore, organizations are looking for new technologies that can satisfy their sustainability criteria. Emerging technologies such as the Internet of Things, Big Data Analytics, and Cloud Computing have provided new opportunities in the healthcare, manufacturing, and service industries (Yadav et al., 2020).

Particularly in emerging nations, the manufacturing sector is vital to the nation's economic development. Due to low production prices and inexpensive labor, numerous multinational corporations (MNCs) have expressed interest in expanding their manufacturing operations in developing nations such as China, India, Thailand, and Brazil. However, in the current manufacturing landscape, Industry 4.0 has emerged as the most important approach for improving supply chain structure and achieving sustainability. Industry 4.0 is widely adopted by large organizations, however it is not utilized by small and medium-sized businesses (Yadav et al., 2020).



The complexity of the technology management process will continue to make it challenging for businesses to establish and implement effective plans. Cyber security and data protection are among the obstacles that will prohibit them from achieving green development. In addition, the disadvantage of normative-mimetic drives is corporate greenwashing, or the misrepresentation of a company's sustainability profile. Regulatory forces, on the other hand, could unwittingly exacerbate the agency dilemma, wherein the divergent or contradictory interests of principal and agent would often manifest as transaction costs through opportunism and deceit. Therefore, the issue must be addressed on a larger scale with the participation of more stakeholders (Li & Wang, 2022).



# Chapter 5: The Future of the Manufacturing Industry

## 5.1 The Potential of Industry 4.0

The Industry 4.0 Working Group believes that Industry 4.0 has enormous potential, as outlined in the following section:

- *Meeting specific customer requirements:* Through Industry 4.0, a customer's unique specifications can be incorporated into the project's planning, design, and manufacturing phases. It allows for last-minute adjustments. Profitable production of unique items with low production volumes is possible.
- *Flexibility:* Ad hoc networking is a type of business process that enables organizations to dynamically configure different facets of their operations. It allows them to streamline their supply chains and improve quality. It can also help them develop more agile engineering processes and more effective products. In addition, it can assist them in dealing with sudden shortages or other temporary problems.
- *Effective decision-making:* One of the most important factors that companies must consider when operating in a global market is their ability to make the right decisions quickly. They now have the necessary end-to-end visibility into their design decisions thanks to Industry 4.0. This enables them to make more informed decisions and increases their productivity.
- *Resource productivity and effectiveness:* The objective of industrial manufacturing processes is still to maximize resource productivity and efficiency. These objectives involve producing the highest quality output with the fewest amount of resources. Using case-based process optimization, manufacturers can now obtain the best possible results from their manufacturing processes. It can assist them in continually increasing their efficiency and decreasing their energy consumption.
- *Creating value through the introduction of new services:* Industry 4.0 can assist businesses in creating new forms of employment and enhancing their productivity by utilizing advanced technologies. Implementing intelligent algorithms that collect and interpret data can also help them manage their various operations. There are numerous opportunities for startups and small and medium-sized businesses to develop Industry 4.0-related B2B services.

- *Adapting to demographic shifts in the workforce:* Industry 4.0 can assist businesses in developing new approaches to demographic shifts, in addition to the numerous initiatives already in place to increase the operational efficiency of their businesses. It is anticipated that the demand for skilled labor will increase as the number of individuals with diverse cultural backgrounds and skills rises. Employers can now create flexible and diverse career paths thanks to Industry 4.0.
- *Work-life balance:* One of the primary benefits of CPS is that it enables businesses to meet the rising demand for flexible work arrangements. It enables them to provide a better balance between personal and professional development for their employees. By utilizing intelligent assistance systems, they can now organize their work in a manner that enables them to meet the needs of their company. The dwindling labor force will provide CPS firms with an advantage when it comes to talent recruitment.
- *A wage-intensive economy that remains competitive:* Through the dual strategy of Industry 4.0, Germany can become a global leader in industrial technology and a leading supplier (Möller, 2016).



Fig. 10: The potential of industry 4.0 (UNIDO, 2017)

## 5.2 Outlook of the Manufacturing Industry Sustainability

Modern technologies will allow machines to perform almost everything from monitoring and mitigation to planning and implementing sustainable projects in a more efficient manner. With sustainability 4.0, small- and medium-sized businesses can

now benefit from the tools and data science to make informed decisions. Using data and artificial intelligence, organizations can now forecast the likelihood of wildfires, droughts, and storms. These factors can then be used to develop effective strategies and improve the efficiency of their operations. The implementation of smart systems is also linked to the development of robotic and automation processes. These systems are built using various technologies, such as wireless, sensors, and databases, which can be used to adapt and respond to their environment. These systems can learn from their environment and develop their own self-regulation and management abilities. The goal of sustainability 4.0 is to transform the way manufacturing is done by making it more sustainable. It will also allow companies to lower their costs and increase their operational efficiency (Javaid et al., 2022).

### 5.3 Performance Measurement for Sustainable Manufacturing

- *The resource perspective (normative-peer pressure)*: When making decisions regarding their products and services, manufacturers give substantial weight to the significance of sustainable development. This is because it assists them in achieving a variety of goals and objectives, such as locating a supplier who can provide them with the necessary resources. The term "normative-peer pressure" was coined to describe the pressure exerted on a group of individuals in order to achieve a particular outcome.
- *The stakeholder view (peer-normative pressure)*: When developing a sustainable framework, it is important to consider the various stakeholder groups involved in the production process. For instance, automotive manufacturers must procure rare earth materials from mining companies to meet the needs of their suppliers. They must also manage their logistics and freight operations. Automotive manufacturers are required to consider the end of their products' lifecycles due to mounting pressure from a variety of stakeholder groups. This notion is known as peer-normative pressure.
- *Institutional theory (regulatory pressure)*: Regulation is the third component of the theoretical framework. Understanding the various factors that influence the development and implementation of regulations is required. A company's sustainability performance is determined by how it uses its indices. Several certifications and price adjustments may occur if a manufacturer's upstream SC is not aligned with the appropriate measures (Mohammad Ebrahimi & Koh, 2021).

## 5.4 Managerial Role

### 5.4.1 Role in Sustainability

Early studies indicated that managers mainly focused on the cost drivers of sustainability strategies. However, recent research has shown that they are now opening up to the opportunity of the shift to consider it as an opportunity. This is in line with a review of a literature study that suggests that increasing focus on sustainability can boost firm competitiveness. According to policymakers, the manufacturing sector can play a vital role in addressing global sustainability issues. However, despite the sector's contribution to the development of sustainable technologies, there is still a lack of knowledge about which innovations are most likely to be financially motivated by firms (Hermundsdottir & Aspelund, 2022).

Despite the positive effects of sustainability on firm competitiveness, there are still many limitations that prevent it from becoming a commercially viable innovation. For instance, while some innovations can create commercial value, the practical questions around how and under what conditions sustainability can be profitable remain unclear. Due to the lack of clarity around the relationship between positive and negative elements of sustainability, many managers are not informed about how they can benefit from its implementation in their organizations. This is why it is important that they have the necessary knowledge to make informed decisions when it comes to adopting new innovations (Hermundsdottir & Aspelund, 2022).

Transition costs are often associated with the changes that are required to improve a company's sustainability performance. Scholars believe that these costs are offset by the internal efforts to develop a more resource-efficient production process. Other scholars believe that the cost of implementing sustainable practices can be offset through superior market performance and by eliminating market-associated risks (Hermundsdottir & Aspelund, 2022).

### 5.4.2 Role in Digitalization

Using intelligent networks, sensors will be able to provide a deeper understanding of the operations of a smart factory. This will allow manufacturers to improve their efficiency and prevent costly errors. The use of the Internet of Things (IoT) in a factory will allow operators to access the necessary information at the right time, across the enterprise, and in real-time. This will allow them to improve their efficiency and prevent costly errors.

Through the use of digital manufacturing and Industry 4.0, plant managers and operators will be able to gain access to the information collected from their suppliers in order to improve the efficiency of their operations. This will be done through a variety of software-based apps that will run on smart devices. Through the use of smart devices, plant managers and operators will be able to gain access to the data collected from their suppliers in order to improve the efficiency of their operations. They will also be able to visualize data and alerts from various locations on the manufacturing line.

Through a smart factory, managers and operators will have the ability to control and improve the quality of their manufacturing processes. This will allow them to achieve higher productivity and improve the efficiency of their operations. They will also adopt the role of quality assurance to ensure that the various processes are performed properly. This will allow them to achieve better control over their manufacturing environment (Möller, 2016).

In terms of team management, it is important that organizations minimize the reluctance of their R&D members to adopt digital technology. They should also increase the number of communication channels between the various departments. To improve the digital literacy of their employees, enterprise managers should regularly assess and promote their digital competence. They should also increase their digital R&D collaboration process' efficiency and minimize the cognitive constraints that can prevent them from making informed decisions. To promote collaboration among members, manufacturing firms should regularly expand their cooperation channels. They can also assign inventors to work on temporary assignments to maintain effective and efficient collaborations (Li & Wang, 2022).

As the business leaders of companies look to improve their operational efficiency, they need to consider how digital technologies can help them achieve their goals. With the increasing pressure to deliver effective and measurable results, many manufacturing firms are looking to improve their operations by implementing digital solutions (Björkdahl, 2020).

Despite the potential of digital transformation to drive profitable growth, many companies have already failed. In the long run, the objective should be to enhance the company's core business while addressing specific customer experience issues. To ensure that its core products are equipped with the necessary digital technologies, the company should regularly update its offerings. This can help minimize risk and

improve the company's competitive advantage. However, it is important to note that the market's stability will determine the best strategy for the company. If the market's stability is the determining factor, then a digital transformation strategy that aims to achieve operational efficiency may be more beneficial than a larger one (Björkdahl, 2020).

## 5.5 Digitalization Blurs Industry Boundaries

The concept of digitalisation refers to the integration of new digital resources into a company's corporate resource base. It can help improve the efficiency of the organization and enable new revenue sources.

The increasing number of capabilities that manufacturers have to acquire and master through digitalisation significantly broadens their scope of competences. They have to develop, master, and integrate a wide range of digital technology solutions that can help them manage their various business functions. This includes the development of new capabilities such as R&D and design. Due to the complexity of the various components and systems that are integrated using digital technologies, it magnifies the need for system integration expertise.

New capabilities are required to develop and master new offerings that combine the digital capabilities of a product with its organic components. Firms also need to build and manage a technology stack that can handle the integration of various data sources and provide them with the necessary insight to improve their operations. To effectively handle the increasing volume of data that is collected and stored in their organizations, they need to invest in the necessary hardware and software tools.

The rapid emergence and evolution of new digital solutions has also prompted organizations to expand their scope of capabilities and resources. They need to develop new business models and implement a slew of applications designed to improve their operations and increase their competitive advantage.

The rapid emergence and evolution of digital technology has created a significant opportunity for manufacturing companies to expand their competitive advantage. It is therefore important that they adopt the necessary strategies and technologies to capitalize on the opportunities that are available to them. Most studies that are focused on the new capabilities required for the digital era highlight the importance of developing effective and dynamic capabilities. Despite the various advantages of

digital technology, many manufacturing companies still lack the necessary knowledge about how to effectively use it to enhance their operational capabilities. This is an important issue that they should address in order to capitalize on the opportunities that are available to them.

There are numerous gaps in the capabilities of manufacturing firms. Due to the complexity of their products and the increasing number of new innovations, many firms lack the necessary knowledge and resources to maintain their competitive advantage. Due to the rapid emergence and evolution of new technologies and the increasing number of global competitors, many manufacturing firms have no time to build their capabilities to meet their customers' needs. To address these challenges, they need to partner with external providers who have the necessary expertise and resources.

In order to access and integrate external capabilities, firms must first develop a set of internal capabilities that are capable of handling the multiple requirements of their operations. These include knowledge management, orchestration, and relational capabilities. They are also required to align their resources and capabilities with those of their partners in order to build an innovation ecosystem.

The rise of digitalisation has prompted firms to adopt an open innovation strategy that enables them to access and integrate various specialized knowledge. This approach is also beneficial for their internal processes as it allows them to enhance their knowledge management and improve their efficiency.

Despite the increasing number of external collaborations that allow companies to access and integrate different specialized knowledge, it is still important that they develop their own internal capabilities to manage their digitalisation efforts. This is because developing these capabilities is very important for the absorption of the knowledge of their partners.

The diversification of a manufacturing company's operations outside of its core technological framework helps strengthen its innovation capability and absorptive capacity. It enables them to take advantage of the latest digital solutions and develop new, enhanced products.

The concept of resource-based theory states that if a manufacturing company's operations are similar to those of other companies in the same industry, then its resources and competences would be similar. However, this doesn't mean that the



same industry's boundaries can be maintained. As a result, a growing number of related industries are formed as a result of the combined knowledge of various knowledge fields.

First, existing companies can expand their scope of operations by commercializing their digital enhanced products. They can also leverage their new capabilities to enhance their competitive advantage. This is done through the external commercialization of their digital technologies. Second, agile representatives of traditional industries can create new competition dynamics by drawing on open innovation.

The importance of developing and implementing effective R&D strategies is acknowledged by manufacturing firms as they look to improve their competitiveness and take advantage of the various advantages of digitalisation. A study typically focuses on the efforts of manufacturing firms to incorporate and utilize the knowledge they have gained from the digital technology industry. Despite the importance of incorporating digital knowledge into their operations, there is still a lack of attention paid to the learning activities of external knowledge providers. They need to expand their scope of knowledge to improve their offerings and performance. To effectively integrate their own solutions into their customers' operations, technology providers need to learn about their partners' core technologies. This knowledge can help them develop effective collaborations and solutions. In this study, we will discuss the various aspects of manufacturing domain knowledge that digital technology providers should develop.

The rapid emergence and evolution of new technology and the increasing number of manufacturing firms that are involved in the digital transformation of their operations are creating a growing convergence of the knowledge and capabilities of both the traditional and digital sectors. This is a blurring of the lines between traditional manufacturing and digital technology.

The concept of blurring the lines between traditional and digital manufacturing is discussed in this article, but it is not focused on the specific activities and competencies of digital technology companies. Instead, it focuses on the broader industry dimension of digital.

Due to the increasing number of similarities between various manufacturing industries, the number of technological domains that are common in them will also



increase. This will reduce the distance between the knowledge and capabilities of different manufacturing firms (Szalavetz, 2022).

## 5.6 Looking Ahead

There are many challenges that organizations face when it comes to implementing and integrating Industry 4.0 initiatives. These include the management of both IT and operations, as well as the ecosystem's evolution. As the rapid pace of technological change continues, these challenges will become more significant.

Due to the complexity of implementing and managing the various aspects of Industry 4.0, many companies are struggling to find the right talent to handle the increasing number of tasks and responsibilities associated with the integration of IT and OT. Even though the demand for engineers has increased, the number of them trained in handling big data and unstructured data is still insufficient. The lack of skilled workers in the shop floor also poses a challenge to the implementation of advanced manufacturing. Many leaders are not comfortable with the new technology and methodologies used in the field. They lack the necessary knowledge about materials and their properties. This can result in a lack of confidence in their ability to implement new technology. To address this issue, leaders should regularly engage in workforce development. They can also partner with educational institutions and other organizations to develop a pipeline of skilled workers.

Interoperability and standards are two of the most critical factors that can affect the success of Industry 4.0 applications. Many of the systems that are used to implement these applications are proprietary. Without interoperability, the full potential of Industry 4.0 technologies can be hindered. Due to the complexity of the issue, various groups, including government agencies and peer consortiums, are currently working on establishing competing sets of standards. This is not yet clear which standards will prevail.

As the value chain becomes more interconnected, there will be more questions about the ownership and control of data. These questions are particularly important as manufacturers and suppliers become more intertwined. As the data collected by various suppliers and vendors within the supply chain become more valuable, they will also have a claim on the information that they provide. This is especially important as it can help drive product improvements and improve the efficiency of the entire

supply chain. As a result, managers should pay close attention to their contracts and ensure that they have the necessary information access and ownership rights. This can help them identify and control the bottlenecks that prevent them from achieving their goals.

Besides data ownership, security concerns are also a major concern when implementing Industry 4.0 initiatives. Although cryptographic algorithms can help improve the security of IoT devices, they can also lead to higher power consumption. As deployments scale, this issue becomes more critical. When it comes to implementing Industry 4.0 initiatives, it is important to consider the security risks associated with the installation of old systems on new ones. Companies should ensure that they have the necessary resources and security measures in place to manage these risks. To minimize the risks associated with implementing Industry 4.0, managers should take a proactive approach when it comes to cybersecurity. This can be done by planning ahead and addressing the security issues before they become a problem (Deloitte University Press, 2016).

The rapid emergence and evolution of smart factories is expected to drive continuous innovation and competitiveness in the manufacturing industry. Most manufacturers are currently investing in the technology infrastructure needed to support these transformations. Most companies are also expected to partner with other organizations in the value chain to adopt these technologies. Over 60% of executives expect to partner with specialized technology firms to further their efforts in the development of smart factories. An example of an ecosystem approach is a collaboration between an electronics manufacturer and a research institute. They are working together to develop a 5G production environment that will allow them to test the use cases of industrial facilities. As the digital core of their organizations is established, manufacturers are also investing in various technologies such as artificial intelligence, blockchain, and augmented reality. One major industrial company is currently using these technologies to improve the efficiency of its workforce. For instance, a major aerospace company is currently using drones, sensors, and cloud technologies to improve the quality control processes of its operations. Some of the early adopters of these technologies are also experimenting with the use of digital platforms to create a seamless and unlimited reality experience. A major automotive manufacturer is currently exploring the metaverse by creating a virtual factory that replicates the entire production line to ensure that all its processes run smoothly. Its technicians are also using AR glasses to fix complex repairs while connected with

other experts through digital twins. As the manufacturing industry continues to move into the metaverse, it is important that organizations remain up-to-date with the latest cyberthreats. While cyber defense is a must, it is also important that businesses focus on their continuity of operations and resiliency in the event of an attack. One of the most important steps that businesses can take to ensure their operations are resilient is by continuously monitoring their operations and technology (Deloitte, 2022).

## 5.7 Summary

Utilizing modern technologies, practically everything can be performed by a machine in the future, from beginning to end, in a sustainable manner. Sustainability 4.0 makes monitoring and mitigation accessible to even organizations with modest budgets, enabling more localized and accurate decision-making. Through the extraction of insights from extensive data, artificial intelligence and data science will aid policymakers in making quicker and more precise decisions. Increased data inputs can result in more robust algorithms that generate more precise predictions. Smart Systems Implementation will be associated with digitalization, robotics advancement, automation, and AI-based processes. These systems are based on technologies that permit sensors, databases, and wireless to collaborate, adapt, and modify their behavior in response to their environment and users. They are capable of learning, utilizing experience, anticipating future behavior, and employing self-management and self-regulation skills. Sustainability 4.0 will be designed to transform the world and make manufacturing more environmentally friendly, while enabling businesses to greatly boost operational efficiency and cut costs by embracing intelligent technology at every value chain level (Javaid et al., 2022).

Earlier study revealed that company management viewed sustainability measures primarily as cost drivers; however, more recent research indicates a change toward viewing the sustainability transition as an opportunity. Therefore, from the perspective of policymakers, recent studies reveal that although while the manufacturing sector is one of the biggest contributors to global sustainability issues, it can also be an integral part of the solution (Hermundsdottir & Aspelund, 2022). Digitalisation significantly broadens the range of skills that established manufacturers must acquire and master. Specifically, they must develop, master, and integrate a digital technology stack that automates or supports a vast array of fundamental business activities and related functions. Creating, deploying, and integrating all of these solutions necessitates new

technological, R&D, and design capabilities. In addition, because digital technologies increase the complexity of everything they are included into, digitalization increases the required system integration skills.

Companies using or seeking to apply Industry 4.0 techniques may encounter a number of issues relating to the management and integration of IT and OT. While some difficulties have an influence at the company level, others exist at the ecosystem level. The rapid evolution of connected devices exacerbates these difficulties.

## Chapter 6: Conclusion

As a result of a number of key concerns, such as the growing importance of digitalization and sustainability in business processes, the manufacturing industry is currently facing a time of great transformation. This development is producing numerous substantial alterations in the sector. Digitalization enables manufacturers to optimize and enhance the efficacy of their operations, which in turn increases their level of competitiveness. A number of technologies, including the Internet of Things, Big Data, and Artificial Intelligence, can be leveraged to accomplish this objective. As a result, it is possible to obtain cost savings in addition to simultaneously increasing production and enhancing the overall quality of the product. Customers and governments are exerting a growing amount of pressure on businesses to operate in an environmentally responsible manner. As a result, sustainability is becoming an increasingly important aspect for manufacturers. This is because customers and governments put stronger pressure than in the past. This is because manufacturers are beginning to grasp the importance of incorporating sustainability factors into their decision-making processes.

The key foci of the examination that will be conducted as part of this research project will be the significance of digitalization in the manufacturing industry and environmentally friendly practices. The formidable combination of these crucial factors in the production process has the potential to result in considerable improvements not only to the organization's operational efficiency but also to its environmental performance. This one has the potential to lead to substantial progress. These technical advancements may have a substantial impact on the organization's capacity to reduce their negative environmental impact. It is possible that using digital technology to monitor, measure, and evaluate the environmental impact of a manufacturer's operations will lead to the identification of improvement opportunities and the formation of data-driven decisions in an effort to reduce the manufacturer's overall carbon footprint. If this occurs, it will be a step in the right direction toward decreasing the manufacturer's carbon footprint as a whole. This action would be conducted in an effort to reduce the manufacturer's total greenhouse gas emissions to a more manageable level.

The inclusion of digitalization into the production process has the potential to greatly improve the environmental friendliness of the final product, according to the conclusions of this study paper. The existence of this concept gives credibility to the

results of this inquiry. Implementing digital technologies such as Industry 4.0, the Internet of Things, and advanced analytics may enable firms to simultaneously boost productivity and decrease waste generation. It is feasible that this will eventually lead to an environmentally friendly manufacturing process. In addition, digitalization can improve supply chain visibility and traceability, which enables more responsible material sourcing and reduces the amount of environmental damage caused by production. This is a benefit brought about by the digital revolution. It is of the utmost importance to draw people's attention to the fact that digitalization alone is not a silver bullet capable of ensuring the future economic sustainability of the manufacturing sector. It must be implemented in conjunction with a variety of other policies and practices that promote sustainability, such as the use of alternative energy sources and the circular economy. This will guarantee its effectiveness. Moreover, the digitization process is accompanied by a new set of environmental issues, including the manufacturing of electronic trash and the high energy consumption of data centers. These issues are a direct consequence of the widespread adoption of digital technologies. These challenges are a direct result of the growing adoption of computers and other forms of digital technology. Both of these issues can be related to the widespread adoption of digital means in recent years, which has led to a rise in the number of activities. To achieve true sustainability in the manufacturing industry, it is crucial to have a well-defined strategy that considers both the positive and negative elements of digitalization in the manufacturing industry. Before beginning work on initiatives related to digitalization and sustainability, firms should do a thorough cost-benefit analysis. To achieve buy-in and have a successful implementation, it is of utmost essential to involve all important stakeholders, such as employees, customers, and suppliers, in the implementation process.

As environmental concerns continue to receive greater attention on a global basis, one of the most critical issues that must be resolved is how to implement environmentally friendly production procedures. The manufacturing industry has the potential to negatively impact the surrounding environment; however, the use of environmentally friendly procedures and technology can help mitigate this effect. This objective can be accomplished by reducing the quantity of energy that is squandered, decreasing the amount of trash created, and increasing the amount of renewable energy sources that are utilized. In addition to recycling, the production method may have a smaller influence on the natural environment near the plant if recyclable and environmentally friendly materials are employed. This is possible because recyclable and eco-friendly materials can be utilized.

To go forward with the implementation of these changes, it is essential to accept that the introduction of digital technology and environmentally responsible practices into the production process will not be devoid of challenges. It will be essential for manufacturing companies to invest in cutting-edge machinery and technology if they wish to take advantage of digitalization and the numerous other opportunities it presents. This is because digitalization will necessitate these kind of expenditures. In order for their enterprises to engage in environmentally responsible commercial operations, they must also modify their organizational structures and operational methods. If the manufacturing industry adopts and implements the suitable approach, it may become both more cost-effective and have a lower negative impact on the environment. The combination of digitalization and sustainability has the potential to transform the manufacturing business into one that is more profitable, sustainable, and efficient than in the past. This is something that should be done since, in the long run, it will be beneficial to both the environment and the bottom line. It is possible that the use of digital technology, which makes it easier to implement circular economy principles such as closed-loop systems, recycling, and remanufacturing, will make it simpler to implement environmentally friendly industrial practices. This is due to the fact that digital technology simplifies the implementation of closed-loop systems, recycling, and remanufacturing. Utilizing digital technology may result in the provision of this service as one of its potential benefits. The monitoring and reporting of environmental performance is another potential application of this technology. Both of these parts of the procedure can benefit from digitalization. This could be applied to encourage both continuous improvement and compliance with regulatory norms.

The analysis concluded that digitization and sustainability in manufacturing are two main issues with the potential to bring about significant breakthroughs in the manufacturing sector. When coupled, environmentally responsible business practices and technical progress have the potential to become a tremendously formidable force for positive change in the manufacturing industry. Companies who take a more proactive approach to adopting these trends will be in a better position to do so, allowing them to boost their market competitiveness, meet the needs of their consumers, and contribute to a more sustainable future. When these two elements are considered together, it is possible to develop a production procedure that is not only less harmful to the environment, but also more cost-effective. This would be beneficial for both the organization's financial line and the environment as a whole. Those companies that see the need to invest in the aforementioned categories today will be in a better position to retain their level of success in the coming years.



Nevertheless, it is essential to emphasize that digitalization alone is not a panacea for ensuring the long-term stability of the industrial sector. Remember this crucial fact at all times. It is impossible to emphasize the importance of this matter enough. In order for it to have the best possible effect, it must be implemented in tandem with other measures that are less detrimental to the natural environment. The use of renewable energy sources and the execution of the ideas that form the basis of the concept of a circular economy are two examples of activities that fall under this category.

It is vital to analyze each of these discoveries in order to evaluate whether or not they can be relied upon, taking their limits into account. When attempting to write an essay about how the manufacturing industry is embracing digitalization and becoming more environmentally conscious, you may encounter some difficulties. There are likely insufficient data to justify the implementation of these technologies and methods or to demonstrate their effectiveness. This is a possible outcome. This is because these ideas are in their infancy and have never been studied before. Currently, this is one of the most significant things working against us. In addition, the implementation costs of new digital technology and environmentally friendly practices could be prohibitive for firms. Because manufacturers are already under pressure to limit their environmental impact, this provides a difficulty. As a result, there is an impending concern, as companies are already under pressure to reduce their environmental impact. Due to the absence of uniformity in the industry as a whole, it may be difficult for individual manufacturers to compare their performance to that of their competitors. This is a dilemma because implementing new digital technologies and environmentally friendly practices can be costly. Measuring the benefits of adopting these technologies and procedures, as well as the return on investment they provide, can be a difficult task at times. This is particularly relevant when calculating the return on investment. It can be difficult and time-consuming to quantify the impact that digitization and environmentally responsible practices have had on the manufacturing industry. This includes the ROI as well as the advantages of adopting certain technologies and processes. In addition, the level of technical proficiency required for the execution of these technologies can be rather complex, making it difficult for manufacturers to acquire the necessary skills. This has been one of the factors contributing to the slow acceptance of these technologies. Due to this reason, the use of these technologies confronts greater difficulties. It is also feasible that manufacturers will never adopt any new processes or technologies in the foreseeable future due to the fact that many firms are resistant to change. This is due to the fact that numerous manufacturers resist change. Due to the fact that the digitization of



production processes has increased the likelihood of cyberattacks, there has been an increase in the number of cybersecurity-related concerns. These issues have arisen as a direct result of the increased danger brought about by recent events. It is likely that socioeconomic reasons, such as the loss of jobs and a rise in consumer prices, could impede the widespread adoption of environmentally friendly practices and digital technologies in the manufacturing sector. This is due to the fact that both job loss and price inflation are direct effects of economic forces. The fact that it is highly probable that such circumstances would have such an effect lends credence to the possibility that this is the case. We must conduct additional research in the areas of digitalization and sustainability in the industrial sector if we hope to fully comprehend the effects of the currently employed methods and technology. This is vital if we are to have any hope of properly grasping the effects of the already employed methodologies and technologies. This is the only way we will be able to comprehend the repercussions of the existing tactics and technology. Long-term case studies and evaluations would provide crucial new insights into the manner in which digitalization affects sustainability over the long term. Establishing industry-wide standards and recommended practices for digitization and sustainability in manufacturing will facilitate the process of adopting and implementing these strategies. These may be beneficial to both components of the procedure. These standards and procedures would be implemented as part of the manufacturing industry's operations. In addition, a cost-benefit analysis is necessary for producers to make educated decisions on the capital investment in these technologies. This will enable them to effectively compete on the global market. With the aid of this research, producers will have a better understanding of the potential and challenges posed by sustainability and digitization in the manufacturing industry.

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## List of Abbreviations and Symbols

R&D.....	Research and development
GDP.....	Gross domestic product
AI.....	Artificial Intelligence
CPS.....	Cyber-physical system
IoT.....	Internet of things
SM.....	Strategic management
ML.....	Machine learning
DL.....	Deep learning
ACS.....	Automated control systems
AR.....	Augmented reality
BDA.....	Big data analytics
DDM.....	Direct digital manufacturing
NAM.....	National Association of Manufactures
IAC.....	Industrial Assessment Center
Tbps.....	Terabytes per second
IFR.....	International Federation of Robotics
GTI.....	Green technological innovation
CAGR.....	Compound annual growth rate
B2B.....	Business-to-Business
OT.....	Operational technology
ROI.....	Return on investment