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An assessment of the Environmental Corporate Social Responsibility Effects of Industry 4.0 in Europe

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II.

Foreword

First of all, I'd like to thank my parents who always supported me throughout my studies, not on practical points but on the environment that offered me the best conditions to succeed.

I would also like to thank Mr. Agrell, for his availability and guidance in the elaboration of this work, his vision and experience have always amazed me.

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1 Introduction

The Fourth Industrial Revolution, known as Industry 4.0, is revolutionizing traditional industries by integrating advanced digital technologies. This transformation has diverse impacts across sectors, from healthcare and automotive to manufacturing (Javaid et al., 2022). For instance, IoT-enabled devices in healthcare allow remote patient monitoring, while in the automotive sector, real-time data improves vehicle performance analysis. Thanks to Industry 4.0, the manufacturing industry has evolved into smart factories, enhancing productivity, efficiency and customization.

The goal of this master thesis is to give the reader a critical perspective on industry 4.0, its different synergies and trade-offs in different industry sectors in Europe. This work is based on in-depth research into the subject, analysing many of the works that have already been published while keeping a critical eye on them.

1.1 Motivation

Nowadays, the quest for efficiency is vital for the industry and particularly in Europe to stay competitive together with being a role-model in sustainability. Industry 4.0 brings therefore strategic success keys for the European industry and process of re-industrialization. Industry 4.0 ensures competitiveness by embracing modern technologies for agile and responsive production systems. With consumer demands for personalized products increase, traditional mass production methods may fall short. Industry 4.0's integration enables resource-efficient and waste-reducing practices, especially with technologies like 3D printing. Circular economy principles also find support through Industry 4.0, offering environmental benefits and cost-saving opportunities.

Traditional manufacturing practices have raised many concerns regarding environmental and social sustainability (Ferreira et al., 2023). Resource extraction and pollution from conventional processes contribute to environmental degradation and social inequalities. Industry 4.0 presents a promising solution, focusing on resource efficiency and eco-friendly production methods. By adopting digital technologies, firms can address social challenges by optimizing production, reducing dependency on low-skilled labour and supporting economic growth.

However, despite the positive environmental CSR effects of Industry 4.0, there remains a need to strengthen the inclusion of social development values in corporate governance (Ferreira et al., 2023). This study aims to explore the environmental CSR impacts of Industry 4.0 in Europe. By examining the incorporation of internal mechanisms for social and environmental sustainability, I seek to demonstrate how Industry 4.0 can enhance performance while achieving broader environmental and social objectives.

1.2 Research Question

What are the synergies and trade-offs of implementing Industry 4.0 in terms of environmental CSR and sustainability and how do they vary among different industry sectors ?

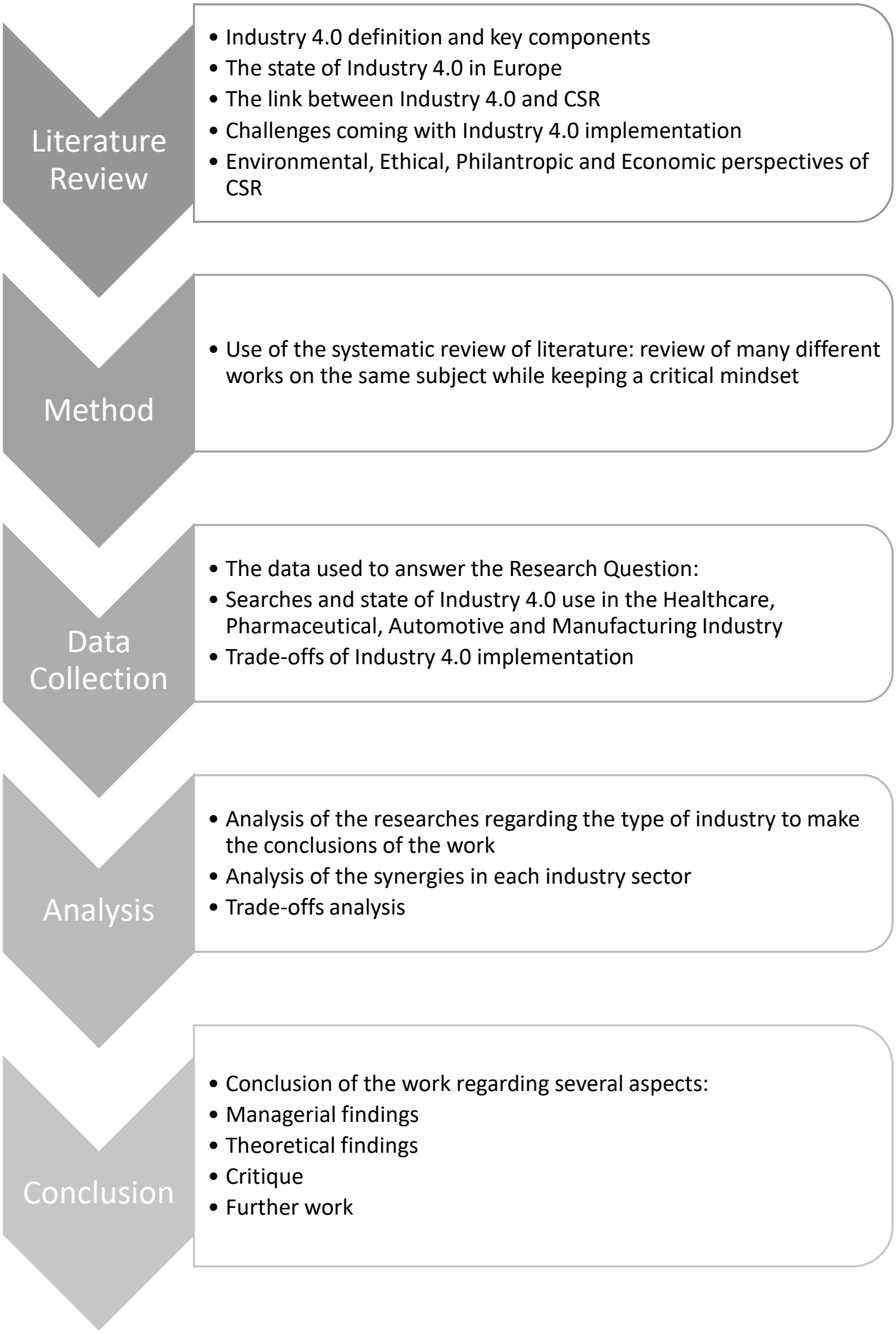
1.3 Limitations

This study faces several limitations, including publication bias. During the systematic review of literature, the availability of articles with a bias towards successful cases of Industry 4.0 may have overlooked negative aspects of the technology, potentially affecting the overall assessment of synergies and trade-offs in its implementation.

Another limitation lies in the study's focus on European industries, possibly overlooking valuable insights from other regions where Industry 4.0 implementation might have different environmental CSR effects. Moreover, certain industries may have been studied more extensively than others, leading to an unbalanced representation.

The concept of Industry 4.0 is relatively new and constantly evolving, which can make it challenging to draw definitive conclusions from the literature, especially regarding long-term impacts. Additionally, assessing the environmental CSR effects of Industry 4.0 is a complex task, involving multiple variables, indirect effects and interrelationships, which may not always be adequately captured in the existing literature.

1.4 Overview of the work



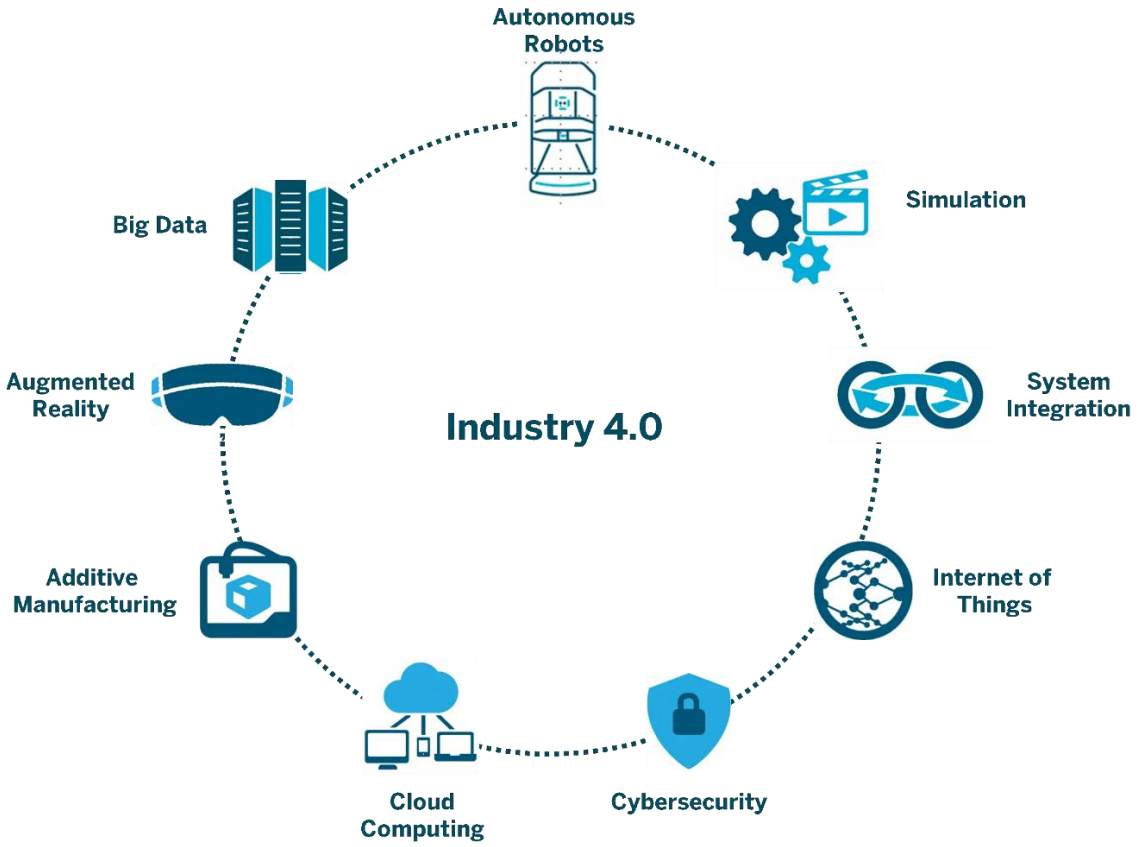
2 Literature review

The development of environmentally sustainable products offers several advantages, including increased efficiency, enhanced corporate branding, sustained competitive advantage and efficient resource utilization and investment (Alam & Islam, 2021). These products enable companies to streamline their operations, reduce resource consumption and waste disposal costs and overall improve efficiency. For instance, the use of energy-efficient technologies or eco-friendly manufacturing processes can lead to reduced energy consumption and lower operating expenses. The adoption of Industry 4.0 technologies can further facilitate the realization of these advantages.

2.1 Industry 4.0

Industry 4.0 refers to the current trend of automation and data exchange in manufacturing processes, bringing significant changes to the business models of manufacturing firms. The core focus of Industry 4.0 is on integrating and enhancing manufacturing operations systems through the incorporation of communication, information and intelligence technologies (Bai et al., 2020). By improving manufacturing operations systems, these technologies enable the monitoring and control of physical processes, autonomous decision-making and seamless communication between different components, including human operators. Consequently, manufacturers can improve their production processes and quickly adapt to shifts in market requirements. The notable transformations brought about by Industry 4.0 technologies in manufacturing business models contribute to environmentally sustainable manufacturing practices.

Figure 1: Industry 4.0 components



Source: Luis. (2022). CAD/CAM in industry 4.0. 12CAD https://www.computeraideddesignguide.com/cad-cam-industry-4-0/?utm_content=cmp-true

As you can see on this graph, Industry 4.0 technologies encompass a wide array of cutting-edge advancements, such as cloud computing, the Internet of Things (IoT), big data and analytics, augmented reality, additive manufacturing and artificial intelligence, among others (Bai et al., 2020). These technologies serve as key components of Industry 4.0, empowering manufacturers to establish intelligent, connected and efficient production systems. The implementation of these technologies brings efficiency, allowing firms to exploit new opportunities and gain a competitive advantage. Consequently, Industry 4.0 technologies play a crucial role in transforming manufacturing processes and business models, enabling companies to seize new opportunities and achieve a competitive move forward.

2.2 Industry 4.0 in European Countries

The adoption of Industry 4.0 holds the potential for European firms to strengthen their manufacturing competitiveness and foster economic growth. This support from the

technology is vital for European industry to manage a triple high: labor costs, CSR standards and dependency to Energy and raw material sources.

Over the years, Europe has developed a robust manufacturing base including a diverse range of industries, such automotive, aerospace, pharmaceuticals and machinery, among others. By embracing Industry 4.0, European countries can improve the manufacturing competitiveness of their firms, thus promoting economic growth in the region. The integration of advanced technologies in manufacturing processes aligns with Europe's emphasis on innovation, enhancing the region's ability to adapt and prosper in the dynamically changing global market. Therefore, the adoption of Industry 4.0 in European countries offers the potential to fortify their manufacturing sector and contribute to overall economic development.

The European economy can leverage the benefits of Industry 4.0 such as sustainable practices, customization and cost optimization to maintain competitive advantage in the global market while ensuring long-term sustainability. The idea of Industry 4.0 will allow the European economy to maintain a sustainable industry and to support a high level of product customization at low costs (Wyrwa et al., 2020). Industry 4.0 technologies can leverage IoT, artificial intelligence and data analytics, allowing companies to optimize resource utilization and reduce environmental impact. The technologies will enable the seamless integration of supply chains, allowing for real-time coordination and collaboration; this facilitates the efficient flow of information and materials, enabling faster customization and delivery of products. Thus, the European economy can leverage the benefits of Industry 4.0 to maintain a competitive advantage in the global market and ensure long-term sustainability.

The use of industrial robots, artificial intelligence and information and communication technologies will allow to integrate the process of manufacturing products. The entire process starting from design to the production of the final commodity will involve the interaction of machines and programs with human beings monitoring the quality of products in an automated production process (Wyrwa et al., 2020). Robots can work with humans, handling repetitive or physically hard jobs, while humans can do more complicated and thinking tasks. The robots may also be integrated with artificial intelligence algorithms, allowing them to learn and optimize their performance over time

leading to enhancement of the efficiency and accuracy of manufacturing processes. Therefore, the use of Industry 4.0 technologies such as industrial robots, artificial intelligence and information technology will enable the integration of product manufacturing processes.

2.3 How Industry 4.0 Has Transformed Industrial Processes

Industry 4.0 technologies present solutions for modern challenges, enabling organizations to embrace socially responsible and environmentally sustainable practices (Javaid et al., 2022). By using the Internet of Things (IoT), companies can collect data throughout the production process, enabling real-time analysis with advanced analytics and artificial intelligence, facilitating data-driven decision-making. Armed with insights from data analysis, firms can implement targeted strategies to enhance environmental performance and meet social responsibility objectives. Additionally, integrating IoT devices and sensors into machinery allows manufacturers to monitor energy consumption and raw material utilization in real time, pinpointing inefficiencies and areas for improvement. Predictive maintenance further aids in avoiding costly breakdowns and reducing unnecessary resource consumption, thereby promoting resource efficiency and waste reduction.

2.3.1 Supply Chain

Industry 4.0 technologies enable supply chain optimization and transparency by allowing firms to track the movement of raw materials and finished products throughout the supply chain. This transparency ensures social and environmental standards compliance and facilitates responsible sourcing and sustainable practices (Rad et al., 2022). Industry 4.0 technologies like IoT sensors and smart devices are key enablers to real-time data collection across the entire supply chain, allowing firms to keep track of the movement of raw materials and finished products at every stage of the supply chain. The real-time data give to companies greater visibility into their supply chain operations, promptly identifying bottlenecks, inefficiencies and potential risks. The enhanced visibility allows for proactive decision-making, enabling swift responses to disruptions that could impact production or delivery schedules. The supply chain transparency can also allow firms to assess their suppliers environmental and social practices more effectively, ensuring that the suppliers align with their sustainability objectives. This encourages responsible

sourcing because companies can make informed choices about working with suppliers who are equally dedicated to sustainability.

Tracking the movements of raw materials and finished products also allows firms to identify opportunities to reduce the environmental impact of transportation. Optimized logistics and distribution can lead to more efficient routes and lower fuel consumption (Rad et al., 2022). In addition, the ability to monitor conditions during transportation helps prevent spoilage or damage, minimizing waste and resource usage. Therefore, Industry 4.0 technologies optimize supply chain operations and provide transparency throughout the process, allowing firms to ensure compliance with social and environmental standards.

2.4 Relationship between Industry 4.0 and Sustainability

The adoption of Industry 4.0 technologies not only improves the supply chain but also presents impactful gains related to sustainability (Bai et al., 2020; Grybauskas et al., 2022). By using real-time data collection and analysis, Industry 4.0 indeed allows companies to find and fix production inefficiencies, make the most of their resources and reduce waste. This all contributes to a more sustainable future. Furthermore, with the integration of smart automation and IoT sensors, resource and energy consumption can be significantly reduced, further enhancing environmental sustainability. Additionally, Industry 4.0 supports social sustainability by enabling smart and autonomous production systems that prioritize employee health and safety, boosting motivation and well-being (Bai et al., 2020).

2.5 Environmental Impacts and CSR Implications of Industry 4.0

The rapid and exponential progress of the Industry 4.0 is bringing about new changes faster than previous industrial revolutions. As a result, there are higher social expectations for businesses to work responsibly. The effects of Industry 4.0 will substantially impact corporate social responsibility (Chen et al., 2020). This impact will involve generating positive social outcomes and enhancing productivity.

One of the key implications of Industry 4.0 on CSR is the potential impact on employment and workforce. With the increasing prevalence of automation and artificial intelligence technologies, there is a concern about potential job replacement. If the Industry 4.0

concept becomes fully implemented, there will be reduction of some jobs which will subsequently affect demographic and socio-economic areas (Chen et al., 2020). On the other hand, there will be creation of new types of employment that corresponds to the need of new technologies. Organizations are required to take responsibility for training of their employees to ensure they can adapt to the changing job landscape. They should also actively collaborate with educational institutions and government agencies to address the societal implications of technological advancements (Naderi et al., 2019). However, the introduction of automated technologies historically has led to a decreased demand for human labor in the long run.

While digitalization and automation can enhance resource efficiency and reduce waste, they also create environmental challenges. For Industry 4.0 to be appreciated, digitization, automation and integration must be done. Consumption and use of energy and raw materials occur at a high level, leaving the environment to produce a lot of waste. Companies must adopt sustainable practices throughout their value chains, from responsible sourcing to energy-efficient production and waste management (Oláh et al., 2020). They should strive to minimize their carbon footprint, promote renewable energy and develop eco-friendly technologies. Recycling should also be encouraged for more energy saving to be achieved, which in return creates a more collaborative solution ensuring environmental stability. Sustainable development goals such as responsible consumption and production or clean energy are all interconnected and interdependently linked to each other. They strongly influence one another. Therefore, they should be balanced carefully to achieve better sustainability.

Data privacy and cybersecurity are additional concerns brought about by Industry 4.0. The extensive use of connected devices and data analytics raises ethical questions regarding the collection, storage and use of personal information. Organizations must prioritize the protection of customer and employee data, ensuring compliance with privacy regulations and implementing robust cybersecurity measures. The organizations should also come up with strategies that ensure transparency and trust in all their systems (Oláh et al., 2020). Furthermore, transparency, consent and accountability should be integral parts of their CSR strategy to build trust with stakeholders.

2.6 Challenges Facing the Adoption of Industry 4.0

Alongside the benefits, adopting Industry 4.0 poses several challenges for organizations (Grybauskas et al., 2022). One key component is the cultural shift required within organizations to embrace Industry 4.0 fully. Hiring and training a workforce with the necessary digital skills is crucial, as traditional manufacturing roles may not naturally align with the emerging digital demands. Upgrading infrastructure to accommodate the new technologies also presents a significant initial investment challenge, which firms must strategically manage to unlock the full potential of Industry 4.0.

Moreover, the shift towards Industry 4.0 may lead to a reduction in human work due to automated systems outperforming humans in certain tasks (Grybauskas et al., 2022). While new job opportunities in technology and digital transformation emerge, it is essential to address the workforce and societal implications thoughtfully

Ethical considerations also come into play, as Industry 4.0 technologies raise concerns about human dignity, well-being and privacy. Automated systems and data-driven decision-making could potentially limit individuals' independence and erode their sense of privacy, calling for ethical design and implementation practices.

Additionally, the evolving nature of Industry 4.0 requires continuous improvement to meet society's current needs, especially concerning environmental corporate social responsibility. Striving for environmentally and socially sustainable approaches will be essential to harness the full potential of Industry 4.0 technologies (Grybauskas et al., 2022).

Organizations can fully embrace the transformative potential of Industry 4.0 by recognizing and tackling these challenges, all the while ensuring a sustainable and socially responsible implementation. The journey towards a connected, efficient and ethical future has begun.

2.7 Industry 4.0 and Environmental Sustainability

The integration of digital technologies in manufacturing processes can contribute to positive environmental impacts. Industry 4.0 can assist manufacturing firms improve environmental performance (Grybauskas et al., 2022). For instance, the technologies can help in reducing waste, improving energy efficiency and eliminating harmful emissions

leading to positive environmental outcomes. Resource efficiency improvement and waste reduction decrease the amount of energy needed for manufacturing, reducing greenhouse gas emissions. In addition to enhancing operational efficiency, Industry 4.0 also supports the transition to a greener and more environmentally responsible manufacturing industry.

The integration of advanced digital technologies can have benefits that positively impact the organization. Industry 4.0 technologies present an opportunity for manufacturing firms to develop digitized, connected, decentralized and intelligent systems while enhancing the social and environmental conditions of the organization (Torres da Rocha et al., 2022). The benefits that can positively impact the social conditions within the organization include investment in human capital, allowing employees to acquire digital culture and promoting career development. In addition to technological advancement, Industry 4.0 also provides an opportunity for companies to create a socially responsible and environmentally sustainable organization.

Industry 4.0 technologies can support corporate sustainability by ensuring that in addition to supporting economic development needs, they also support social and environmental development needs (Torres da Rocha et al., 2022). The technologies can support corporate sustainability by addressing economic, social and environmental development needs simultaneously. Corporate sustainability, also referred to as the triple bottom line approach, emphasizes the integration of economic, social and environmental considerations into business strategies. This improves the firm's ability to meet market demands and expand its market share. Connected systems enable better supply chain visibility, allowing companies to identify and partner with environmentally responsible suppliers, promoting sustainable practices throughout the value chain.

2.8 The State of CSR in Europe and its Effects on Supply Chain Fields

Corporate Social Responsibility (CSR) is a concept that enables businesses to review their social and environmental impact, with a particular focus on minimizing negative environmental effects (Cyfert et al., 2021). As industries adapt to emerging challenges and technological advancements, the adoption of Industry 4.0, often referred to as the fourth industrial revolution, has had a profound impact on society. The integration of production

systems and advanced machines characteristic of Industry 4.0 has reshaped the workforce, leading to changing roles as automation takes over various responsibilities. Consequently, this transformation prompted a reevaluation of industries' societal roles and their environmental impact, giving rise to the CSR concept.

CSR plays a key role in guiding enterprises to adopt environmentally sustainable initiatives, aiming to reduce their environmental footprint and contribute to societal prosperity. It helps address technological challenges and align business strategies with consumer and societal preferences. Enterprises, recognizing the importance of addressing stakeholders' needs and concerns, have shifted focus towards CSR, aiming to address the environmental and social consequences of their activities.

Understanding the different dimensions of CSR explains how economic, social and environmental factors influence its implementation (Cyfert et al., 2021). Global economic crises have further emphasized the significance of CSR initiatives, providing organizations with a mechanism to tackle emerging challenges, such as climate change. Through CSR, enterprises renew their assumptions and strategies, proactively mitigating potential adverse impacts. This approach not only safeguards against crises but also contributes to building a positive reputation, fostering loyalty among stakeholders, including customers and high-level employees. A favorable reputation enables enterprises to enhance their profitability and pursue diversification opportunities in products and services.

The four main dimensions of corporate social responsibility include environmental, ethical, philanthropic and economic responsibility. Embracing these dimensions equips enterprises to address economic challenges, navigate global crises and uphold a sense of social and environmental responsibility. By incorporating CSR principles into their operations, businesses can foster sustainable practices and positively impact supply chain fields.

2.8.1 Environmental Responsibility

Environmental CSR focuses on an organization’s ability to adopt environmentally friendly initiatives. Enterprises must review all their production or service delivery stages to understand the eco-friendly nature of their energy use, water use, waste management, emissions and recycling initiatives (Stobierski, 2021). Organizations can demonstrate their

environmental responsibility by adopting green initiatives, such as utilizing renewable energy and adopting emerging technologies to address greenhouse gas emissions. Furthermore, environmental responsibility includes initiatives enabling organizations to minimize their environmental impact. These include creating and utilizing recyclable materials, locally manufactured products to reduce fuel costs, planting trees, or donating to environmentally-related programs. These efforts reduce the financial cost to enterprises and improve their reputation. Hence, environmental responsibility ensures that organizations' activities at all stages remain environmentally friendly.

2.8.2 Ethical Responsibility

Ethical responsibility inspires organizations to operate fairly. Enterprises often set their ethical standards based on external forces and the interests of their clients. Ethical responsibility demonstrates how organizations can relate to their employees, customers and suppliers (Stobierski, 2021). For example, ethical responsibility influences whether an organization treats its customers fairly, provides favorable pay and benefits to its workers, or works with different suppliers regarding their race or gender. Ethical responsibility also influences the likelihood that an organization fulfills its legal obligations, such as implementing measures to reduce pollution to ensure the safety of workers and the environment. Thus, ethical responsibility ensures that organizations operate fairly regarding treating other people and honoring available legislation.

2.8.3 Philanthropic Responsibility

Philanthropic responsibility inspires organizations to make the world a better place. It challenges organizations to utilize their resources to contribute to change in society. An organization's mission guides the extent to which an enterprise can engage in charities and non-profit events (Stobierski, 2021). Examples of philanthropic efforts that organizations can engage in include donating to charities, creating a trust to serve societal needs, supporting employees' philanthropic endeavors, or working with suppliers with similar philanthropic missions. Therefore, philanthropic responsibility enables firms to utilize their resources to contribute positively to society.

2.8.4 Economic Responsibility

Economic responsibility is the final dimension of CSR that defines financial decisions influencing environmental, ethical and philanthropic dimensions of CSR. Making informed financial investments influences the capacity to create a positive impact (Stobierski, 2021). An organization can enhance its economic responsibility through research and development to ensure the production of sustainable products, recruitment of diverse talent, organization of workshops to encourage employees to address environmental concerns and timely and transparent publication of financial reporting, which will not only encourage current stakeholders but it can also attract new shareholders into the business. Hence, combining the different dimensions of corporate social responsibility enables organizations to contribute positively to the planet. CSR is a certified qualitative effort, but its general effect on society can be expressed through its positive or negative impacts on people and the environment. It promotes the adoption of sustainable practices.

2.9 Role of CSR in Promoting Sustainable Practices

Implementation of Industry 4.0 and sustainable practices have influenced the knowledge structure adopted by the young generation. Technology has been used in research and in the delivery of knowledge (Scavarda et al., 2019). The Internet of Things have been adopted in the learning process. Moreover, technology facilitates the integration of systems and people, which has largely influenced the human resource framework. Technology utilization in teaching promotes knowledge acquisition by the young generation, thereby facilitating their absorption into the job market. Sustainability is the main concept used to address environmental concerns and global crises affecting productivity. Human resources influence the adoption of concepts in an organization to ensure environmental sustainability and social responsibility. The disruptive tools provided by Industry 4.0 can be leveraged by human resources to aid in the education of the workforce to adopt sustainable practices. Human resources also utilize the tools to control the organization’s environmental impact. Therefore, a sustainable human resource positively impacts corporate social responsibility. The human resource creates ethics and culture that influence CSR.

Human resources can promote CSR and the adoption of sustainable practices in the workplace. Organizations can create volunteer or intern programs that expose the young

generation to technological integrations in the job market (Scavarda et al., 2019). Different crises affect a jurisdiction's environmental, social and economic sectors. CSR enables organizations to work with the young generation to develop solutions to address these challenges through cultural change in the working environment. Implementing innovative and technological investments developed by the young people help create business models that define the relationship between human resource and Industry 4.0. It inspires the development of initiatives that promote cultural change and ethical behavior. Therefore, harnessing technological investments to promote the youth's education, job opportunities and insertion into the job market inspires human resources to adopt new models to ensure sustainability and corporate social responsibility. CSR facilitates the implementation of sustainability concepts.

CSR promotes adopting environmental, social and governance (ESG) concepts, which are beneficial to a business and ensure sustainability. The concepts influence value creation for the business and society by including and formulating mutual relations (Henisz et al., 2019). Environmental concepts include environmentally friendly strategies, such as using renewable energy sources and reducing carbon emissions to reduce the impact of climate change. Business operations require energy to use and produce wastes that require elaborate disposal mechanisms to minimize their environmental impact. Social concepts include strategies to forge community relations and create a good reputation. It analyzes employed labor relations and the inclusion of all diverse groups. The governance concept entails internal systems, controls and procedures that influence operations and define organizations' compliance with existing laws. It also demonstrates mechanisms utilized to realize stakeholder needs. Hence, the implementation of ESG concepts is facilitated by CSR and it ensures sustainability.

ESG is a proactive mechanism that promotes dialogue and ensures environmental law compliance. Global investments in sustainability have increased to address corporations' environmental impact (Henisz et al., 2019). CSR enables organizations to review their governance aspect of ESG to identify potential areas where violations against environmental laws exist and address them before they could occur. It promotes a dialogue between consumers and stakeholders to minimize potential risks and increase the value of the corporations. ESG contributes to value creation in five ways: ensuring top-

line growth, minimizing costs, reducing regulatory interventions, enhancing employee productivity and increasing investments. Thus, adopting ESG concepts is a proactive approach that minimizes environmental risks and promotes value creation in the business.

Implementation of ESG enables organizations to attract new clients and expand their customer base in an existing market. CSR promotes the implementation of ESG that focuses on sustainable options, enabling organizations to acquire licenses and approvals that enhance access to fresh opportunities, ensuring growth (Henisz et al., 2019). CSR promotes social engagement initiatives between organizations and stakeholders, enabling companies to gain a competitive edge as the available social capital minimizes delays occasioned by communal conflicts. It also helps determine consumer preferences, which informs the development of sustainable products. For instance, engaging with consumers enhances the adoption of green products despite their higher value because consumers can weigh their benefits compared to non-green products. Therefore, ESG enables companies to create more value by creating opportunities to venture into new markets and expand current ones by addressing consumer preferences. ESG reduces operations costs, thereby influencing the organization's profit margin.

3 Method

In this study, an overview of Industry 4.0 and how it affects Environmental Corporate Social Responsibility is provided. I conducted a systematic review of literature to present the current trends in the implementation of Industry 4.0 technologies and how it affects Environmental Corporate Social Responsibility. The choice of a systematic review of the literature for assessing the environmental corporate social responsibility effects of Industry 4.0 in Europe was appropriate because it is a robust and structured method of research that involves identifying, interpreting and categorizing relevant articles from existing literature in a systematic manner. This method is particularly suited for addressing complex research questions. A systematic review of the literature ensured that a wide range of literature on the topic was considered, leading to a comprehensive overview of the available evidence. Given the broad scope of the research question, a systematic

review allowed for the synthesis and analysis of a large body of literature from diverse industries.

I conducted literature search and obtained different sources that provided information about the Industry 4.0 and how it relates to environmental corporate social responsibility. I used the established five-step process of conducting systematic literature review (Denyer & Tranfield, 2009), that involves formulation of research question, locating studies, study selection and evaluation, analysis and synthesis and results reporting (Rad et al., 2022) as indicated in the figure below.

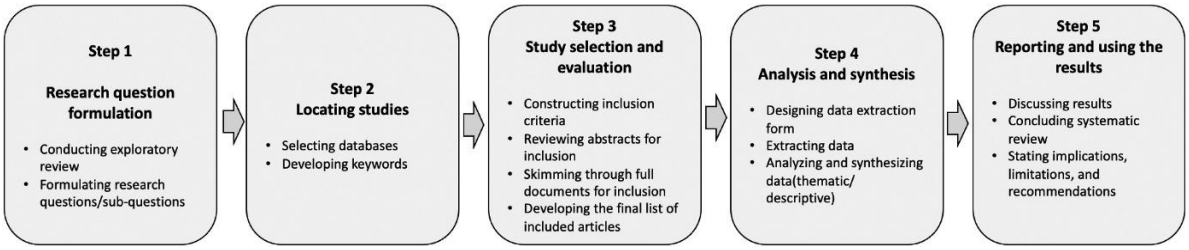


Figure 2: Systematic literature review process (Rad et al., 2022)

I selected keywords and phrases that helped in searching for sources from different online databases. The keywords and phrases I used to search for articles online include Industry 4.0 in manufacturing, Industry 4.0 in manufacturing and its effects on environmental corporate social responsibility, how industry 4.0 affects corporate social responsibility, Industry 4.0 in healthcare, Industry 4.0 in automotive industry and Industry 4.0 in pharmaceuticals.

The retrieved data were filtered based on the year of publication. The articles were then screen based on the topic and abstract. In this study, I compared the effects of Industry 4.0 on the CSR for different sectors such as healthcare, automotive, pharmaceutical and manufacturing. I considered the synergies and trade-off in each industry that result from the implementation of Industry 4.0. In the analysis, I focused on determining the synergies and trade-offs of implementing Industry 4.0 in terms of corporate social responsibility and sustainability and the synergies and trade-offs vary among different industries. I considered different industries such as healthcare, automotive, pharmaceuticals and manufacturing.

4 Data Collection

To collect data for this study, I focused on reviewing the literature on different sectors and how they have implemented Industry 4.0. The work also focused on the synergies and trade-offs that come with the implementation of Industry 4.0 in healthcare, automotive, pharmaceuticals and manufacturing sector. Systematic literature focuses on identifying, interpreting and categorizing articles that are relevant to the topic and research question. This allowed me to present a comprehensive overview of existing literature. The research question for this study was formulated to reflect the scope and aim of the study. The study focuses on linking the concept of Industry 4.0 and environmental corporate social responsibility in different industries such as healthcare, automotive, pharmaceuticals and manufacturing.

4.1 Industry 4.0 in Healthcare Industry

Industry 4.0 enables the use of remote monitoring systems, which plays a major role in the healthcare industry (Paul et al., 2021). Remote monitoring systems allow healthcare providers to collect real-time data from patients monitoring them continuously where they are provided with important insights concerning their health conditions. This allows the healthcare providers to detect any abnormalities early enough. Additionally, patients with chronic diseases benefit greatly from remote monitoring because healthcare providers remotely track their vital signs ensuring timely interventions. This approach ensures better disease management and personalized treatment plans.

Industry 4.0 maintains the privacy and security of patients and health providers data. Industry 4.0 can enhance expensive and complex health-related systems by improving their efficiency, optimizing resource usage, and implementing better record management for health information. (Paul et al., 2021). It introduces cybersecurity measures that safeguard electronic health records from illegal access to patients records. Industry 4.0 uses secure communication methods to ensure the transmission of data is protected from tampering. It enhances access control methods that restrict data access to only authorized personnel. Through the application of Industry 4.0 in healthcare, patients and health providers data can be better protected from unauthorized access.

Industry 4.0 allows health institutions to store all the data needed to avoid the extra costs of maintaining physical servers (Paul et al., 2021). It has improved data storage in healthcare industry by encouraging cloud computing and other advanced technologies. With Industry 4.0, healthcare institutions can store vast amounts of data on remote servers, eliminating the necessity of maintaining physical servers on-site. This helps in reducing the cost associated with maintaining and upgrading physical servers. By using cloud-based data storage, healthcare institutions do not require to buy expensive servers and networking equipment hence cutting down the cost savings in the long run. By using industry 4.0, healthcare institutions can save on infrastructure costs while offering efficient and cost-effective services to the patients.

Through digital supply chain, Industry 4.0 has enabled effective management of product and services from manufactures to the patients (Ahsan & Siddique, 2022). It allows healthcare institutions to create a transparent and auditable record of all products from the manufacturer to the patient. This transparency allows the tracking of medications and other healthcare products which helps in quick identification of quality issues in the products allowing quick removal from the circulations and reducing potential harm to patients. Additionally, Industry 4.0 assists healthcare institutions in meeting various regulatory requirements and safety standards. Digital supply chain enhances transparency and accuracy by ensuring the delivery of the right products to the right patients promoting overall quality in patient care and involvement.

Since the introduction of industry 4.0, cloud settings have become one of the most enticing areas for hackers since the bulk of healthcare systems store patient data on the cloud (Ahsan & Siddique, 2022). Industry 4.0 has brought a lot of improvement in the healthcare industry by allowing cloud computing provide storage and processing abilities for huge amount of data. However, with the growing adoption of cloud computing in the healthcare industry, cybersecurity has also become a huge concern. The healthcare systems have become a major target for hackers since they contain sensitive patient data. Hackers can exploit this data for financial gain or identity theft. To avoid hacking issues, healthcare institutions should invest in strong cybersecurity measures and encryption of sensitive data to protect patients' data.

4.2 Industry 4.0 in Pharmaceutical Industry

In the pharmaceutical industry, industry 4.0 is changing the manner into which the pharmaceutical processes have been taking place. The application of robotics, connectivity and artificial intelligent develops an advanced and efficient environment that reduces human participation and maximizes productivity. Industry 4.0 has enabled the achievement of a high-performance system of manufacturing and production of medicines. The use of digital twin technology allows optimization and virtual simulation of production processes. Industry 4.0 also allows supply chains to more efficient and responsive with real-time tracking and forecasting of consumer demand. Remote work and virtual collaboration improve quality and patient care while driving adaptability and innovation in an increasingly interconnected ecosystem (Arden et al., 2021).

The application and integration of multiple data sources in the pharmaceutical industry plays a major role in the development of a strong and dynamic ecosystem (Arden et al., 2021). External information composed of various variables such as supplier inventory and public health inventories can be used together with internal data sources such as energy and resource management to digitize the pharmaceuticals operations and management processes. Data integration in the pharmaceutical industry also allows personalized medicine initiatives by customizing treatments to individual patients improving global health outcomes.

Integration and implementation of industry 4.0 in the pharmaceuticals involve digitizing and bringing together different aspects of the value chain to enhance productivity, efficiency and decision-making (Arden et al., 2021). By digitizing the supply chain, it involves tracking the variability of raw materials and global movement across various facilities. This way, the pharmaceutical companies can get access to real-time insights into their supply chain and optimize their inventory management.

A vital component of applying industry 4.0 to pharmaceuticals is the industrial internet of things (IoT). It involves interconnecting computer devices, sensors and equipment that gather and exchange data over the internet (Arden et al., 2021). The use of advanced technologies is required to ensure efficiency, flexibility and quality while maintaining data security and privacy. In the pharmaceutical industry, the IoT develops a cyber-physical

system where integration of different devices and components into a cohesive network takes place resulting in seamless communication and data sharing.

In the pharmaceutical industry, have improved the medication processes using video monitoring that allows the companies to get real-time insights (Arden et al., 2021) . Video monitoring helps in continuous monitoring of the production processes ensuring maximum quality and safety standards. This data-driven method gives opportunity to identify inefficiencies to maximize productivity. The video surveillance powered by IoT empowers the company management to make informed decisions and allows predictive maintenance to prevent loses.

To create profitable intelligent systems in pharmaceuticals industry continuously bring together online data with production systems and customer demand, the pharmaceuticals companies will require developments in powerful computing architectures and enhance high-speed communications (Arden et al., 2021). The goal should be to improve the system capability to analyzing huge amount of data, predicting customers' demands and allowing real-time decision making. By using developed computing architectures, pharmaceutical industry can take control of online data integration and intelligent decision making. Going for cheaper implementations of these developments will be vital in making these technologies accessible and achievable for widespread executions across the pharmaceutical industry. Eventually, this will lead to advanced operational efficiency, enhanced utilization of resources and better meeting customer demands.

In pharmaceutical manufacturing, complete process automation involves detailed application of cloud-connected PAT (Process Analytical Technology) to capture every process performance data. The data is analyzed in detail putting it together into meaningful data. The AI-based algorithms are implemented to convert the data into valuable knowledge. This knowledge can be used to get valuable insights into the manufacturing process, allowing better control and optimization. In pharmaceutical manufacturing, process controls and process performance are often separated. This separation causes delays in implementing essential modifications to control systems, especially when process performance drifts outside specified parameters. By using PAT and AI-based algorithms to process performance data, it makes it easier to bridge the gap

between process controls and process performance (Arden et al., 2021). This ensures that deviations from specifications are identified faster allowing smooth adjustments to the control system, hence maintaining product quality and minimal wastage.

The application of Big Data in pharmaceutical industry, comes with a lot of challenges on the utilization of knowledge and insights resulting from it. Having huge data gathered from different sources such as clinical trials, patient data and the process of medication manufacturing, the biggest challenge lies in interpreting which data is relevant and applicable. Pharmaceutical companies need to overcome these challenges to be able to make informed decisions for internal auditing purposes, making sure they adhere to quality standards and compliance (Arden et al., 2021). These companies face challenges in balancing Big Data for strategic advantages while maintaining ethical standards, data privacy and regulatory compliance to enhance the overall efficiency of the pharmaceutical ecosystem.

4.3 Industry 4.0 in the Automotive Industry

Historically, the automotive industry has been a major contributor towards anthropogenic environmental impacts, especially because of the fossil fuels in gasoline-burning vehicles. The burning of diesel and gasoline fuels emit greenhouse gases causing significant environmental and public health inferences such as adverse health effects, air pollution and climate change. In response to growing concerns regarding the environmental effects of automotive industry products and the need to address corporate citizenship, the industry has been moving towards more sustainable transportation solutions that reduce negative effect on the environment. Industry 4.0 has brought new opportunities to implement and shape the future of vehicles, their designs and usage (Valladares Montemayor & Chanda, 2023). The automotive industry has come up with the solution of adopting electric vehicles which has proved to be more sustainable than gasoline-driven vehicles. The shift to electrical vehicles offers an ideal opportunity to incorporate systems that will have long-term positive impact environmentally and economically.

Environmental policies on electrical vehicles vary widely across the world. Each country has their own policies and regulations to promote the adoption of electrical vehicles and address environmental issues related to transportation. These policies differ across the

world because of different environmental priorities, economic conditions, capabilities in technology and difference in infrastructure. Some countries have been pushing toward the implementation of electric vehicle due to climate change, air pollution and energy security while others entirely focus on other forms of environmental and economic development.

Application of digital technology in automotive industry represent approximately half of the total value of each modern vehicle. Not only have the integration of digital technology in automotive industry improved the functionality of the vehicles, but it has also increased their complexity (Llopis-Albert et al., 2021). It has improved vehicles' safety and driver connectivity features enhancing the driving experience for consumers. Industry 4.0 has made significant progress in the development of autonomous vehicles where digital mechanisms are highly required to control these vehicles on the road.

Digitization of automotive industry has brought important developments to the value chain by enhancing efficiencies, developing greater innovation and lowering costs. Digital technologies have automated different developments across the automotive value chain, resulting in more efficiency (Llopis-Albert et al., 2021). Form design, engineering to manufacturing and supply management, digitizing the automotive industry has optimized workflows and reduced manual intervention, making the operations faster and more accurate.

Customer experience is and will always be a vital differentiator in the automotive industry and since the application of Industry 4.0 in the automotive industry, customer experience has been improved greatly. Digital technologies have enhanced the entire customer experience regardless of the area in the industry. From online configuration of the vehicle and virtual tests drives to seamless buying and after-sale support, digitization has made the customer experience smoother and enjoyable (Llopis-Albert et al., 2021).

4.4 Industry 4.0 in Manufacturing Industry

Industry 4.0 has had significant impact on different industries such as healthcare, automotive, pharmaceuticals and manufacturing. The findings in this study indicate that Industry 4.0 in Europe has had the most significant impact in the manufacturing industry. Europe has a long-standing and robust manufacturing tradition, with many European

countries having a strong industrial base and a well-developed manufacturing sector. Integrating Industry 4.0 technologies into this existing infrastructure has allowed for a smoother transition and faster adoption of advanced manufacturing techniques. In addition, Europe has been at the forefront of technological advancements and many European countries have invested heavily in research and development. This has resulted in creation of innovative technologies and solutions that are readily applicable to the manufacturing industry, enabling companies to embrace digital transformation.

In the manufacturing industry, Industry 4.0 in Europe has affected environmental corporate social responsibility in different ways. Industry 4.0 technologies enable transparency and traceability in supply chains. Manufacturing firms can track raw materials from their sources to the finished product, ensuring compliance with sustainability standards and responsible sourcing. This transparency helps firms identify and address environmental risks in their supply chains and work towards more sustainable practices, promoting environmental CSR. In addition, Industry 4.0 technologies enable remote monitoring of manufacturing equipment and predictive maintenance, ensuring that machines operate at peak efficiency. Reduced downtime and optimized equipment usage lead to lower energy consumption and reduced waste, positively impacting environmental CSR. Another way in which Industry 4.0 affects environmental CSR is that it facilitates the implementation of circular economy practices in manufacturing. Through real-time data and connectivity, firms can implement closed-loop systems, recycling and reusing materials within their processes. This circular approach contributes to minimizing waste generation and reducing the overall environmental footprint of manufacturing operations.

Another factor that has affected the impact of Industry 4.0 in the manufacturing sector is the integration of digital technologies with lean manufacturing principles. Combining lean manufacturing with the capabilities of Industry 4.0 technologies creates a synergy that enhances manufacturing operations. For instance, Industry 4.0 enables the concept of "smart factories", where machines can be reconfigured quickly to accommodate changes in production demands. Lean manufacturing principles, such as one-piece flow and just-in-time production, are further empowered by the agility and responsiveness of Industry 4.0.

Industry 4.0 and lean manufacturing have also had significant synergy due to the ability of Industry 4.0 to enhance the waste reduction capabilities of lean manufacturing. Lean manufacturing principles concentrate on minimizing waste, including overproduction, excess inventory, and defects. Waste can be identified and addressed more effectively with Industry 4.0's connectivity and data-driven insights. Manufacturing firms can optimize material usage, minimize energy consumption and eliminate defects by leveraging real-time monitoring and analytics.

4.5 Trade-offs of Industry 4.0 implementation

The adoption of Industry 4.0 technologies may also have tradeoff where it causes an increase in pollution and traffic congestions. For instance, in Europe, there has been a rapid increase in express delivery for different items including food products. This has been supported by increased growth in e-commerce. Order tracking empowered by IoT and artificial intelligence has led to the customers enjoying cheaper and faster delivery services of their products ordered online (Sun et al., 2021). The main tradeoff to this development is that the responsive logistics requires frequent last-mile deliveries leading to increased traffic congestion and carbon emissions. The transportation sector plays a significant role in generating greenhouse gas emissions, which contribute to climate change and air pollution. The surge in last-mile deliveries has added to these emissions, making it essential to find sustainable solutions to mitigate the environmental impact of express delivery services. Firms should focus on adopting innovative and sustainable solutions to strike a balance between responsive delivery services and reducing its environmental impact.

In addition, the online platform requires the individuals involves in delivery to follow a strict schedule to ensure on-time delivery. The strict requirements have raised concerns about job satisfaction and safety of the individual involved in delivering these products (Sun et al., 2021). The demanding schedules and time-sensitive nature of last-mile deliveries can make it challenging for delivery personnel to maintain a healthy work-life balance, leading to limited flexibility in their work hours, which can lead to increased stress and dissatisfaction. Addressing these concerns is crucial for ensuring the well-being and job satisfaction of individuals involved in delivery.

An increased number of sensors in different digital technology devices can lead to increased consumption of power, leading to a tradeoff in the use of Industry 4.0 technologies. Although Industry 4.0 has the potential to reduce waste generation and resource consumption, the use of a high number of sensors in smart devices such as robots and IoT devices leads to increased energy consumption and a potential negative impact on the environment (Sun et al., 2021). Sensors play a crucial role in Industry 4.0 technologies, as they collect data and enable smart devices to make informed decisions; however, these sensors require power to operate and continuously gather data. Firms can mitigate the negative environmental impact associated with the increased energy consumption of sensors and smart devices in Industry 4.0 by ensuring that the devices use energy-efficient designs and renewable energy sources.

Digital technologies will lead to an improvement in efficiency and production for firms. However, when considering it from a social sustainability perspective, Industry 4.0 technologies will lead to anxiety among employees whose roles are at risk of work being replaced by digital technologies. Employees with difficulty using the new technologies especially aging workers will also be negatively affected (Sun et al., 2021). In addition, there will be actual job loss as the digital technologies will inevitably replace some workers (Sun et al., 2021). Automation and the adoption of smart factories systems may lead to job displacement for certain workers, especially those performing repetitive tasks that can be automated. As a result, there is a risk of widening the gap between skilled and unskilled workers, leading to income inequality and potential social unrest. Therefore, although digital technologies can lead to improvement in efficiency and production for firms, they may also have a tradeoff regarding social sustainability issues.

The lack of general guidelines on how Industry 4.0 should be embraced in different industries acts as a tradeoff for the adoption of digital technologies. The different industries implement Industry 4.0 in their own unique way without following standard guidelines and this can have challenges to the sustainability of the technologies (Sun et al., 2021). Different industries have distinct processes, requirements and goals; thus, without standardized guidelines, each industry may adopt Industry 4.0 technologies uniquely, leading to a lack of uniformity and compatibility across sectors. This can result in inefficiencies and difficulties in integrating systems. Without standardized guidelines,

companies within the same industry might invest in different digital technologies or platforms. Consequently, achieving seamless interoperability and data exchange between various systems becomes challenging (Sun et al., 2021). This lack of integration can hinder the real-time flow of information and hamper the potential benefits of Industry 4.0, such as data-driven decision-making and predictive maintenance. Developing general guidelines for implementing Industry 4.0 can help ensure a more standardized approach, promoting compatibility and scalability.

Another tradeoff relates to the cost involved in ensuring Industry 4.0 digital technologies devices can communicate with existing devices that were not designed for Industry 4.0. A high cost is required to ensure that existing equipment can communicate with Industry 4.0 equipment (Sun et al., 2021). Since existing equipment was not designed with Industry 4.0 in mind, integrating it with modern technologies often requires custom solutions. Each upgrading project may need to be tailored to the specific equipment and its functionalities, leading to higher development and engineering costs. In addition, since Industry 4.0 relies heavily on data collection and analysis to optimize processes and make informed decisions, upgraded equipment must be able to process and transmit data effectively, which may necessitate additional computing resources and software integration, adding to the overall cost.

Then, an additional tradeoff is that adopting Industry 4.0 digital technologies exposes firms' systems and networks to cyber-attacks and data safety challenges (Sun et al., 2021). Adopting Industry 4.0 involves integrating various digital components, such as IoT devices and cloud computing, among other technologies, which can create new vulnerabilities and risks. The connected devices in Industry 4.0 significantly expand the attack surface for potential cyber threats. Each interconnected device becomes a potential entry point for cybercriminals to exploit weaknesses and gain unauthorized access to critical systems. To address these challenges and minimize the risks associated with Industry 4.0 adoption, firms need to prioritize cybersecurity as an integral part of their digital transformation.

5 Analysis

5.1 Analysis of Synergies in Healthcare Industry

During the COVID-19 pandemic, the healthcare industry experienced significant growth in the use of digital technologies. The rapid movement towards digitized healthcare services was due to the need to deal with the COVID-19 pandemic and contain its spread (Ahsan & Siddique, 2022). Healthcare providers had to use new technologies such as remote monitoring and mobile apps to keep up with the demands of the patients during the pandemic. Healthcare providers worldwide faced significant challenges in managing the surge of patients, implementing infection control measures and ensuring the safety of both patients and healthcare professionals, leading to the invention of new technologies. The technologies enabled healthcare providers to conduct virtual consultations and offer medical advice without needing in-person visits. In addition, digital healthcare services helped manage patient flow and optimize resources, allowing hospitals to allocate resources efficiently and prioritize those in need of immediate care. Thus, the need to contain the spread of COVID-19 led to the rapid development of digital technologies in the healthcare industry.

Telemedicine served as a bridge between healthcare providers and patients in remote and underserved areas during the pandemic. Telemedicine became an important aspect as it made it possible for healthcare providers to reach patients in remote and isolated areas while avoiding the risk brought about by physical contact during the pandemic (Ahsan & Siddique, 2022). The highly contagious nature of the COVID-19 virus made it essential to minimize physical contact and reduce the risk of transmission. In addition, remote monitoring devices allow healthcare providers to track patients' vital signs and recovery progress from a distance. Adopting telemedicine and remote monitoring technologies indicated healthcare providers' ability to adapt and commit to delivering quality healthcare during unprecedented times.

Additive manufacturing has brought significant advancements to the field of healthcare, offering numerous benefits to both patients and medical professionals. The technology is revolutionizing the medical industry by enabling the production of personalized medical devices such as implants (Rouf et al., 2022). Conventional manufacturing methods often

create standardized devices that may not perfectly match a patient's individual anatomy. With 3D printing, medical devices, such as implants and prosthetics, can be precisely tailored to individual patients, improving their comfort. Additive manufacturing is transforming the medical industry by bringing high levels of personalization to the production of medical devices such as implants, improving surgical outcomes and ensuring greater accessibility to personalized medical solutions.

5.2 Analysis of Synergies in the Pharmaceutical Industry

Integrating Industry 4.0 technologies in the pharmaceutical industry offers significant opportunities to improve the delivery of pharmaceutical services. In the pharmaceutical industry, Industry 4.0 technologies can be integrated to exploit synergies that will improve the delivery of pharmaceutical services (Hole et al., 2021). Industry 4.0 technologies such as IoT sensors, data analytics and real-time monitoring can enable companies to get data throughout the drug development and manufacturing process. This data can provide valuable insights into the performance and quality of pharmaceutical products, helping identify potential issues or areas for improvement. In addition, Industry 4.0 technologies can support the production of personalized medicines and customized treatments tailored to individual needs. Integrating Industry 4.0 technologies in the pharmaceutical industry offers numerous benefits that help deliver better pharmaceutical services.

5.3 Analysis of Synergies in the Automotive Industry

Industry 4.0 brings opportunities for enhanced synergies and optimization in the automotive industry in areas such as customer relations and research and development. For instance, manufacturing workers or consumers can have access to expert advice developed and presented by digital technologies without the need to have an expert present (Hickie & Hickie, 2022). This can be achieved using digital technologies such as augmented reality, where manufacturing workers and consumers can access expert advice without the need for a physical expert to be present on-site. This can help resolve technical issues, provide training, or offer guidance during the manufacturing process.

In research and development, Industry 4.0 has also played a key role by introducing new tools and methodologies, leading to greater optimization in the automotive industry. For instance, advanced simulation and modeling tools allow automotive firms to design and

test new vehicle models virtually, reducing the need for physical prototypes and accelerating the research and development cycle (Hickie & Hickie, 2022). In addition, IoT sensors installed in vehicles and production lines generate data that can help automotive companies gain valuable insights into customer preferences, usage patterns and vehicle performance. These insights can then be used for data-driven decision-making in the research and development process, leading to more customer-centric designs. Industry 4.0 offers the automotive industry opportunities for enhanced synergies and optimization that help increase customer satisfaction.

5.4 Analysis of Synergies in the Manufacturing Industry

The adoption of Industry 4.0 reduces the length of supply chains, making them leaner (Sartal et al., 2022). The technologies facilitate a digitized approach to supply chain management, optimizing different processes. This allows firms to have the right inventory in the right place at the right time, making it possible for supply chain managers to minimize carrying costs and improve overall efficiency. Industry 4.0 fosters collaboration among supply chain partners through interconnected systems and data sharing. In addition, the technologies allow firms to monitor and assess supplier performance in real-time (Sartal et al., 2022). This data-driven supplier relationship management helps identify reliable and efficient suppliers, reducing the risk of supply disruptions and supporting a more agile supply chain. Thus, the adoption of Industry 4.0 technologies enables companies to create leaner and more efficient supply chains.

Automation leads to increased accuracy and speed. Digital technologies in the manufacturing industry bring a level of accuracy and speed that human beings cannot achieve (Sartal et al., 2022). The technologies have revolutionized traditional manufacturing processes by introducing a new era of automation and efficiency. Industry 4.0 can execute complex operations with high accuracy, leading to high-quality products. Human workers might find it challenging to maintain the same level of precision due to fatigue and the possibility of human errors. Automated machines can work continuously without breaks, reducing production time compared to human labor, which requires rest and shift changes.

Industry 4.0 provide a transformative pathway for manufacturers to achieve mass customization. Digital technologies provide new alternatives for mass customization and distributed manufacturing (Sartal et al., 2022). For example, additive manufacturing supports direct production and rapid manufacturing of different products (Sartal et al., 2022). Constructing products layer by layer from digital 3D models enables the creation of personalized designs that would be difficult to achieve using traditional manufacturing methods. Digital technologies allow manufacturers to customize products without the need for costly retooling or significant changes in the production line. Each product can be tailored to individual customer preferences without significantly compromising efficiency or increasing production costs. It also leads to the reduction or elimination of waste since only the necessary materials for the specific product are used.

Digital technologies allow manufacturers to unlock the full potential of their plants and drive significant improvements in performance and sustainability. Industry 4.0 technologies are key in significantly improving plant performance across various industries. As indicated by Sartal et al. (2022), Industry 4.0 technologies significantly contribute to improving plant performance. The technologies monitor the health of machines and equipment in real-time, detecting potential issues before they lead to breakdowns. The technologies can also identify bottlenecks and inefficiencies, suggesting improvements to enhance operations. By analyzing energy usage patterns, manufacturers can pinpoint high-consumption areas and implement energy-saving measures, resulting in enhanced energy efficiency.

Lean practices can be integrated with digital transformation to achieve high levels of operational excellence and competitiveness. Industry 4.0 may be combined with lean practices to achieve optimal performance in the manufacturing industry (Sartal et al., 2022). Lean practices emphasize the elimination of various types of waste, such as overproduction, excess inventory, and non-value-added activities. Digital technologies facilitate data-driven decision-making, allowing manufacturers to make informed choices to optimize processes and address issues proactively, aligning with lean principles of continuous improvement. Lean manufacturing advocates for pull-based production systems, where products are manufactured in response to actual customer demand. On the other hand, Industry 4.0 technologies enable real-time demand sensing, supporting a

demand-driven production approach and minimizing excess inventory. The combination of Industry 4.0 and lean practices creates a powerful synergy that drives optimal performance in the manufacturing industry.

5.4.1 Opportunities for Achieving Synergies in Manufacturing

Lean production is a subfield of lean management which is considered an approach that involves different principles which assist a firm to achieve a competitive advantage and eliminate waste. Combining digital technologies and lean manufacturing principles can improve firm performance and CSR outcomes. Lean manufacturing and Industry 4.0 use different approaches; however, they have similar principles that focus on making work more efficient (ELAFRI et al., 2022). Therefore, manufacturing firms that harness the capability of lean manufacturing and Industry 4.0 are likely to gain economically and in terms of environmental corporate social responsibility. For instance, integrating Industry 4.0 technologies, real-time data and analytics help identify inefficiencies and bottlenecks, allowing manufacturers to optimize processes and minimize waste generation. The synergy leads to improved efficiency, reducing the firm's environmental footprint.

Both Industry 4.0 and lean manufacturing share common goals of optimizing processes, reducing waste and enhancing overall efficiency. The interaction between the design principles provided by Industry 4.0 and lean manufacturing can help firms achieve synergy (Sanders et al., 2017). When the principles are combined effectively, they reinforce and complement each other, resulting in greater productivity, competitiveness and sustainability. Industry 4.0 technologies support predictive maintenance, reducing machine downtime and minimizing equipment-related waste. Lean principles complement this by targeting other forms of waste, such as overproduction and excess inventory, leading to comprehensive waste reduction. The synergy between Industry 4.0 and lean principles fosters a culture of continuous innovation and digitalization.

Both Industry 4.0 and lean production aim to improve efficiency and effectiveness in manufacturing processes, but they do so from different perspectives. The main difference between Industry 4.0 and lean production is in the strategic approach used by each (Sanders et al., 2017). Lean focuses on minimizing complexity while Industry 4.0 focuses on simplifying the complexity from the user's point of view. Lean practitioners use tools

like value stream mapping, 5S, Kanban and continuous improvement (kaizen) to identify and reduce complexity with the goal of creating a smooth and streamlined process flow, minimizing delays and inefficiencies. Industry 4.0 embraces the idea of simplifying complexity from the user's point of view. This means that even though the manufacturing process itself may become more complex due to the integration of digital technologies, the user experience is simplified and made more user-friendly. Industry 4.0 technologies seek to make processes more transparent and easier to control for operators and managers. Therefore, the two approaches contribute to improved efficiency and effectiveness in manufacturing, but they do so through different paths.

The combination of Industry 4.0 and lean manufacturing creates a powerful force for productivity and efficiency in manufacturing. The synergies achieved through the implementation of the two approaches indicate the possible opportunities that will come with the implementation of interconnected smart factories (Sanders et al., 2017). Notably, smart factories leverage real-time data from Industry 4.0 technologies and incorporate lean principles to optimize production processes continually, leading to reduced lead times, minimized downtime and streamlined workflows. The synergies between lean and Industry 4.0 open doors for sustainable practices within smart factories, contributing to more environmentally friendly manufacturing processes that align with corporate sustainability objectives. Therefore, the implementation of interconnected smart factories, driven by the synergies of Industry 4.0 and lean manufacturing, offers opportunities for manufacturers to achieve new heights in productivity and efficiency.

Lean production has limitations in that it does not address the futuristic changing demands of customers. Incorporating Industry 4.0 in lean production helps address the challenge of volatile customer demands (Sanders et al., 2017). Integrating Industry 4.0 technologies into lean production systems helps firms monitor customer demands in real-time and respond quickly to changes, allowing for more flexible production processes. Predictive analytics helps lean production anticipate shifts in demand patterns, enabling firms to adjust their production schedules and inventory levels proactively. By minimizing the risk of overproduction or stockouts, these practices lead to improved customer satisfaction and reduced waste. In addition, Industry 4.0 technologies enable firms to engage with customers through digital channels gathering customer feedback and

preferences. This enables firms to comprehend customers' needs and preferences, facilitating continuous improvement. Therefore, incorporating Industry 4.0 into lean production empowers firms to meet the challenges posed by the futuristic changing demands of customers.

Different lean management tools benefit from the introduction of Industry 4.0. For example production smoothing, automation, waste elimination and Kanban will be improved with the introduction of Industry 4.0 (Sanders et al., 2017). Smoother production helps eliminate inefficiencies caused by production breakdowns and starts, leading to improved throughput. The technologies also support better production planning and scheduling, making it possible for manufacturing firms to achieve production smoothing. The use of the Kanban tool allows lean production to control inventory. Kanban can be incorporated with Industry 4.0 technologies to ensure that as products move through the supply chain, the technologies automatically trigger replenishment orders. The different lean management tools work together to improve efficiency and eliminate waste. Therefore, integrating Industry 4.0 technologies with lean management tools benefit firms aiming for leaner, more efficient operations, enabling them to achieve higher levels of productivity and customer satisfaction while following lean principles.

5.4.2 3D Printing and Environmental Sustainability

3D printing supports environmental corporate social responsibility due to its unique advantages over traditional manufacturing processes. For instance, 3D printing reduces energy consumption and carbon dioxide emissions (Rouf et al., 2022). In traditional manufacturing, subtractive processes are common, involving the removal of excess material to achieve the desired shape, leading to significant material waste. However, in 3D printing, an additive process is used where the material is selectively deposited layer by layer to build the final product, minimizing material waste, leading to higher material efficiency and reducing raw materials demand. 3D printing offers unique advantages that support environmental corporate social responsibility through the reduction of material waste, energy consumption and carbon dioxide emissions. Therefore, 3D Printing offers pollution control and waste management benefits, making it appropriate for smart factories.

Moreover, 3D technology presents a cost-saving opportunity for companies by enabling on-site production of spare parts. Having 3D printers within the company premises eliminates the need for transportation costs and reduces expenses related to expediting. In comparison to overseas production, on-site manufacturing of spare parts proves to be more economical, considering factors such as transportation, urgency, and delays. Consequently, companies can bypass suppliers and utilize 3D printing technology to produce spare parts independently.

5.5 Trade-offs of Implementing Industry 4.0 in Different Sectors

Although Industry 4.0 brings numerous opportunities in the manufacturing industry. There are also different challenges that arise with the implementation of Industry 4.0 technologies. The different trade-offs that may exist among different sustainability indicators include inequality issues, technology maturity and lifecycle effects on the environment (Sun et al., 2021). Industry 4.0 technologies are continuously evolving and some companies may struggle to keep up with the pace of advancements. Small and medium-sized enterprises (SMEs) and less developed regions might face challenges in accessing and implementing these technologies due to cost. While Industry 4.0 technologies can lead to improved resource efficiency and reduced environmental impact in the manufacturing process, their entire lifecycle should be considered. For instance, the production and disposal of electronic components, such as sensors and IoT devices, may have environmental consequences (Sun et al., 2021). Additionally, the energy consumption associated with the operation of smart factories should be carefully managed to minimize the overall environmental impact.

Another tradeoff is the relation of Industry 4.0 cybersecurity. The increased reliance on interconnected devices and data exchange in Industry 4.0 raises concerns about data privacy and cybersecurity (Sun et al., 2021). Manufacturing companies collect sensitive data from production processes, supply chains and customer interactions. Ensuring the secure handling and storage of this data is critical to prevent data breaches, maintain customer trust and protecting business competitiveness. Therefore, firms should prioritize cybersecurity in the context of Industry 4.0 implementation to ensure data and systems protection. In order to tackle cybersecurity challenges, companies should adopt proactive measures to protect their systems and data.

6 Conclusion

In this master thesis, I aimed to provide a critical perspective on Industry 4.0, exploring its synergies and trade-offs in different industry sectors in Europe in terms of environmental corporate social responsibility (CSR) and sustainability. My research went through the transformative impacts of Industry 4.0, considering its adoption in healthcare, pharmaceutical, automotive and manufacturing. I conducted an in-depth analysis, incorporating existing literature while maintaining a critical lens throughout the study.

6.1 Managerial Findings

Industrial companies in Europe have well understood that the efficiency gains offered by Industry 4.0 technologies is a question of survival. My analysis reveals that Industry 4.0 has brought significant advancements and opportunities in various industry sectors. In the healthcare industry, the integration of IoT-enabled devices and digital technologies enabled remote patient monitoring and virtual consultations, enhancing patient care and resource allocation. The automotive sector experienced real-time data analysis, improving vehicle performance and enhancing customer satisfaction.

The manufacturing industry emerges as the most valuable sector for the effects of Industry 4.0 in Europe. By embracing digital technologies, the manufacturing sector has witnessed remarkable advancements in productivity, efficiency, and customization. Industry 4.0 has enabled the creation of smart factories, optimizing supply chains and automating processes for higher accuracy and reduced production time. The sector's adoption of 3D printing has led to significant reductions in material waste, energy consumption, and carbon emissions, aligning with circular economy principles. Additionally, Industry 4.0's real-time monitoring of machines and data-driven decision-making has improved plant performance and energy efficiency. The manufacturing industry, with its sustainable and agile practices, showcases the transformative potential of Industry 4.0 for Europe's re-industrialization and strategic success. However, challenges and trade-offs must be addressed to ensure a holistic and inclusive approach to sustainability across all sectors.

6.2 Theoretical Findings

The theoretical insights from my study indicate that Industry 4.0 plays a vital role in addressing environmental and social sustainability challenges. By embracing modern technologies and digital solutions, firms can optimize production, reduce resource consumption, and minimize environmental impacts. The integration of Industry 4.0 technologies offers a promising solution for enhancing environmental CSR, supporting sustainable practices in different industry sectors, on top of offering valuable efficiency gains.

The analysis of synergies in various sectors reveals that the combination of Industry 4.0 technologies and lean manufacturing principles leads to significant improvements in productivity, efficiency, and environmental corporate social responsibility.

However, my analysis also highlights the need to strengthen the inclusion of social development values in corporate governance to fully realize the social and environmental potential of Industry 4.0 (Ferreira et al., 2023).

6.3 Critique

While acknowledging the positive environmental CSR effects of Industry 4.0, I recognize certain limitations and trade-offs. My study may have faced publication bias, potentially overlooking negative aspects of Industry 4.0, which could influence the overall assessment of its implementation's synergies and trade-offs. Additionally, the focus on European industries might have overlooked valuable insights from other regions. Moreover, the concept of Industry 4.0 is relatively new and constantly evolving, making it challenging to draw definitive conclusions, especially concerning long-term impacts. The complexity of assessing environmental CSR effects, involving multiple variables and indirect interrelationships, may not always be adequately captured in the existing literature.

The adoption of Industry 4.0 technologies could bring numerous advantages, there are also challenges and trade-offs to consider across various sectors.

Industry 4.0 implementation has trade-offs, including increased pollution and traffic congestion due to rapid growth in express delivery supported by e-commerce and IoT technologies. This responsive logistics leads to more last-mile deliveries, contributing to

carbon emissions and climate change. Job satisfaction and safety concerns arise for delivery personnel due to strict schedules and time-sensitive deliveries. The use of numerous sensors in Industry 4.0 devices increases energy consumption, affecting the environment negatively. Automation and smart factories may lead to job displacement and income inequality, impacting social sustainability. The lack of standardized guidelines hinders interoperability and data exchange across industries. Integrating existing equipment with Industry 4.0 technologies is costly, and adopting digital technologies exposes firms to cyber-attacks and data safety challenges, emphasizing the need for strong cybersecurity measures.

6.4 Further Work

Firstly, conducting more extensive studies on industries in regions outside of Europe will provide a more comprehensive understanding of the environmental CSR effects of Industry 4.0. This can offer valuable insights into potential regional differences and support global sustainability efforts.

Further research is needed to explore how Industry 4.0 technologies can be made more accessible and cost-effective, particularly for SMEs and less developed regions in the healthcare and pharmaceutical industries. Identifying strategies and solutions to address cost barriers can lead to a more equitable distribution of digital healthcare services and personalized medicines.

Investigating the entire lifecycle impact of Industry 4.0 technologies in the manufacturing industry is crucial to identify potential areas for improvement and sustainable practices. Understanding the environmental implications throughout the lifecycle, from production to disposal, can guide companies in making more responsible decisions and achieving higher levels of environmental corporate social responsibility.

Additionally, further exploration into cybersecurity measures and best practices in the context of Industry 4.0 implementation in the automotive and manufacturing sectors is essential. Developing proactive cybersecurity strategies and ensuring data protection will be crucial in safeguarding businesses and maintaining the integrity of interconnected smart factories.

Overall, continued research into Industry 4.0 technologies and their integration with different industries can provide valuable insights into achieving optimal performance, sustainability, and positive social impact across various sectors. Understanding the trade-offs and challenges involved.

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