



Implementing Artificial Intelligence to promote Sustainability Efforts in Manufacturing: A Study of German SMEs

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Abstract

Title: Implementing Artificial Intelligence to promote Sustainability Efforts in Manufacturing: A Study of German SMEs

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This study explores the trending topic sustainability and the rapidly developing technology artificial intelligence (AI). The research analyzes their influences on the implementation of AI for sustainability efforts in manufacturing in the context of German small and medium sized enterprises (SMEs). The potential of AI to increase sustainability performance in manufacturing is still underexplored, particularly in the German SME sector and requires therefore further research.

A qualitative research approach was applied and data was collected by interviewing twelve industry experts and analyzed using Gioia's methodology. The study highlights both the drivers, such as competitive pressure and the challenges, such as a lack of expertise, faced by German SMEs. Furthermore, opportunities for actions are identified through the conducted research, for example, collaboration with other SMEs, which can facilitate the implementation of AI for sustainability. It reveals that the main driver for the adoption of AI for sustainability efforts is cost reduction in manufacturing through process optimization and resource efficiencies. The existing literature highlights the potential of sustainable manufacturing in combination with AI to optimize resources such as energy consumption or waste disposal. This research adds to the literature by identifying advanced environmental AI optimizations that traditional approaches cannot fully exploit due to their limitations. Therefore, manufacturers could leverage their environmental and economic efforts to the maximum. This study aims to be a useful reference for both industry practitioners aiming to leverage AI for enhanced sustainability and researchers studying the intersection of technology and environmental management.

Keywords: Artificial Intelligence, Sustainability, Manufacturing, German SMEs, Influences, Implementation

Sumário

Título: Implementar a Inteligência Artificial para promover os esforços de Sustentabilidade na indústria transformadora: Um estudo das PME alemãs

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Este estudo explora o tema da sustentabilidade e a tecnologia em rápido desenvolvimento da inteligência artificial (IA). A investigação analisa as suas influências na implementação da IA para os esforços de sustentabilidade na indústria transformadora no contexto das pequenas e médias empresas (PME) alemãs. O potencial da IA para aumentar o desempenho da sustentabilidade na indústria transformadora é ainda pouco explorado, particularmente no sector das PME alemãs, pelo que requer mais investigação.

Foi aplicada uma abordagem de investigação qualitativa e os dados foram recolhidos através de entrevistas a doze peritos do sector e analisados utilizando a metodologia de Gioia. O estudo destaca tanto os factores como os desafios enfrentados pelas PME alemãs. Além disso, são identificadas oportunidades de ação através da investigação realizada, por exemplo, a colaboração com outras PME, que pode facilitar a implementação da IA para a sustentabilidade. Revela que o principal motor para a adoção da IA para os esforços de sustentabilidade é a redução de custos no fabrico através da otimização de processos e da eficiência de recursos. Esta investigação contribui para a literatura existente ao identificar otimizações avançadas de IA que as abordagens tradicionais não podem explorar plenamente devido às suas limitações. Por conseguinte, os fabricantes podem tirar o máximo partido dos seus esforços ambientais e eco-nómicos. Este estudo pretende ser uma referência útil tanto para os profissionais da indústria que pretendem tirar partido da IA para uma maior sustentabilidade como para os investigadores que estudam a intersecção da tecnologia e da gestão ambiental.

Palavras-chave: Inteligência Artificial, Sustentabilidade, Manufatura, PME alemãs, Influências, Implementação

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List of Abbreviations

AI	Artificial Intelligence
ENGO	Environmental Non-Governmental Organizations
SDG	Sustainable Development Goals
SME	Small and Medium-sized Enterprises

1. Introduction

Between 2030 and 2052, global warming is expected to approach the 1.5°C threshold set by the Paris Agreement. Thus, operationalizing sustainability is becoming increasingly important for companies, while at the same time, digital transformation and the widespread adoption of smart technologies are driving significant changes (Miehe et al., 2021). Sustainability and digitalization represent a wide range of issues with significant challenges and opportunities. The characteristics of both areas are rarely analyzed and strategies developed with the aim of overlapping the two areas. (Del Río Castro et al., 2021). In the context of sustainability, artificial intelligence is considered a key technology that is currently on the threshold of diffusion into a wide range of application areas (World Economic Forum, 2018; Umweltbundesamt, 2019; Capgemini Research Institute, 2020). Based on the Capgemini study results, AI-driven use cases have the potential to support companies to achieve up to 45% of their emissions reduction target of the Paris Climate Agreement by 2030. Furthermore, while 67% of companies in various industries have made climate action a strategic priority, only 13% are successfully combining their climate vision with AI capabilities and have driven scalable solutions („Studie Climate AI“, 2023). To promote the AI implementation within the companies, the German government's "Strategy for Artificial Intelligence" was published in November 2018. The aim is to establish and promote a dynamic and sustainable AI ecosystem in Germany. In addition, the AI Federal Association and its regional member associations are strengthening Germany's attractiveness as a location for AI companies. However, there is still work to be done in many areas (KI Bundesverband). There is an opportunity for researchers in this sector, as there has been rarely theory development on the application of AI in the field of sustainability (Nishant et al., 2020).

This study addresses the paradox that the growing importance and widely recognized benefits of AI for sustainability efforts are in contrast with the low adoption rates of this technology. Furthermore, research on AI for sustainability initiatives is lacking in several areas, particularly manufacturing. Only a few studies have outlined the variables that influence the implementation in SMEs. This study addresses the following research question in order to contribute to the existing research gap:

What factors are influencing the implementation of Artificial Intelligence in order to promote sustainability efforts in manufacturing of German SMEs?

By identifying the factors that influence the use of AI for sustainability efforts in manufacturing, this research aims to enhance existing knowledge. The study deals with the key drivers, challenges and opportunities influencing the implementation of AI for sustainability efforts in manufacturing. The purpose is to provide insightful data for both industry practitioners aiming to leverage AI for enhanced sustainability in manufacturing and researchers studying the intersection of technology and environmental management. The research's findings will assist them in dealing strategically and tactically with AI and sustainability efforts in the future.

This research is structured into six chapters in order to answer the defined research question and organized according to the format of an academic research dissertation. The “Introduction” aims to highlight the significance and potential of using AI to increase sustainability in the SME manufacturing sector.

In Chapter 2, the Literature review ensures a critical understanding and theoretical foundation for the examined topic. The theoretical concepts of sustainability, AI and manufacturing will be addressed. The SME context will be discussed in the following chapter, as this proved to be an important factor in the analysis, ensuring a seamless transition from theory to application.

Chapter 3, the Methodology section outlines the procedures for the sample strategy, the data collection and analysis, and the reasons for choosing a qualitative research approach.

Chapter 4, titled Findings, discusses the results of the data analysis using Gioia's method of analysis. An extensive table visualizes the results. This offers a data-driven understanding of the research question and includes a short textual elaboration on the findings.

This leads into Chapter 5, where the Discussion is designed to connect the insights of the revised literature to identify the theoretical contributions of the study. In addition, the chapter addresses the limitations of the study and suggests potential areas for future research.

Finally, Chapter 6 serves as the Conclusion of the research, providing an in-depth examination of the study's key findings and the contribution of the research to the existing literature.

2. Literature Review

A literature review is an essential component of any research field (Dhialf et al. 2021). It offers insights that are valuable to the chosen topic and identifies future research directions (Govindan et al. 2015). Furthermore, the results of a literature review can be used to identify research gaps within an academic field (Tranfield et al. 2003). The part is divided into three main sections: Sustainability, AI and the combination of Sustainability and AI in manufacturing.

2.1 Sustainability

The concept of sustainability has recently gained increasing attention within society and politics. The most frequently used definition comes from the Brundtland Commission of the United Nations from 1987. The Brundtland Report defines sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland, 1987). In order to provide a more detailed definition, it is necessary to identify three dimensions of sustainability called economic, environmental and social (Elkington, 1994; Kar et al., 2022). Strategies for economic sustainability include those that optimize resource utilization and promote economic growth. One of the main challenges is to achieve a balance between social and environmental responsibility and profitability, which frequently demands the application of innovative techniques and technologies (Moldan et al., 2012). In general, the aim of environmental sustainability is to ensure environmental preservation through the appropriate use of natural resources and pollution reduction. To ensure that natural resources are available for future generations, strategies and measures are implemented to minimize the negative impact on the environment and ensure ecological balance (Purvis et al., 2019). The social dimension addresses concerns relating to justice, community well-being, ethical and fair behavior and trust (Osburg, 2017).

Corporate sustainability builds on the principle of sustainable development (Engert & Baumgartner, 2016). The United Nations published in 2015 an Agenda 2030 for Sustainable Development. The agenda is a crucial political framework aimed to achieve a sustainable future and to address key sustainability issues. One of its main accomplishments is the establishment of 17 Sustainable Development Goals (SDGs) (United Nations, 2015). The goals are in line with the three dimensions of sustainability (Sartal et al., 2020). An increasing number of companies are adopting SDGs as a basis for assessing the impact of their economic activities and their contribution to global sustainability goals. Various factors, including political regulations, customer demands, and investor expectations for measurable sustainability, influence

corporations to operate in a more sustainable way. However, achieving sustainable practices in companies requires extensive data analysis and complex business process optimization (Boll et al., 2022).

The shared value concept of Michael Porter should be taken into account for corporate sustainability which is defined as enhancing “competitiveness of a company while simultaneously advancing the economic and social conditions in the communities in which it operates” (Kramer & Porter, 2011, p.6). The concept assumes that in order to create value, companies should integrate social and economic values. Both must consider value principles that relate to relative costs and benefits. The future competitiveness of a company should be seen as a long-term investment in shared value creation. (Kramer & Porter, 2006; 2011).

2.1.1 Sustainability in manufacturing

In the global economy, the manufacturing sector plays a crucial role in the production of goods and services that are essential for maintaining a high living standard. The manufacturing sector consists of more than just production. "Manufacturing" refers to any industrial process that occurs along the supply chain, from the factory to the customer and back (Kshitij et al., 2022). Competitive pressure on global markets has led to a strong drive for lower costs, higher quality and shorter delivery times in the manufacturing industry (Sartal et al., 2020). Optimized processes that minimize the negative impact on the environment are becoming increasingly important in modern manufacturing (Kshitij et al., 2022). Managers should consider sustainability and environmental issues when developing their corporate strategy, given the growing customer demand for environmentally friendly products (Sartal et al., 2020). As a result, two of the 17 SDGs are sustainable production and consumption. SDG 12 aims to achieve, among other things, the efficient and sustainable use of natural resources by 2030 (Miehe et al., 2021). Furthermore, SDG 9 aims to develop a resilient infrastructure, promote sustainable industrialization and foster innovation (Sartal et al., 2020). In addition, government support programs and international regulations make an important contribution to sustainable production. They attempt to achieve this goal by establishing clear standards and creating incentives that encourage companies to introduce environmentally friendly processes. Financial benefits such as subsidies, tax reductions and grants can motivate manufacturers to invest in sustainable technologies and processes (Onu & Mbohwa, 2021). Integrating sustainability into manufacturing is seen as an effective solution to support continuous growth and expansion (Latif et al., 2017). The integration of systems and processes that enable the production of high-quality goods and services with reduced energy and material consumption is called 'sustainable manufacturing' (Giret et

al., 2015). Sustainable manufacturing involves developing strategies, processes and managing competitive and responsive technologies. Conservation of energy and natural resources is the most important aspect of sustainability in manufacturing (Kshitij et al., 2022). Reducing the environmental impact of manufacturing requires efficient and sustainable management of resources. This includes the effective optimization of energy and materials to reduce waste and pollution, protect natural resources, and reduce environmental damage (Yadav et al., 2020). The implementation of more sustainable manufacturing methods can result in a reduction of the costs associated with optimization while simultaneously contributing to the creation of a cleaner and safer working environment (Onu & Mbohwa, 2021).

2.1.2 Sustainability adaption in SMEs

SMEs make a significant contribution to overall economic value creation (Baumann-Pauly et al., 2013). There is no universal interpretation in the literature of an SME and for this reason research is based on different definitions (Jenkins, 2004). However, according to the European Commission (2003), a SME has less than 250 employees, an annual turnover of no more than 50€ million or/ and an annual balance sheet of no more than 43€ million (European Commission, 2003). It is important to acknowledge that SMEs are responsible for over 70% of global pollution, which highlights their significance in achieving sustainable development (Caldera et al., 2018). Moreover, to operate sustainably, it is important to balance human, financial and material resources with their social and environmental responsibilities. Achieving this balance can be challenging for SMEs, particularly in terms of financial and time constraints. As a result, some SMEs may not view sustainability as a competitive advantage due to the above mentioned limitations (Bergmann & Posch, 2018). The financial aspect presents a significant challenge due to limited budgets and the high capital costs associated with adopting more sustainable practices. In addition to the fact that higher prices deter potential customers in the short term, this can prevent SMEs from adopting sustainability, even if long-term success may be expected (Caldera et al., 2019). The initial investment can often lead to long-term savings through more efficient use of resources through sustainable practices (Álvarez Jaramillo et al., 2019). Environmental management frequently highlights regulatory requirements as a significant aspect, but they can also pose financial barriers. Adapting to changing legislation and managing the related costs can be a challenge for SMEs. They face challenges in financing proactive environmental management strategies due to the high costs of compliance (Ervin et al., 2012). By adopting sustainable practices or collaborating with environmental non-governmental organizations (ENGOS), SMEs can expand their customer and supplier bases. ENGOS can provide

valuable environmental, scientific, and professional support to help SMEs access resources that they may not have been able to access independently (Stekelorum et al., 2020).

2.2 Artificial Intelligence

This study analyzes the implementation of AI to support sustainability efforts in the manufacturing industry of SMEs in Germany. As a result, a relevant definition and description of the functionalities of AI technologies is necessary.

Currently, there is no standardized definition of artificial intelligence in the literature. Several definitions have been proposed to differentiate AI from other conventional information technologies. To capture the concept of AI, it is necessary to first understand the terms 'artificial' and 'intelligence' independently. The term 'intelligence' refers to cognitive processes such as thinking, reasoning and learning. In contrast, the term "artificial" is used to describe something that has been created by humans (Enholm et al., 2022). McCarthy et al. (1955) define the term 'artificial intelligence' in the humanistic way as "machine behaves in ways that would be called intelligent if a human were so behaving" (1995, p. 4). Another, more results-oriented and factual definition sees AI as a "system's ability to interpret external data correctly, learn from such data and use those learnings" (Kaplan et al., 2019).

2.2.1 Advantages of implementing AI

In general, AI is a technology that has the potential to facilitate significant operational transformations in many organizations. It is widely recognized as an important area of development in today's world (Aloini et al. 2018; Felice et al., 2022). A recent global study of 1,600 company decision-makers found that the majority believed AI adoption is essential for future business success and a determining factor for the growth of organizations (Naidoo & Dulek, 2022). AI can uncover insights which would otherwise remain hidden in large amounts of unstructured data. Such processes would otherwise require human management and analysis. The technology has the potential to leverage a significant amount of computing resources to address highly complex problems (Nishant et al., 2020). In the manufacturing industry, for example, AI offers companies the opportunity not only to reduce costs in the long term by improving error detection in production, but also to tailor production to specific customer requirements (Vaidya et al., 2018).

While it is recognized that businesses can largely benefit from AI in all areas of their operations, only a limited number of businesses have been able to successfully implement AI applications

beyond pilot projects so far (Enholm et al., 2022). The following section presents the challenges that companies face when implementing this technology.

2.2.2 Challenges of implementing AI

If AI is integrated in a beneficial way, there are various challenges that companies need to overcome. Alsheibani et al. (2018) noted that various factors, including technology readiness, organizational preparation, and environmental readiness, which encompasses governmental regulations, can impact the implementation of artificial intelligence. Other potential challenges may arise, such as the recruitment of qualified personnel, reliance on external partners, and infrastructure costs (Alsheibani et al., 2018). Therefore, it is beneficial to gain a deeper understanding of the various elements that facilitate the integration of AI into organizations and the development of AI skills (Holton & Boyd, 2021). As a result, successful AI implementation requires a comprehensive understanding of relevant AI readiness factors. AI readiness is “the preparedness of organizations to implement change involving applications and technology related to AI” (Jöhnk et al., 2021, p.6). These factors include an operationalized readiness assessment and a customized alignment between an organization's current AI readiness and its desired AI adoption goal (Jöhnk et al., 2021). According to Alsheibani et al. (2018), it is recommended to evaluate the AI readiness in order to proactively identify potential gaps in the organization for a successful adoption of AI (Jöhnk et al., 2021). For example, in the manufacturing industry, there can be several challenges, including difficulties with data collection and management, infrastructure, human resources, trust, security risks and implementation barriers. For instance, obtaining the necessary data to train AI models can be costly due to the large datasets required (Plathottam et al., 2023). Overall, the implementation of AI can be challenging due to its unique technological features and knowledge requirements, which differentiate it from other digital technologies that are easier to use and adopt (Lokuge et al., 2019).

2.3 Combining Sustainability and Artificial intelligence in manufacturing

Manufacturing industries are changing the way they operate, moving from traditional methods to the implementation of digital technologies. This shift towards more digitalized and sustainable practices is referred to as “The Fourth Industrial Revolution”, also called Industry 4.0 (Matin et al., 2023; Onu & Mbohwa, 2021). Data analysis, machine learning, and artificial intelligence, as part of Industry 4.0, generally enable the desired digitalization and connectivity of industrial processes and leading to opportunities in all three dimensions of sustainability (Müller et al., 2018). The core idea of Industry 4.0 is the use of the emerging technologies to

make production operate in an efficient and sustainable way with constant high quality and low costs (Machado et al., 2020). AI can address key issues in sustainable manufacturing, including waste management, supply chain management, energy efficiency, and logistics. For instance, AI can predict and improve the energy consumption of manufacturing processes (Li et al., 2017). This approach helps to reduce environmental impact and improve sustainability (Plathottam et al., 2023). Moreover, AI can be used to meet customer demands, ethical standards and legal requirements while respecting environmental principles and profitability throughout the lifecycle of a product or service (Gupta et al., 2020). Therefore, AI has relevance for the three dimensions of sustainability: economics, environment and social (Awasthi et al., 2020). In addition to technological support for sustainability efforts in manufacturing, collaboration with stakeholders such as other manufacturers, suppliers and customers can help promote the exchange of best practices and support the use of technology for sustainable purposes (Gupta et al., 2020). However, the introduction of Industry 4.0 technologies only seems to be successful in large companies, while SMEs have difficulties implementing sustainability effectively (Yadav et al., 2020).

3. Methodology

The objective of this research is to use scientific methods to address complex questions. The main aim of this research is to uncover new knowledge and provide insights into the area under investigation. This research aims to gain a deeper understanding of the status of AI for sustainability efforts in the manufacturing industry.

A dissertation can employ three primary research methodologies, called quantitative, qualitative, and mixed methods (Snyder, 2019). Quantitative research is a methodology that aims to comprehend and interpret the complexities of social processes, experiences and social situations (Creswell & Poth, 2016). Qualitative research is concerned with the subjective assessment of attitudes, opinions and behavior (Kothari, 2004). Given the new challenges, opportunities and market configurations that are emerging, qualitative research can make a significant contribution to the exploration of a topic that has not yet been developed. (Mick et al., 2004). Contrasting with quantitative methods, qualitative research is more convenient to uncover the underlying meanings, perspectives and contextual nuances that quantitative methods may miss (Creswell & Poth, 2016). Mixed methods refers to the use of both quantitative and qualitative data collection techniques (Al-Ababneh, 2020). A good research design generally reduces bias and increases the reliability of the data collected and analyzed (Kothari, 2004).

In conclusion, the decision to use qualitative research focusing on collecting primary data on the AI implementation impact for sustainability efforts in manufacturing seems appropriate for several reasons. Firstly, due to the multifaceted and complex nature of AI, it is essential to adopt an approach that can effectively capture and address its complexities. Qualitative research allows for in-depth investigation and provides a comprehensive picture of the difficulties managers face when implementing AI. It is an appropriate tool for exploring complicated issues. Furthermore, the goal of the research is to uncover the practical issues of experts with experience in AI initiatives related to sustainability. A qualitative method is suitable for this target since it allows to uncover real-world insights from interviewees. Semi-structured interviews with experts in the field allow for a thorough investigation of the influences on the adoption of AI to promote sustainability efforts, aligning well with the research objective.

3.1 Sample Strategy

To answer the research question, qualitative research is conducted based on the findings of experienced experts in the fields of AI and sustainability. Experts describe the specific role of the interview partner as a source of specialized knowledge about the social issue to be researched. Expert interviews are a method of obtaining this knowledge (Gläser & Gritt, 2010). To identify and contact appropriate experts that fit the research objective, the following criteria provide a more reliable framework. Both criteria are independent of each other and the expert must meet one of the two criteria in order to provide in-depth insights into the research question. Either the interviewee is working directly in the industry and demonstrating a comprehensive understanding of the company's sustainability efforts, or they are providing consulting services to German manufacturing SMEs on implementing AI with a focus on sustainability. The diversity of the data allows for a broad understanding of AI implementation for sustainability efforts, revealing the specific influences associated with different companies. The selection of interviewees is geographically restricted to the German region. Limiting the geographical boundaries to a country in which these two topics, AI and sustainability, are relevant, enables a more homogeneous context and hence better comparability among the interviewees.

A purposive sampling strategy is applied to select the sample for this study. The strategy, also known as judgment sampling, is based on the specific characteristics of the interviewee selected by the researcher (Etikan et al., 2016). The researcher employs purposeful sampling to select respondents who are most likely to provide accurate and useful information and to select a broad range of experts that align with the study's objective. The method helps to identify and

to select cases that optimize the utilization of available research resources (Campbell et al., 2020). Employing purposive sampling, the researcher made use of her personal and professional network, including connections on the networking platform LinkedIn. Furthermore, snowball sampling is used as an additional method, as it is criticized in the literature for its potential for selection bias (Parker & Scott, 2019). Snowball sampling helps to expand the pool of experts with a diversity of opinions regarding the objective of the study. At the end of the interview, the researcher asked the interviewees if they could recommend any other experts in the field of research. This proved to be an advantageous strategy for recruiting additional interviewees.

3.2 Data Collection Method

According to Saunders et al. (2009), interviews are a frequently used method for obtaining reliable and authentic research data. Interviews can be structured, semi-structured, or unstructured (Saunders et al., 2009). Semi-structured interviews provide interviewees with the opportunity to further elaborate on their responses. This approach can facilitate the incorporation of critical new elements into the study that might otherwise have been overlooked. (Yin, 2018; Saunders et al., 2009). The aim is to get an in-depth understanding of the research objectives, that is, the influences of implementing artificial intelligence to support sustainability initiatives in the manufacturing sector. Furthermore, the method allows the modification of the interview guide throughout the research process to correspond with any unexpected developments (Gioia et al., 2013). The interview guide includes a standard set of questions that can be categorized into the following five topics:

1. Background and general information
2. Benefits of implementation
3. Challenges of implementation
4. Internal and external influences
5. Future perspectives and recommendations

Due to geographical restrictions, the interviews were conducted via online video conferencing platforms such as Zoom or Microsoft Teams, as this seems to be the most efficient and sustainable method (Gray et al. 2020). Before the start of the interview, the experts were given a brief introduction to the topic and the study's purpose. Thereafter, the researcher obtained consent for the recording and emphasized that all information was kept confidential and used only for

the purpose of this study (Appendix 1). This procedure is important to ensure that the interviewed person is willing to share confidential information and to avoid withholding relevant data for the research. The interviews had an average duration of 45 minutes and were only recorded with the expert's authorization. The researcher transcribed the interviews with the AI transcription tool Fyerflie.ai. The interviewees originally spoke in German, which is their native language and the context of the research. Afterwards, the statements were translated into English using the AI translator DeepL and in order to improve readability, filler words and dialect were excluded from the transcription (Rädiker & Kuckartz, 2019). After completing this study, the research results are sent to the respondents along with an email thanking them for their participation. This is in response to the expressed interest by the participants in receiving the results at the end of the study.

3.3 Data Analysis Method

Data analysis involves a series of closely related tasks, such as creating categories, coding raw data, creating tables and finally drawing statistical conclusions. The Gioia method was employed to analyze the results and to address the previously defined research question. The main reason for adopting this approach is that it enables in-depth analysis of the collected data and provides comprehensive and detailed insights (Gioia, 2021). Moreover, the data analysis method is well-suited for analyzing qualitative research data as it directly addresses the common criticism of inductive research lacking 'qualitative rigor' (Gioia et al., 2013).

Gioia and colleagues (2013) propose two key phases in the thematic data analysis process, the systematic mapping of both 'first order' analysis, which uses informant-centered concepts and codes, and 'second order' analysis, which uses researcher-centered concepts, themes and dimensions (Gioia et al., 2013). Gioia's method of open coding divides the data into smaller, content-related units during the first stage of the analysis. This step is considered crucial as it allows the direct extraction of first-order concepts grounded on the interviewees' statements (Gioia et al., 2013). Gioia's approach involves a method called axial coding, which includes a second-order analysis. This method helps to identify groups of commonalities, duplications, and differences, which are then used to create second-order themes and arrange first-order concepts into theoretical categories. The resulting second-order themes are more abstractly formulated compared to the first-order concepts, making patterns and relationships in the data evident (Gioia et al., 2013). The aim is to explore emerging concepts that lack theoretical references in the existing literature. The development of a workable set of themes and concepts is crucial, leading to what

Glaser and Strauss referred to as 'theoretical saturation' (Glaser & Strauß, 1967). Constructing a data structure requires completing a full set of first-order concepts, second-order themes, and aggregate dimensions (Glaser & Strauß, 1967; Gioia et al., 2013). The findings of this study examined through Gioia's analysis process are discussed in the following section.

4. Findings

The findings of the qualitative content analysis with Gioia's method reveal several important themes and dimensions derived from twelve semi-structured interviews. These results are systematically organized in a table (Table 1), which provides a visual representation of the analysis. The data from the first-order concepts is structured around 14 second-order categories, which are grouped into five aggregate dimensions. The first dimension is about the drivers of AI, which indicates how AI can support manufacturing to improve sustainability performance, e.g. through improved resource efficiency. The second dimension, Organizational challenges address internal limitations, e.g. a lack of effective IT infrastructure. The third dimension, Human resources and cultural challenges, concerns the mindset of managers and employees. The fourth dimension, External market forces, examines regulations, customers and competition as they influence the use of AI for sustainability efforts. The final dimension, Opportunities for action, provides practical advice for managers planning a successful adoption of AI for sustainability efforts.

Table 1: *Overview of qualitative data analysis*

First-Order Concepts	Second-Order Themes	Aggregate Dimensions
"Sustainability is often a by-product of cost savings. For example, shortening my supply chain by sourcing locally usually results in lower CO2 emissions. Saving on waste also results in less pollution." (RF)	Cost efficiency through AI adoption in manufacturing and sustainability as a secondary benefit	<p style="text-align: center;">AI enhanced Drivers:</p> Cost and resource efficiency drive adoption, while sustainability is perceived as a secondary benefit
"By producing more sustainable cost savings can be achieved, which means there is a strong win-win situation." (OZ)		
"The sustainability aspect is only a side effect in the prioritisation of AI applications, which were mainly determined by cost and benefit considerations." (CH)		
"AI in manufacturing not as the main driver for sustainability aspects but as an add-on to operate more transparently." (AT)		
"AI can produce more cost-effectively, which means that at the end of the day my product can also be cheaper." (RV)		
"Increased efficiency in various areas such as process optimisation and quality control." (CP)	Advanced resource efficiency through process optimizations, which can not be fully exploited through traditional approaches, by using AI as a driver	
"AI can optimize the energy consumption, e.g. media, water, electricity, gas - Germany has contributed to the fact that energy prices have risen so immensely that you suddenly feel the pain. Because every euro that I spend more on energy is a pure loss of profit." (RV)		
"The use of AI can help to increase both sustainability and resource-efficient production." (SH)		
"Resource efficiency and process optimization are areas where AI can provide support." (MT)		
"Optimising processes can lead to waste minimisation in the product." (CP)		
"Increased efficiency in various areas such as process optimisation and quality control." (CP)		
"It is about how to save resources. An interesting example of this is the reduction in the reject rate, it reduces the consumption of expensive materials and therefore less waste. A positive side effect of this is that it is also more sustainable and can be communicated to the outside world in balance sheets and reports." (LZ)		
"I have previously seen that companies can initially significantly reduce their energy costs through traditional, continuous improvement approaches. However, these measures will eventually reach their limits. At this point, AI becomes unavoidable if you want to achieve further optimization. This follows the typical Pareto principle: while 80% of improvements are achievable without AI, the remaining 20%, which often involve substantial sustainability benefits, require AI's advanced capabilities. AI is a tool to get even more out of it, to optimise even more." (RV)		
"AI's added values extend far beyond existing ideas. AI is particularly effective in optimizing order sequences, value flows and energy consumption, key elements that can often not be fully exploited in traditional approaches." (AT)		

Source: *Own illustration based on qualitative content methodology of Gioia (2013)*

"Smaller companies are more agile because they have fewer layers of decision-making and can implement ideas faster, which often leads to stagnation or slowdown in large companies." (CP)	Organizational agility of SMEs as an advantage compared to large corporations when introducing AI	<p style="text-align: center;">Organizational Challenges: Agility facilitates adoption, but lack of effective IT infrastructure and SMEs' short term focus may deter adoption</p>
"[The implementation of AI] Is more likely to occur in a small company, where passionate individuals can explore the topic and experiment more quickly." (HA)		
"In general the advantage of small teams is that you can be fast, you can be agile, you can try things out quickly and represents the start-up spirit that makes them so popular." (MT)		
"Smaller companies can try new technologies more quickly." (CP)		
"Medium-sized companies are more agile than large scale companies." (AT)	Infrastructure setup impacts AI readiness and can potentially lead to issues in implementation	
"In the SME sector, the keyword AI readiness should be seen as a question mark. Are the data systems set up in such a way that it is realistic to use AI solutions for a sustainability goal?" (MT)		
"It's not that easy to get AI into production facilities. It starts with activating the security firewall and goes from very simple things to setting up an more complex infrastructure." (HA)		
"Small Companies have a technological problem; at the moment we have an absolute lack of high-performance IT infrastructure in Germany. We hardly have any high-performance infrastructure here in Germany." (RF)		
"Data acquisition and processing infrastructure is necessary and therefore adaptations to machines and systems are required. This is more complicated for smaller companies because of their lacking IT infrastructure." (AT)		
"The integration of AI in production process requires a modern IT infrastructure; outdated systems can be a significant barrier for the implementation of AI." (RV)		
"We have already tried to use AI on a small scale in manufacturing, but our systems failed in the implementation phase." (LZ)		
"The short-term focus on cost-benefit considerations often makes a holistic sustainability strategy more difficult." (CP)		
"Higher risk for such a company to realise something like this, because if it goes wrong, you have invested for nothing" (CP)		
"Smaller companies can experiment more quickly, but they face a higher relative risk to their overall revenue if the projects fail." (CP)		
"SMEs face obstacles such as limited resources for technology investments or internal structures." (AT)		
"The use of AI to achieve sustainability goals is a very long-term strategic decision, because strategic processes require a lot of time, knowledge and commitment." (MT)		
"Sustainability is often not systematically taken into account, especially in smaller companies that have to focus on short-term economic benefits." (CP)		
"If it will definitely save us more costs than it causes us, then perhaps we will do it." (MP)		
"When you introduce AI, you also want to see a very strong return on investment, because AI topics are very expensive." (OZ)		
"[The implementation of AI for sustainability efforts] It costs money, it costs time, those are resources we can use in other areas." (MP)		
"I believe that if the concrete benefit is so clear or so high that you want to implement it directly but there is no need right now for our company and we have other priorities in our company." (MP)		
"AI is almost always seen as a nice to have at the moment." (OZ)		
"The use of AI, particularly for sustainability, is not widespread, especially among smaller companies, and is considered a very specialised topic." (CP)		
"The three pillars of sustainability - economic, environmental and social - are not always immediately profitable, which makes it difficult to implement new business models. More pressing matters in business take priority." (CP)		

Source: Own illustration based on qualitative content methodology of Gioia (2013)

"In SMEs everything is bundled into the management and it's a barrier if the mindset is not there for AI implementation." (OZ)	Leadership mindset as crucial factor for implementation decision	Human Resources and Cultural Challenges: Leadership and operating team mindset and lack of expertise and specialized departments can deter AI adoption
"Support from management is a decisive factor. The financing of new projects often becomes an obstacle if the benefits are not clearly communicated and understood at management level." (CH)		
"The company's sustainability efforts tend to be downstream and depend very much on who you talk to in the company. The production manager does not always have sustainability at the top of his agenda." (MT)	Operating team mindset and culture as acceptance driver for the introduction of new technologies	
"From what I've seen so far, everyone in our company sees the problem of doing business more sustainably, but not everyone sees the problem or the opportunity of introducing new technologies like AI." (LZ)		
"As a young and small team we are very open-minded when it comes to things like new technologies. We use artificial intelligence applications on a small scale in daily tasks but not in manufacturing." (MP)		
"We have people in our production who have been working in this company for several years, who are waiting until they retire and see no need to introduce new technologies and are sceptical about them." (SH)		
"It is a fear of loosing the workplace because they fear AI is replacing them but it can also be fear of dealing with the new technology and adapting to it." (HA)	Lack of spezialized departments and missing expertise as challange for successful AI implementation	
"Organizational restrictions, because there are no departments or employees who can take care of it 100 percent." (RV)		
"SMEs do not have departments or divisions, so there is no organizational structure that can deal with the implementation of AI for sustainability and they have to rely on external knowledge." (UW)		
"The biggest problem I have indentified is the question of who takes care of this issue in the company?" (RF)		
"SMEs often have to source knowledge from outside, because even the implementation is lacking." (AT)		
"In most cases, they lack the knowledge and expertise to implement it themselves within the company. SME employees are not familiar with the new technologies. They don't know what's available. They don't know how to apply it." (RV)		

Source: Own illustration based on qualitative content methodology of Gioia (2013)

"The market is asking for sustainable products and companies can then use AI for internal processes to fulfil this goal. Customers are demanding sustainability, but they are often indifferent to the exact method of implementation." (HA)	Customers demand sustainable innovation, independent of used technology	<p style="text-align: center;">External Market Forces: Competition and customers are forcing sustainability, while regulations can deter investment in AI and sustainable initiatives</p>
"End customer will never specifically say, I want sustainability driven by AI. The customer doesn't care. They just want a sustainable product." (HA)		
"Competitors who successfully establish green products motivate others to reconsider less sustainable products."(HA)	Competition pushes companies towards sustainability which can also create an competitive advantage by sustainable brand positioning	
"The market also demands competition. One is the customer's advantage, but the other is the competition, which simply drives and pushes me to do something about it." (RV)		
"Competition is forcing companies to develop sustainable solutions." (HA)		
"I know from previous initiatives in our company that sustainability efforts and communication about them to the end customer creates a competitive advantage." (LZ)		
"You can positioning your company as a sustainable company." (AT)		
"It helps in marketing as a competitive advantage if the company can communicate, for example: "We now produce 80% from recycled material or we have saved 30% material." These are already marketing-relevant topics." (RV)		
"We are very active on LinkedIn, and when we tell the business community about our sustainability efforts and the adoption of AI in manufacturing, it's a game changer because everyone is interested in these topics right now and when you hear about best practices and insights, your company definitely becomes more recognized, and that's what we want to achieve. LinkedIn is therefore an important communication tool for us for innovations like this." (SH)		
"It's an image gain positioning the company well with customers, because some people are already paying more attention to the fact that products are somehow sustainable and in which extend." (CP)		
"When new legal frameworks are established in the area of sustainability, this has a direct impact on our corporate management and strategies." (MP)	Regulations can push and hinder companies to invest in AI and sustainability initiatives	
"Many production managers would probably agree to make products cheaper, even if it meant doubling CO2 emissions. At the moment, companies are more likely to be incentivized by politicians to act sustainably, but there is often a lack of real transparency and strict targets, which allows them to make environmentally damaging compromises." (RF)		
"Regulations are evolving rapidly and becoming more stringent regarding sustainability. As a result, we will focus more on sustainability in production, although the specific extent and methods remain unclear." (SH)		
"Regulation is often a major obstacle, as the fear of high [money] penalties and the use of data or AI models can conflict with regulatory requirements, especially for small companies that lack expertise. [...] The recently adopted EU AI Act is an important part of the European Union's data strategy and affects companies of all sizes." (CH)		
"Is it worth dealing with such issues now, when it is not yet clear if and to what extent this will happen due to regulations and what we will have to do then? Of course, it is also an opportunity to deal with it now, because in the end you will have to do it anyway." (CP)		

Source: Own illustration based on qualitative content methodology of Gioia (2013)

"There are a variety of specialised providers and start-ups specialized in AI and SMEs actually have to rely more on smaller service providers." (HA)	Collaborations with other SMEs to share best practices	<p style="text-align: center;">Opportunities for Action: Collaboration, external expertise and a focused approach can support the implementation of AI-driven sustainability practices</p>
"SMEs need to work together more closely and share best practices in order to benefit better from these economies of scale from AI." (AT)		
"Sharing information with other companies in the same sector that have had similar experiences can be very helpful." (MT)		
"Strong networking as a success factor for SMEs."(HA)	Seeking expertise from external consultants and institutions	
"And I would definitely pay someone for their expertise." (MP)		
"So there are actually more factors in favor of using AI in SMEs than against, e.g. German SMEs are much more likely to have access to state or government fundings, because they want to promote these kind of companies for the use of AI." (RF)		
"But there are also other consultants operating in this field. They know what data they need. They simply have the experience. And they can, within a short period, within a few weeks, identify what needs to be done differently. I have experience in this and I definitely recommend that the companies should get help and expertise at an early stage, as the process of developing an in-house solution is both costly and time-consuming." (UW)		
"Close co-operation with local initiatives and universities definitely helps. This is also highly recommended, because they can give you access to invaluable resources." (OZ)	Need of focused approach and strategy for successful AI Implementation for sustainability efforts	
"Yes, it's important to learn from other countries best practices and also to take this strengthening of Europe with us so that we are simply much more transparent." (OZ)		
"It is advisable to first find out about best practices and check what can be implemented in your own company. It is best to start small and, if possible, employ someone to do this. You should always bear in mind that resources are required." (CP)		
"The use of AI incurs costs for equipment and energy, which must always be taken into account. Sometimes it does not make sense to use AI if there are no clear gains to be expected in terms of resource efficiency. It is important to weigh up the benefits against the resource consumption before deciding to use AI." (CP)		
"Before using AI in sustainability management, you should first assess the current status of your own sustainability strategy and whether the use of AI makes sense." (MT)		
"To use AI effectively, companies must first systematically collect relevant data, store it in a meaningful format and make it available for use. An example of this is the digital product passport, which allows data to be collected and shared between companies, on which AI applications can then be built." (UW)		
"SMEs have to start small, fail fast, that sort of thing. So start at all. And fail fast is a bit like having a culture of failure, not giving up after the first try, to be honest. I think the potential is huge, both for sustainability and for business efficiency. In SMEs and also in the corporation in general." (RF)		
"SMEs need to make a potential analysis in the company." (AT)		

Source: Own illustration based on qualitative content methodology of Gioia (2013)

4.1 AI enhanced Drivers: *Cost and enhanced resource efficiency drive adoption, while sustainability is perceived as a secondary benefit*

Evidence shows integrating AI into the manufacturing processes is mainly motivated by cost reduction, optimizations and resource efficiency, with sustainability benefits often emerging as a secondary yet valuable outcome. The interviewees explain that sustainability is not the initial focus but frequently arises as a “by-product of cost savings” (RF) and is “only a side effect” (CH) of prioritizing AI technology. Sustainable production methods can also result in significant cost savings by fostering “a strong win-win situation” (OZ) that optimizes both economic and ecological efficiency. These decisions often prioritize economic benefits over direct climate action (CH). Implementing AI can make production more cost-effective, leading to cheaper product sales, thereby supporting the economic justification for the introduction of AI (RV).

Some interviewees highlighted that AI significantly improves process optimization and quality control, which further reduces waste and energy consumption (CP; RV; SH; MT; AT). For instance, reducing the defect rate in production through AI decreases the use of expensive materials and results in less waste, which contributes to sustainable manufacturing (LZ). RV’s comment about the sharp rise in energy costs in Germany highlights the immediate economic impact of inefficiencies, driving companies to adopt AI to mitigate these losses. The value of AI in manufacturing exceeds simple cost savings. AI improves several aspects of production, including “optimizing order sequences, value flows and energy consumption, key elements that can often not be fully exploited in traditional approaches” (AT). AI becomes crucial for realizing advanced optimizations and “AI’s added values extend far beyond existing idea” (RV). According to the Pareto principle, “while 80% of improvements are achievable without AI, the remaining 20%, which often involve substantial sustainability benefits, require AI’s advanced capabilities” (RV).

To summarize, the integration of AI in manufacturing for German SMEs is primarily driven by the economic incentives of cost savings. This motivation is combined with improvements in corporate sustainability, resulting in environmental benefits.

4.2 Organizational Challenges: *Agility facilitates adoption, but lack of effective IT infrastructure and SMEs’ short term focus may deter adoption*

The first finding from this analysis indicates that SMEs are more agile than large corporations while introducing new technologies (AT, CP). CP highlights that “smaller companies are more agile because they have fewer layers of decision-making and can implement ideas faster, which

often leads to “stagnation or slowdown in large companies”. This capability is supported by the SMEs ability to “experiment more quickly” (HA) and “represent the start-up spirit” (MT), which encourages rapid innovation. The agility of SMEs not only allows them to adopt AI solutions faster, but also to realize the benefits of AI-supported sustainability practices more quickly.

SMEs are more agile than larger companies, but interviewees emphasize that they are not yet ready to use these technologies effectively in practice. Some interviewees expressed the challenge that AI readiness “requires a modern IT infrastructure” (RV) and technical expertise in place. The lack of the necessary IT infrastructure is a considerable constraint to the effective integration of AI into systems. “Integrating AI into production processes requires a modern IT system. (RV). The required IT infrastructure includes “data acquisition and processing infrastructure” (AT) or an “active (...) security firewall” (HA). Interviewees recommended evaluating the company's data system setup and assessing the feasibility of using AI solutions to achieve sustainability goals (MT). If this is not feasible, “adaptations to machines and systems are required” (AT).

In addition, some interviewees expressed the challenge that “[...] AI topics are very expensive” (OZ), which requires a high return on investment. The risks associated with such technological investments primarily affect smaller businesses with limited resources. As CP indicates, “smaller companies can experiment more quickly, but they face a higher relative risk to their overall revenue if the projects fail.” Companies face the problem that “the use of AI to achieve sustainability goals is a very long-term strategic decision because strategic processes require a lot of time, knowledge and commitment.” (MT). “The short-term focus on cost-benefit considerations often makes a holistic sustainability strategy more difficult” (CP) and therefore SMEs do not take sustainability systematically into account. Moreover, evidence emphasizes that AI is not a primary focus for the most manufacturing companies' sustainability initiatives. Skepticism toward AI is widespread, with only a minority of companies willing to integrate it into their business processes (CP). Instead, experts called it as a “nice to have” (OZ) rather than a disruptive force or a necessity. As a result, there is currently no focus on implementing AI for sustainability efforts, as managers are prioritizing their resources on other topics. This is reflected by the statement, “I believe that if the concrete benefit is so clear or so high that you want to implement it directly, there is no need right now for our company and we have other priorities”(MP).

Overall, SMEs agility facilitates the AI adoption and organizational infrastructure setup plays a fundamental role in the successful implementation. AI topics are expensive, risky, and require long-term strategic decisions, making them difficult for smaller companies. AI is not a primary focus for most manufacturing companies' sustainability initiatives.

4.3 Human Resources and Cultural Challenges: *leadership and operating team mindset and lack of expertise and specialized departments can deter AI adoption*

The mindset of SME managers is crucial in overcoming the challenges associated with the successful adoption of AI for sustainability efforts. The introduction of AI often depends on the leadership's mindset, because “in SMEs everything is bundled into the management” (OZ) and “support from management is a decisive factor” (CH). An understanding of the benefits that AI can bring to the company's sustainability goals is fundamental for management due to the allocation and prioritization of resources such as budget. The management needs to have the right mindset about these emerging topics, otherwise the prioritization of AI projects is likely to be unsuccessful (CH).

Furthermore, employee acceptance of the technology within companies significantly impacts its successful implementation. Employees may be concerned about the potential loss of their jobs because of the fear that the new technology can replace them (HA). In addition, the lack of perceived need for the introduction of new technologies can prevent the implementation of AI due to a lack of support from employees (SH; HA). Awareness about sustainability efforts is present but not the need to implement new technologies such as AI (LZ). In contrast, MP’s states, “as a young and small team, we are very open-minded when it comes to things like new technologies” (MP). The size of the team and the age of the team members can therefore be identified as crucial factors that influence the acceptance of new technologies in the company.

Interviewees identified a lack of specialized departments or employees that take responsibility for the integration and management of AI technologies (RV; UW; RF). This gap is a major obstacle to the successful implementation of AI. UW indicates that SMEs do not have an “organizational structure that can deal with the implementation of AI for sustainability.” Furthermore, “SME employees are not familiar with the new technologies” (RV) and are missing the required expertise in order to use those technologies efficiently (AT). Because of this lack of knowledge for the sustainable use of technology, companies "have to rely on external knowledge" (UW) and expertise. This scenario not only increases dependency, but also increases the cost and complexity of adopting AI.

In conclusion, German SMEs encounter challenges when it comes to human resource management and the adoption of AI for sustainability. These challenges can arise due to the management mindset and cultural factors, as well as the lack of specialized departments and expertise within the company.

4.4 External Market Forces: *Competition and customers are forcing sustainability, while regulations can deter investment in AI and sustainable initiatives*

According to the interviewed experts, consumer preferences and priorities are a key driver of manufacturing companies' sustainability initiatives. However, the analysis shows that consumers are not expressing a desire for AI-driven sustainability products. As reflected by the statement, "end customers will never explicitly say: I want sustainability driven by AI" (HA). Customers demand sustainable innovation, independent of used technology. This finding underlines the consumers attitude toward prioritizing the sustainability of the end product over the refinements of the production process.

Despite this indifference of AI driven sustainability, consumers are increasingly aware of the environmental impact of products. As a result, "[...] people are already paying more attention to the fact that products are somehow sustainable and in which extend" (CP). Corporations can therefore gain a competitive advantage and image gain through strategic positioning. "[...] Companies can then use AI for internal processes to fulfil this goal" (HA). RV explains how AI can improve sustainability performance in manufacturing and states an exemplary marketing claim for these efforts "We now produce 80% from recycled material or we have saved 30% material" (RV). Communicating the sustainability improvements also enhances a company's brand image through "positioning [the] company as a sustainable company" (AT).

Furthermore, market regulations are key factors influencing both the introduction of sustainable manufacturing practices and the integration of artificial intelligence into these processes. As noted in the interviews, new regulatory frameworks concerning sustainability contribute directly to the design of corporate strategies "when new legal frameworks are established in the area of sustainability, this has a direct impact on our corporate management and strategies" (MP). This statement highlights that regulatory initiatives determine the direction of a company's sustainability strategy. Some interviewees expressed that regulations are not always fully effective in promoting sustainable practices. Shortcomings in transparency and the lack of defined targets by governments allow companies to make environmentally damaging trade-offs, as reflected in the statement "many production managers would probably agree to make products cheaper, even if it meant doubling CO₂ emissions" (RF). Another critical element in

the conflict of regulations and the use of AI is the fear of high financial penalties. The use of data or AI models can be in direct conflict with regulatory requirements, especially for small companies that lack expertise (CH). This finding highlights the conflict between the benefits of using artificial intelligence and the regulatory constraints that SMEs face from adopting innovative technologies. As a result, regulatory requirements play a crucial role in fostering innovation and the adoption of sustainable practices. However, they can also create challenges when it comes to the deployment of such policies.

Finally, external market forces such as consumer expectations, competitive pressures, and regulatory requirements are critical factors in the adoption of AI for sustainability in the manufacturing industry. Companies are forced to meet consumer expectations, remain competitive and comply with regulations in a rapidly changing regulatory landscape. Understanding and addressing these external forces is critical to gain a competitive advantage.

4.5 Opportunities for Action: *Collaboration, external expertise and a focused approach can support the implementation of AI-driven sustainability practices*

The findings suggest the need to focus on building or acquiring the necessary expertise in order to use AI effectively. Working with other SMEs that have already established AI applications and engaging in "strong networking" (HA) may contribute to a successful implementation. For SMEs, it can be very helpful to work closely together and share best practices (AT).

Enhancing collaboration with local universities and specialized AI providers, including startups, can significantly elevate the expertise of SMEs. Additionally, RF states that "SMEs are much more likely to have access to state or government funding because they want to promote these kinds of companies for the use of AI". It is recommended "that the companies should get help and expertise at an early stage, as the process of developing an in-house solution is both costly and time-consuming" (RV).

Findings highlight the need of a focused approach and strategy for the successful AI implementation for sustainability efforts. This can include the adoption of a lean strategy that aims to be more agile, commonly referred to as "start small, fail fast" (RF). This approach allows companies to learn from mistakes quickly and without major consequences, leading to more effective solutions. Furthermore, SMEs are recommended to conduct an analysis to identify the potential of AI and understand the specific benefits that AI can offer their businesses, particularly in terms of sustainability (AT). This includes "assessing the current state of their own sustainability strategy and whether the use of AI makes sense" (MT). In addition, it could also be useful

to understand industry best practice and consider the AI benefits against the related costs. By starting small and potentially hiring staff specifically for this initiative, SMEs can manage their resources more effectively and ensure a targeted approach for AI implementation in manufacturing.

Overall, by building expertise through collaborations with other SMEs and external consultants and adopting a focused approach, German SMEs can use AI more effectively. This will not only strengthen sustainability efforts, but also enhance greater business efficiency in an increasingly competitive and resource-constrained environment.

5. Discussion

This research offers theoretical implications for both AI and sustainability. A comparison of this study's findings with those from the literature review reveals the confirmation of previous research results and the emergence of new insights. These insights are critical for industry practitioners seeking to use AI to achieve improved sustainability outcomes. At the end of the Discussion chapter, the limitations of this study are presented and further research directions are defined.

5.1 Theoretical and Managerial Contributions

Researchers have already addressed the potential benefits and drivers of AI in manufacturing in terms of sustainability, leading to a well-established body of literature. This research largely confirms the existing literature on the drivers of using AI, such as improving industrial processes, leading to significant cost reductions, as well as highlighting the importance of resource efficiency and process optimization for sustainable production (Giret et al., 2015; Chavan, 2005; Kamarul Bahrin et al., 2016). According to the experts, a strong win-win situation can be created in which both economic and ecological efficiency are optimized. Porter & Kramer claim that companies often prioritize economic benefits over direct climate actions (Porter & Kramer, 2006). By identifying advanced optimizations through AI that traditional approaches cannot fully exploit due to their limitations, the conducted research introduces a novel contribution that has not received much attention in previous research. Advanced optimization is a key benefit, as manufacturers can maximize their economic and environmental performance by using AI, an outcome that is limited by conventional methods. Interviewees claim that managers can therefore take full advantage of AI to achieve, for example high-cost reductions that contribute to a competitive advantage. This study aligns with the broader literature on business

motivation by highlighting improved sustainability efforts as a secondary effect of the above-mentioned AI benefits in manufacturing.

The literature greatly confirms the research findings on the organizational challenges associated with AI adoption for sustainability efforts. The existing research highlights that technological readiness and organizational readiness have a significant impact on AI adoption (Alsheibani et al., 2018). The conducted research confirms these, as the experts mentioned organizational agility and the IT infrastructure setup as important factors influencing AI adoption. The adoption of AI for sustainability efforts, perceived as uncertain, specific investments, aligns with SMEs' short-term focus on immediate cost benefits. The focus on short-term financial performance ignores long-term success factors and societal needs. Machado et al. (2020) emphasize the need for industrial companies to achieve higher returns on investment while minimizing their environmental footprint. The literature suggests managers to consider sustainability and environmental issues when developing their corporate strategy, given the growing customer demand for environmentally friendly products (Sartal et al., 2020). This finding is consistent with the shared value strategy of Kramer & Porter (2006). Companies should avoid short-term, socially harmful activities to ensure long-term economic well-being (Kramer & Porter, 2006; Caldera et al. 2019).

The third finding highlights the human and cultural challenges of adopting AI for sustainability. Existing literature supports these findings, stating that resistance to new technologies, especially AI, is often due to cultural reservations (Machado et al., 2020; Yadav et al., 2020). Employees frequently worry about technology replacing them and causing job insecurity. However, SMEs face significant barriers due to a lack of internal expertise and specialized departments to manage implementation. This finding is consistent with Lokuge et al. (2019), which highlights the importance of knowledge capabilities for AI adoption. By addressing cultural reservations and knowledge gaps, SMEs can facilitate the adoption of emerging technologies such as AI.

Existing literature frequently mentions regulatory requirements as a significant aspect of environmental management (Ervin et al., 2012). The experts interviewed for this research confirmed this finding, but they also contributed a novel insight about the recently adopted EU AI Act, which is an important part of the European Union's data strategy. The EU AI Act can prevent companies from adopting AI in manufacturing because they fear high financial penalties if they do not use AI models correctly. This finding extends the existing literature, as regulations can not only promote innovation but also hinder progress. Furthermore, the finding about the

external market pressures for sustainability is expanding the literature, while customers mainly focus on the end product's sustainability and do not necessarily prioritize AI utilization.

The fifth finding highlights opportunities for action to successfully implement AI for sustainability in manufacturing. The literature clearly states that collaborations and relying on external knowledge are valuable resources for sustainable innovation (Stekelorum et al., 2020). The experts highlight the need for collaborating with other SMEs and seeking expertise from external consultants. The results contribute to the literature, indicating that German SMEs have a higher likelihood of accessing state or government funding, as these entities aim to encourage the use of AI. The findings are consistent with the German government's "Strategy for Artificial Intelligence," which aims to establish and promote a dynamic and sustainable AI ecosystem in Germany. Easy access to this type of support is invaluable to managers seeking sustainable innovation in manufacturing.

The following figure (Figure 1) provides a summary and illustration of the key factors influencing the AI implementation for sustainability in manufacturing. These factors can be divided into three main categories: drivers, challenges and opportunities. The process of categorizing involves data from "aggregate dimensions" and related "second-order concepts" from which all relevant elements were extracted and grouped (table 1).

Figure 1: Drivers, challenges and opportunities influencing AI adoption for sustainability efforts in German manufacturing SMEs



Source: Own illustration based on the research findings

5.2 Limitations and further Research

This study provides valuable insights into the influence of using AI to promote sustainability in manufacturing. However, it is important to recognize and address the limitations of this research, as they also provide opportunities for future research directions.

The primary data sources for this study consisted of consultants who have provided guidance to both large and small corporations about the implementation of AI in manufacturing. More people with a primary AI background than with a sustainability background confirmed their participation in the study as experts. For this reason, the result direction of the study may be more related to AI than to sustainability. In addition, sustainability experts from manufacturing companies are included in order to get answers to the research question. While this sample diversity provides important insights, it does not capture the broader range of perspectives and experiences of other key stakeholders. In addition, time and resource constraints made it difficult to achieve theoretical saturation because if more people had been interviewed, it could have been achieved, even with a diversity of backgrounds.

The qualitative design of this study, which focuses on content analysis and interviews, allows a thorough analysis of the topic. Nevertheless, the use of non-probabilistic sampling methods limits the generalizability of the results. The use of quantitative research methods could serve as a basis for sector-wide generalization and help validate the qualitative findings. Common trends and correlations that are less obvious through qualitative research alone can be found through statistical analysis.

The study's exclusive focus on German SMEs excluded the inclusion of larger companies and SMEs in other countries, thereby considering only one specific context with its own idiosyncrasies. Including SMEs from other countries could contribute to the emergence of new knowledge and offer insights that will broaden the understanding of the cultural, economic, and legal influences on the adoption of AI. The study was limited to the manufacturing sector and focused on the production part without considering other areas that might be relevant for sustainability purposes. Other manufacturing areas could be distribution or supply chain management, which presents a potential direction for further research.

AI and manufacturing are fast-developing fields. This study offers a temporary analysis of the current situation. It is possible that insights will become less relevant due to the rapid technological and regulatory changes that are occurring. To keep up with the rapid advances in the

field and to maintain an accurate understanding of the potential uses of AI for sustainability initiatives, further research on the topic is required.

Finally, there are several limitations to this study and AI is the only technology analyzed in the context of sustainability efforts in manufacturing. Due to space and time constraints, the study did not consider other innovative technologies, such as blockchain, that could also impact the sustainability efforts of manufacturing SMEs. Investigating alternative technologies can provide new perspectives and enhance the understanding of how technology can advance sustainability in manufacturing. Future analysis requires additional and ongoing research to examine the evolving landscape of AI applications in the manufacturing sector.

6. Conclusion

Future predictions indicate that AI will become increasingly important in sustainability (World Economic Forum, 2018; Umweltbundesamt, 2019; Capgemini Research Institute, 2020). This study provides insights into the factors influencing the use of AI for sustainability initiatives in manufacturing, specifically within the context of German SMEs. The literature review sheds light on the increasing importance of sustainability in manufacturing, as well as the advantages and challenges of implementing AI. To provide recommendations for managers and practitioners, qualitative research was conducted by interviewing 12 industry experts. The results of this study include several key drivers, challenges and opportunities that contribute addressing the research question.

The findings include organizational challenges such as a lack of IT infrastructure and human resources, as well as cultural challenges such as managers' attitudes. Additionally, adopters view AI-enhanced factors like resource efficiency as valuable outcomes. Furthermore, external market forces, such as regulations, have a significant impact on AI adoption because they drive companies to adopt innovative technologies and promote sustainability performance.

The conducted research introduces novel contributions that have not received much attention in previous research. Manufacturers can maximize their economic and environmental performance by using AI, a key benefit that conventional methods limit. Managers can therefore take full advantage of AI to achieve, for example, high efficiency that contributes to a competitive advantage. While AI offers significant improvements in operations and cost-effectiveness, its adoption is primarily motivated by economic incentives rather than sustainability efforts. Furthermore, while customers demand sustainable products, they do not express an interest in AI-driven sustainability.

Experts assess AI as a valuable resource that not only reduces costs but also enhances the environmental aspects of manufacturing processes. To address the challenges associated with implementing AI, SMEs should first adopt a focused approach and strategy in order to assess the potential and successfully implement AI for sustainability efforts. Second, German SMEs should search for collaborations with other SMEs to share best practices. Thirdly managers should seek the expertise of external consultants and institutions that can provide guidance in implementing AI projects. For German SMEs, the study provides practical action opportunities and a guide for the implementation of AI for sustainability efforts in manufacturing.

References

- Al-Ababneh, M. (2020). Linking Ontology, Epistemology and Research Methodology. SSRN Scholarly Paper 3708935. <https://papers.ssrn.com/abstract=3708935>
- Aloini, D., Dulmin, R., Mininno, V., Pellegrini, L. and Farina, G. (2018). Technology assessment with IF-TOPSIS: an application in the advanced underwater system sector. *Technological Forecasting and Social Change*, Vol. 131, pp. 38-48. <https://doi.org/10.1016/j.techfore.2017.07.010>
- Alsheibani, S., Cheung, Y., & Messom, C. (2018). Artificial Intelligence Adoption: AI-readiness at Firm-Level. *PACIS 2018 Proceedings*. 37. <https://aisel.aisnet.org/pacis2018/37>
- Álvarez Jaramillo, J., Zartha Sossa, J. W., & Orozco Mendoza, G. L. (2019). Barriers to sustainability for small and medium enterprises in the framework of sustainable development—Literature review. *Business Strategy and the Environment*, 28(4), 512–524. <https://doi.org/10.1002/bse.2261>
- Awasthi, A., Saxena, K. K., & Arun, V. (2020). Sustainability and survivability in manufacturing sector. In *Modern Manufacturing Processes*. Woodhead Publishing, pp. 205-219. <https://doi.org/10.1016/B978-0-12-819496-6.00011-7>
- Baumann-Pauly, D., Wickert, C., Spence, L. J., & Scherer, A. G. (2013). Organizing Corporate Social Responsibility in Small and Large Firms: Size Matters. *Journal of Business Ethics*, 115(4), 693–705. <https://doi.org/10.1007/s10551-013-1827-7>
- Bergmann, A., & Posch, P. (2018). Mandatory Sustainability Reporting in Germany: Does Size Matter? *Sustainability*, 10(11), 3904. <https://doi.org/10.3390/su10113904>
- Boll, S., & Schnell, M. (2022). Mit Künstlicher Intelligenz zu nachhaltigen Geschäftsmodellen. *Nachhaltigkeit von, durch und mit KI*. Whitepaper aus der Plattform Lernende Systeme, München. <https://cta4.plattform-lernende-systeme.de/>
- Caldera, S., Desha, C., & Dawes, L. (2018). Exploring the characteristics of sustainable business practice in small and medium-sized enterprises: Experiences from the Australian manufacturing industry. *Journal of Cleaner Production*, 177, 338-349. <https://doi.org/10.1016/j.jclepro.2017.12.265>
- Campbell, S., Greenwood, M., Prior, S., Shearer, T., Walkem, K., Young, S., Bywaters, D., & Walker, K. (2020). Purposive sampling: Complex or simple? Research case examples.

- Journal of Research in Nursing, 25(8), 652–661.
<https://doi.org/10.1177/1744987120927206>
- Creswell, J. W., & Poth, C. N. (2016). *Qualitative inquiry and research design: Choosing among five approaches*. Sage publications. [https://books.google.de/Creswell\(2016\).Qualitative_inquiry_and_research_design](https://books.google.de/Creswell(2016).Qualitative_inquiry_and_research_design)
- Del Río Castro, G., González Fernández, M. C., & Uruburu Colsa, Á. (2021). Unleashing the convergence amid digitalization and sustainability towards pursuing the Sustainable Development Goals (SDGs): A holistic review. *Journal of Cleaner Production*, 280, 122204. <https://doi.org/10.1016/j.jclepro.2020.122204>
- Dhiaf, M. M., Atayah, O. F., Nasrallah, N., & Frederico, G. F. (2021). Thirteen years of Operations Management Research (OMR) journal: a bibliometric analysis and future research directions. *Operations Management Research*, 14, 235-255.
<https://doi.org/10.1007/s12063-021-00199-8>
- Enholm, I. M., Papagiannidis, E., Mikalef, P., & Krogstie, J. (2022). Artificial Intelligence and Business Value: A Literature Review. *Information Systems Frontiers*, 24(5), 1709–1734. <https://doi.org/10.1007/s10796-021-10186-w>
- Ervin, D., Wu, J., Khanna, M., Jones, C., & Wirkkala, T. (2012). Motivations and Barriers to Corporate Environmental Management. *Business Strategy and the Environment*, 22, 390-409. <https://doi.org/10.1002/bse.1752>
- European Commission (2003). Commission Recommendation 2003/361/EC. *Official Journal of the European Union*, p. 36. <https://eur-lex.europa.eu/CommissionRecommendation>
- Etikan, I., Musa, S. A., & Alkassim, R. S. (2016). Comparison of convenience sampling and purposive sampling. *American journal of theoretical and applied statistics*, 5(1), 1-4.
[doi: 10.11648/j.ajtas.20160501.11](https://doi.org/10.11648/j.ajtas.20160501.11)
- Felice, F. D., Petrillo, A., Luca, C. D., & Baffo, I. (2022). Artificial Intelligence or Augmented Intelligence? Impact on our lives, rights and ethics. *Procedia Computer Science*, 200, 1846–1856. <https://doi.org/10.1016/j.procs.2022.01.385>
- Gioia, D. (2021). A systematic methodology for doing qualitative research. *The Journal of Applied Behavioral Science*, 57(1), 20-29. <https://doi.org/10.1177/0021886320982715>

- Gioia, D. A., Corley, K. G., & Hamilton, A. L. (2013). Seeking Qualitative Rigor in Inductive Research: Notes on the Gioia Methodology. *Organizational Research Methods*, 16(1), 15-31. <https://doi.org/10.1177/1094428112452151>
- Giret, A., Trentesaux, D., & Prabhu, V. (2015). Sustainability in manufacturing operations scheduling: A state of the art review. *Journal of Manufacturing Systems*, 37, 126–140. <https://doi.org/10.1016/j.jmsy.2015.08.002>
- Glaser, B. G., & Strauss, A. (1967). *The discovery of grounded theory: Strategies for qualitative research*. Chicago, IL: Aldine. <https://doi.org/10.4324/9780203793206>
- Gläser, J. & Gritt, L. (2010). *Experteninterviews und qualitative Inhaltsanalyse*, 4. Auflage, VS Verlag für Sozialwissenschaften. [https://books.google.de/Gläser\(2010\).Experteninterviews+und+qualitative+Inhaltsanalyse](https://books.google.de/Gläser(2010).Experteninterviews+und+qualitative+Inhaltsanalyse)
- Gray, L. M., Wong-Wylie, G., Rempel, G. R. & Cook, K. (2020). Expanding qualitative research interviewing strategies: Zoom video communications. *The qualitative report*. <https://doi.org/10.46743/2160-3715/2020.4212>
- Gupta, S. M., Güngör, A., Govindan, K., Özceylan, E., Kalaycı, C. B., & Piplani, R. (2020). Responsible & sustainable manufacturing. *International Journal of Production Research*, 58(23), 7181–7182. <https://doi.org/10.1080/00207543.2020.1841968>
- Holton, R., & Boyd, R. (2021). ‘Where are the people? What are they doing? Why are they doing it?’ (Mindell) Situating artificial intelligence within a socio-technical framework. *Journal of Sociology*, 57(2), 179–195. <https://doi.org/10.1177/1440783319873046>
- Jenkins, H. (2004). A Critique of Conventional CSR Theory: An SME Perspective. *Journal of General Management*, 29(4), 37–57. <https://doi.org/10.1177/030630700402900403>
- Jöhnk, J., Weißert, M., & Wyrski, K. (2021). Ready or not, AI Comes—An Interview Study of Organizational AI Readiness Factors. *Business & Information Systems Engineering*, 63(1), 5–20. <https://doi.org/10.1007/s12599-020-00676-7>
- Kaplan, A., & Haenlein, M. (2019). Siri, Siri, in my hand: Who’s the fairest in the land? On the interpretations, illustrations, and implications of artificial intelligence. *Business Horizons*, 62(1), 15-25. <https://doi.org/10.1016/j.bushor.2018.08.004>
- Kar, A. K., Choudhary, S. K., & Singh, V. K. (2022). How can artificial intelligence impact sustainability: A systematic literature review. *Journal of Cleaner Production*, 376, 134120. <https://doi.org/10.1016/j.jclepro.2022.134120>

- KI Bundesverband (2024). Academy for Artificial Intelligence. <https://ki-verband.de/projekte/>
- Kothari, C. R. (2004). Research Methodology: Methods and Techniques. New Age International. http://dl.saintgits.org/ResearchMethodology_Methods_and_Techniques
- Kramer, M. R. & Porter, M. (2006). The link between competitive advantage and corporate social responsibility. Harvard business review, 84(12), 78-92. https://Porter_Business_Case_for_CSR-libre.pdf
- Kramer, M. R. & Porter, M. (2011). *Creating shared value* (Vol. 17). Boston, MA, USA: FSG. https://moodle.lunive.KramerPorter_CreatingSharedValue
- Kshitij, G., Khanna, N., Yıldırım, Ç. V., Dağlı, S., & Sarıkaya, M. (2022). Resource conservation and sustainable development in the metal cutting industry within the framework of the green economy concept: An overview and case study. Sustainable Materials and Technologies, 34, e00507. <https://doi.org/10.1016/j.susmat.2022.e00507>
- Kuckartz, U., & Rädiker, S. (2019). Datenaufbereitung und Datenbereinigung in der qualitativen Sozialforschung. Handbuch Methoden der empirischen Sozialforschung, 441-456. https://doi.org/10.1007/978-3-658-21308-4_31
- Latif, H. H., Gopalakrishnan, B., Nimbarte, A., & Currie, K. (2017). Sustainability index development for manufacturing industry. Sustainable Energy Technologies and Assessments, 24, 82–95. <https://doi.org/10.1016/j.seta.2017.01.010>
- Li, B., Hou, B., Yu, W., Lu, X., & Yang, C. (2017). Applications of artificial intelligence in intelligent manufacturing: A review. Frontiers of Information Technology & Electronic Engineering, 18(1), 86–96. <https://doi.org/10.1631/FITEE.1601885>
- Lokuge, S., Sedera, D., Grover, V., & Dongming, X. (2019). Organizational readiness for digital innovation: Development and empirical calibration of a construct. Information & management, 56(3), 445-461. <https://doi.org/10.1016/j.im.2018.09.001>
- Machado, C. G., Winroth, M. P., & Ribeiro Da Silva, E. H. D. (2020). Sustainable manufacturing in Industry 4.0: An emerging research agenda. International Journal of Production Research, 58(5), 1462–1484. <https://doi.org/10.1080/00207543.2019.1652777>
- Matin, A., Islam, M. R., Wang, X., Huo, H., & Xu, G. (2023). AIoT for sustainable manufacturing: Overview, challenges, and opportunities. Internet of Things, 24, 100901. <https://doi.org/10.1016/j.iot.2023.100901>

- McCarthy, J., Minsky, M. L., Rochester, N., & Shannon, C. E. (1955). A proposal for the dartmouth summer research project on artificial intelligence. *AI magazine*, 27(4). <https://doi.org/10.1609/aimag.v27i4.1904>
- Mick, D. G., Burroughs, J. E., Hetzel, P., & Brannen, M. Y. (2004). Pursuing the meaning of meaning in the commercial world: An international review of marketing and consumer research founded on semiotics. <https://doi.org/10.1515/semi.2004.2004.152-1-4.1>
- Miehe, R., Waltersmann, L., Sauer, A., & Bauernhansl, T. (2021). Sustainable production and the role of digital twins—Basic reflections and perspectives. *Journal of Advanced Manufacturing and Processing*, 3(2), e10078. <https://doi.org/10.1002/amp2.10078>
- Moldan, B., Janoušková, S., & Hák, T. (2012). How to understand and measure environmental sustainability: Indicators and targets. *Ecological Indicators*, 17, 4–13. <https://doi.org/10.1016/j.ecolind.2011.04.033>
- Müller, J. M., Kiel, D., & Voigt, K. I. (2018). What drives the implementation of Industry 4.0? The role of opportunities and challenges in the context of sustainability. *Sustainability*, 10(1), 247. <https://doi.org/10.3390/su10010247>
- Naidoo, J., & Dulek, R. E. (2022). Artificial intelligence in business communication: A snapshot. *International Journal of Business Communication*, 59(1), 126-147. <https://doi.org/10.1177/2329488418819139>
- Nishant, R., Kennedy, M., & Corbett, J. (2020). Artificial intelligence for sustainability: Challenges, opportunities, and a research agenda. *International Journal of Information Management*, 53, 102104. <https://doi.org/10.1016/j.ijinfomgt.2020.102104>
- Onu, P., & Mbohwa, C. (2021). Industry 4.0 opportunities in manufacturing SMEs: Sustainability outlook. *Materials Today: Proceedings*, 44, 1925–1930. <https://doi.org/10.1016/j.matpr.2020.12.095>
- Osburg, T. (2017). Sustainability in a digital world needs trust. In *Sustainability in a digital world* (pp. 3-19). Springer, Cham. <https://link.springer.com/chapter/10.1007/978-3-319-54603-21>
- Parker, C., Scott, S., & Geddes, A. (2019). Snowball sampling. *SAGE research methods foundations*. <https://eprints.glos.ac.uk/id/eprint/6781>
- Plathottam, S. J., Rzonca, A., Lakhnori, R., & Iloeje, C. O. (2023). A review of artificial intelligence applications in manufacturing operations. *Journal of Advanced Manufacturing*

- and Processing, 5(3), e10159. <https://doi.org/10.1002/amp2.10159>
- Purvis, B., Mao, Y., & Robinson, D. (2019). Three pillars of sustainability: In search of conceptual origins. *Sustainability Science*, 14(3), 681–695.
<https://doi.org/10.1007/s11625-018-0627-5>
- Sartal, A., Bellas, R., Mejías, A. M., & García-Collado, A. (2020). The sustainable manufacturing concept, evolution and opportunities within Industry 4.0: A literature review. *Advances in Mechanical Engineering*, 12(5), 168781402092523.
<https://doi.org/10.1177/1687814020925232>
- Saunders, M., Lewis, P., & Thornhill, A. (2009). *Research methods for business students*. Pearson education. [https://books.google.de/Saunders,+2009\).+Research+methods+for+business+students.+Pearson+education](https://books.google.de/Saunders,+2009).+Research+methods+for+business+students.+Pearson+education).
- Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, 104, 333–339.
<https://doi.org/10.1016/j.jbusres.2019.07.039>
- Stekelorum, R., Laguir, I., & ElBaz, J. (2020). Can you hear the Eco? From SME environmental responsibility to social requirements in the supply chain. *Technological Forecasting & Social Change*, 158. <https://doi.org/10.1016/j.techfore.2020.120169>
[Get rights and content](#)
- Studie Climate AI (2020). *Wie Sie mit künstlicher Intelligenz Ihre Klimaschutzstrategie wirkungsvoll realisieren*. (o. J.). Capgemini Germany. Retrieved on 7. March 2024,
<https://www.capgemini.com/Report-Climate-AI-4.pdf>
- Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *British journal of Management*, 14(3), 207-222. <https://doi.org/10.1111/1467-8551.00375>
- Umweltbundesamt (2019). *Künstliche Intelligenz im Umweltbereich. Anwendungsbeispiele und Zukunftsperspektiven in Sinne der Nachhaltigkeit*. Kurzstudie. Texte 56/2019.
https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2019-06-04_texte_56-2019_uba_ki_fin.pdf
- United Nations (2015). *Sustainable Development*. <https://sdgs.un.org/goals>
- Vaidya, S., Ambad, P., & Bhosle, S. (2018). Industry 4.0—a glimpse. *Procedia Manufacturing*, 20(1), 233-238. <https://doi.org/10.1016/j.promfg.2018.02.034>

World Economic Forum (2018). Harnessing Artificial Intelligence for the Earth.

<https://www3.weforum.org/>

World Commission on Environment Development (1987). Report of the World Commission on Environment and Development: Our Common Future. <https://publikationen/nachhaltige-entwicklung/brundtland-report.html>

Yadav, G., Kumar, A., Luthra, S., Garza-Reyes, J. A., Kumar, V., & Batista, L. (2020). A framework to achieve sustainability in manufacturing organisations of developing economies using industry 4.0 technologies' enablers. *Computers in Industry*, 122, 103280. <https://doi.org/10.1016/j.compind.2020.103280>

Yin, R. K. (2018). *Case study research and applications*. Sage. https://Artikel_Yustinus_Calvin_Gai_Mali-libre.pdf

Appendix

Appendix 1: Semi-structured interview protocol

Introduction

(Note: All interviews are conducted in German)

This academic interview discusses the implementation of Artificial Intelligence (AI) for sustainability efforts in manufacturing, with a specific focus on German manufacturing SMEs. The main objective of this research is to gain a better understanding of the influences implementing AI for sustainability efforts in manufacturing.

The purpose of this interview is to gather firsthand experiences and perspectives from industry experts, including yourself, who possess direct involvement or knowledge in this field. Your insights will greatly aid in comprehending the practical aspects, opportunities and challenges associated with the integration of AI technologies for sustainability efforts in manufacturing.

Before proceeding, it is important to note that this interview will be recorded for academic purposes only. Your participation in this interview implies your consent to be recorded. Please note that all information you provide will be kept confidential and used solely for the purpose of this research. Thank you very much for your participation and authorization.

Background and General Information

- Is it right, that XX is your position in your company?
- In what ways/kinds of activities have you been involved in sustainability practices before? Can you give examples for that?
- What is your understanding of sustainability efforts within the manufacturing industry?
- In your opinion, how important is AI as a driver for sustainability efforts?
- Has your company implemented any AI-driven initiatives specifically aimed at improving the sustainability of production processes?

Benefits and Challenges of adopting AI-driven sustainability practices in production

- Do you have any experience with AI-driven sustainable practices in production?
 - In what why were you involved?
 - Do you remember the motivation behind it?
 - If so, can you first describe them and share any benefits or advantages you have observed?

- Please go back in the process - Can you remember of challenges or barriers, such as technological, financial, or organizational constraints, that have related the adoption of AI-driven sustainable practices in your experience?
 - What did the company do face these challenges?
 - What were the reactions?
 - What would you do differently now?

Internal and External Influences

- What internal factors influence the adoption of AI-driven sustainable practices in production, such as organizational culture, knowledge, or resistance to change, specific capabilities, human resources?
- Did external factors such as market dynamics, the competitive landscape or the regulatory environment affect the company's ability to implement AI-driven sustainable practices in production?

Future Perspectives and Recommendations

- What would you say are any future trends or developments regarding the use of AI for sustainability efforts in manufacturing SMEs?
- Based on your experiences, what recommendations would you provide to other manufacturing SMEs looking to adopt AI for sustainability efforts in production?
- Can you recommend anyone you know who has knowledge in that area and might be interested in helping me with this research?

Appendix 2: Interviewed experts

#	Identification	Position	Company Type
1	Expert RV	Senior Consultant AI	Consulting Firm
2	Expert MP	CEO of a Sustainable fashion manufacturer	Fashion Manufacturer
3	Expert CP	Project Manager at German Research Center for AI	AI Institute
4	Expert OZ	Manager Systems Engineering (AI implementations for manufacturer)	Consulting Firm
5	Expert AT	Consultant AI in manufacturing and ESG topics	Consulting Firm
6	Expert HA	Senior AI Advisor	Consulting Firm
7	Expert MT	Project Manager for AI implementation in SMEs	AI Institute
8	Expert RF	Operations Director with focus on sustainability practices	Metal Fabrication
9	Expert LZ	Sustainability Team Lead	Automotive Fabrication
10	Expert CH	Consultant for AI implementation in manufacturing firms	Consulting Firm
11	Expert UW	ESG Manager	Machinery Manufacturer
12	Expert SH	CSR Manager	Battery Manufacturer