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# Impact of ArcelorMittal's Sustainability and Digitalization Initiatives on Environmental Performance

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**KEYWORDS:** sustainability, digitalization, innovation, environmental performance, steel industry

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**ABSTRACT**

This study examines the impact of digitalization and sustainability initiatives on environmental efficiency performance at ArcelorMittal Temirtau, a steel manufacturing company in Kazakhstan. Using an explanatory case study design, the research applies Innovation Diffusion Theory (IDT), Resource-Based View (RBV), and Institutional Theory. Data was collected through a structured questionnaire from 123 employees with at least three years of relevant experience. Statistical analysis, including SEM, CFA, and correlation analysis, was conducted using SPSS and AMOS.

Findings indicate that sustainability efforts, particularly collaboration with external stakeholders, are well-received, while employee training needs improvement. Digital transformation enhances production efficiency, decision-making, and waste management, yet training gaps persist. Hypothesis testing reveals that firm capabilities do not significantly benefit from digitalization alone, and institutional pressure does not moderate its environmental impact. However, sustainability efforts, digitalization, and R&D investments contribute positively to environmental outcomes, with internal resources acting as a mediator.

The study recommends structured employee training, AI-powered analytics, blockchain-enabled supply chains, and digital twin technologies for optimizing sustainability and operational efficiency. Future research should explore long-term sustainability impacts and industry-specific regulatory responses. The findings provide valuable insights for companies and policymakers aiming to enhance sustainability through digital innovation.

## INTRODUCTION

Steel is everywhere in our lives and homes. It has built the modern world and would be essential product as more mega infrastructure are being designed. In 2023, 97.65% of steel industry raw materials were converted into steel products or co-products (World Steel Association, 2023). The world's steel production has seen tremendous increase since 1950. In the 2023, 1892 million tonnes of steel were produced, while 1890 million tonnes was produced in 2022. According to the World Steel Association (2023) steel-producing companies rank, ArcekirMittal, a Kazakhstan company emerged as the second largest producer of steel in million tonnes (68.52) with China Baowu Group being ranked the number one. Globally, Kazakhstan is ranked $37^{th}$ in terms of major steel production worldwide, and it produced 3.9million tonnes of steel in 2023 (WSA, 2024)

However, in recent years, the global steel industry has faced increasing pressure to adopt more sustainable practices and integrate innovative digital solutions. For instance, the number of injuries per million hours worked was 0.76 for employees and contractors combine in 2023 (World Steel Association, 2024). Also, the World Steel Association sustainability indicator revealed that in 2022, 1.91 tonnes of CO2 were emitted per tonne of crude steel cast, while the material efficiency and environmental management system represent 67.67% and 83.15% respectively. Moreover, United Nation's (2023) sustainability report discovered that steel production accounted for 7%- 9% of global $CO_2$ emissions.

Meanwhile, the steel sector, known for its resource-intensive processes and high carbon footprint, is now seeking pathways to improve efficiency, reduce environmental impact, and enhance competitiveness in an evolving industrial landscape (Miskiewicz & Wolniak, 2020). One major practical application has been the industry 4.0 and 5.0 concepts in the improving steel production strategies. Sarfraz et al. (2022) explored pathways to sustain steel production performance with innovative capabilities, green process and digital leadership. Their results have identified a significant correlation between innovation capabilities, green process innovation, and sustainable performance. Miskiewicz and Wolniak (2020) concluded that implementation of new solution based on digitalization caused increased energy and material efficiency in steel operations. Gajdzik and Wolniak (2021) established that digitalization determines the creation of new or modified products, processes, techniques and expansion of Poland Steel company's infrastructure and sustainability.

Researchers (Grabowska & Saniuk, 2022; Stock & Seliger, 2016) on innovation and sustainability in the steel production is gaining attention, the but era of digital transformation is too dynamic. This requires regular and intense investigation on new strategies to meet the changing landscape of digitalization in steel production sector. For example, the growing environmental regulations, energy price volatility, and societal demands for responsible corporate practices, there is a need for steel manufacturers to innovate by adopting more sustainable methods. ArcelorMittal Temirtau, like many others in the sector, must strike a balance between increasing production efficiency and reducing environmental harm. Despite the global trend toward sustainability and digital transformation, limited research has been done on how these changes are being implemented in the steel industry in Central Asia, particularly Kazakhstan. This study will address the knowledge gap by exploring how ArcelorMittal is leveraging digitalization to drive innovation and sustainability in the steel manufacturing sector. The primary objectives of this study are:

- To analyze the key innovation strategies adopted by ArcelorMittal Temirtau in its transition toward sustainability.
- To explore the role of digital technologies in transforming production processes at ArcelorMittal Temirtau.
- To evaluate the impact of ArcelorMittal Temirtau's sustainability and digitalization initiatives on environmental performance.

**Research Methodology**

This study employs an explanatory case study design, focusing on ArcelorMittal Temirtau's (a steel manufacturing company) digitalization and sustainability initiatives in Kazakhstan. The case study approach allows for an in-depth examination of causal links between digital transformation, sustainability policies, and operational efficiency. The study applies Innovation Diffusion Theory (IDT), Resource-Based View (RBV), and Institutional Theory to analyze the impact of digitalization and sustainability initiatives. The population consists of employees directly involved in digitalization and sustainability projects, including senior management, R&D personnel, operations managers, and environmental compliance officers. A purposive sampling technique ensures the selection of relevant experts, with 123 participants drawn from key departments. The study also applies inclusion criteria, requiring respondents to have at least three years of relevant experience. A structured questionnaire is the primary data collection tool. It consists of four sections covering respondent demographics, innovative strategies, digital transformation, and key research hypotheses. A 5-point Likert scale is used for measurement. The survey is administered online for convenience, with pilot testing conducted to ensure clarity and reliability. For data analysis, responses are screened using Excel and analyzed with SPSS and AMOS. Statistical techniques such as Cronbach's alpha reliability test, exploratory factor analysis (EFA), confirmatory factor analysis (CFA), structural equation modeling (SEM), and correlation analysis are applied. Ethical considerations include informed consent, confidentiality, and data protection. Participants are assured anonymity, and the organization will receive a copy of the final research findings.

**Results**

The study examines the demographics and engagement of participants in sustainability and digitalization initiatives at ArcelorMittal Temirtau. The majority of respondents are male, aged between 26 and 35, with a bachelor's degree and a master's degree. The majority have 6-10 years of industry experience. The study shows that 51.2% are directly involved in digitalization and sustainability initiatives, and 44.7% have attended multiple training sessions. The findings highlight the importance of firm capabilities, digitalization, and sustainability in shaping environmental performance and strategic decision-making.

As presented in Table 5.4, the mean values for all the key innovation strategies range between 3.81 and 3.91, indicating a generally positive perception of the company's sustainability initiatives. The highest-rated strategy is collaboration with external stakeholders (mean = 3.91, SD = 0.914), suggesting that respondents perceive partnerships with government agencies, NGOs, and industry partners as a crucial driver of sustainability innovation. This finding highlights the importance of external engagement in achieving sustainability goals.

**Table 5.4 Key innovative strategies**

| Description of innovative strategies | Min | Max | Mean | SD |
|---|---|---|---|---|
| Our company has implemented strategic sustainability initiatives, such as carbon footprint reduction and energy efficiency improvements. | 1.00 | 5.00 | 3.87 | 1.05 |

| | | | | |
|---|---|---|---|---|
| Investments in green technology and renewable energy sources are a priority for our company's sustainability strategy. | 1.00 | 5.00 | 3.84 | .978 |
| Sustainability considerations are integrated into our product design, production, and supply chain processes. | 1.00 | 5.00 | 3.86 | 1.003 |
| Our company collaborates with external stakeholders (e.g., government, NGOs, and industry partners) to enhance sustainability innovation | 2.00 | 5.00 | 3.91 | .914 |
| Employee training and awareness programs on sustainability initiatives are actively promoted within the organization | 1.00 | 5.00 | 3.81 | 1.051 |

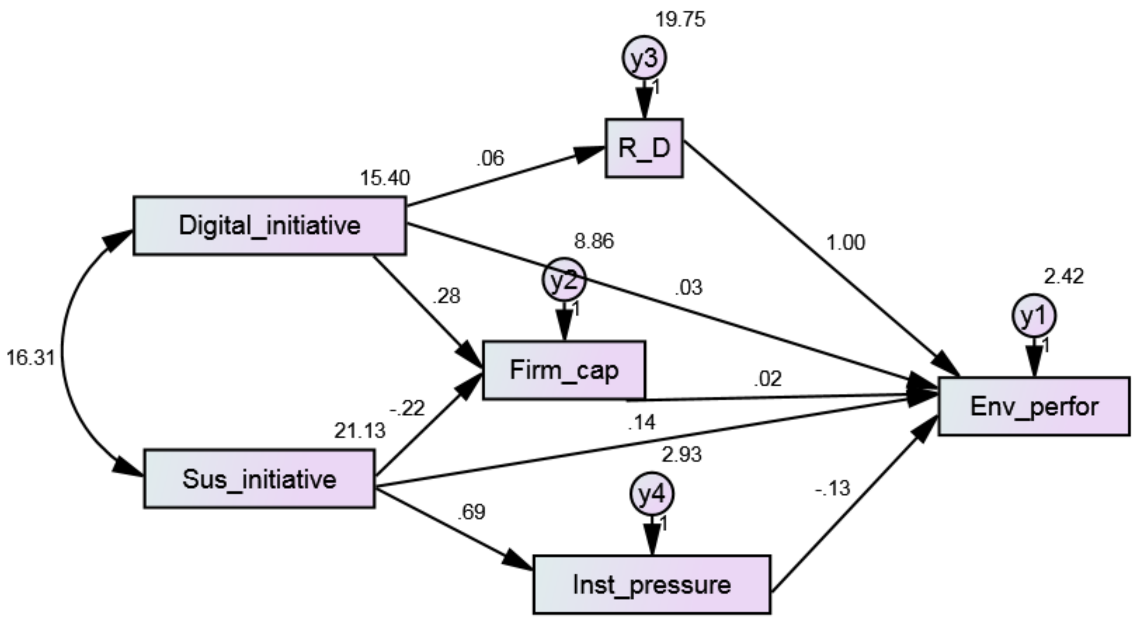
Table 5.5 presents the role of digital technologies in enhancing production efficiency and sustainability at ArcelorMittal Temirtau. The highest-rated item is the adoption of digital technologies such as AI, IoT, and automation (mean = 3.682, SD = 1.002), highlighting that these innovations are perceived as effective in improving overall production efficiency. The use of data analytics for decision-making is also rated positively (mean = 3.626, SD = 0.8238), suggesting that respondents acknowledge the impact of digital tools in optimizing manufacturing processes. Similarly, digital transformation's role in reducing operational costs and waste management inefficiencies is recognized (mean = 3.609, SD = 1.106), reflecting its contribution to cost-saving measures and sustainability improvements.

**Table 5.5 Role of digital technologies in transforming ArceloMittal**

| Description of items | Min | Max | Mean | SD |
|---|---|---|---|---|
| Our company has adopted digital technologies (e.g., AI, IoT, and automation) to enhance production efficiency. | 1.00 | 5.00 | 3.682 | 1.002 |
| The use of data analytics has improved decision-making in our manufacturing processes. | 2.00 | 5.00 | 3.626 | .8238 |
| Digital transformation has led to a reduction in operational costs and waste management inefficiencies. | 1.00 | 5.00 | 3.609 | 1.106 |
| Employees are adequately trained to use digital tools and technologies in production. | 1.00 | 5.00 | 3.593 | 1.151 |
| Our company's digitalization efforts have significantly improved product quality and environmental performance. | 1.00 | 5.00 | 3.268 | 1.109 |

**Direct effects relationships**

After the conducting several measurement model such as EFA, CFA, reliability and correlational analysis, the research found the dataset adequate and credible for further probing the research hypothesis. First, the direct relationships among the study variables as assumed in the research hypothesis development were conducted in this section. The results of the overall structural model and direct relationships among the study variables are presented in figure 5.3 and table 5.13 respectively.



**Regression Weights: (Group number 1 - Default model)**

| Path relationship | | | Estimate | S.E. | C.R. | P | Label |
|---|---|---|---|---|---|---|---|
| Firm_cap | <--- | Digital_initiative | .279 | .161 | 1.733 | .083 | |
| Firm_cap | <--- | Sus_initiative | -.223 | .137 | -1.626 | .104 | |
| Inst_pressure | <--- | Sus_initiative | .690 | .034 | 20.452 | *** | |
| R_D | <--- | Digital_initiative | .221 | .070 | 3.156 | .002 | |
| Env_perfor | <--- | R_D | 1.002 | .032 | 31.604 | *** | |
| Env_perfor | <--- | Digital_initiative | .199 | .048 | 4.123 | *** | |
| Env_perfor | <--- | Firm_cap | .206 | .044 | 4.669 | *** | |
| Env_perfor | <--- | Sus_initiative | .259 | .056 | 4.620 | *** | |
| Env_perfor | <--- | Inst_pressure | -.134 | .082 | -1.626 | .104 | |

H1a: Digital Initiatives Have a Positive Impact on Firm Environmental Performance
The regression analysis indicates that digital initiatives significantly influence firm environmental performance, with a coefficient of 0.199 and a p-value of less than 0.001. The positive coefficient suggests that as firms engage in digital initiatives, their environmental performance improves. The low p-value confirms that this effect is statistically significant, providing strong support for H1a. This implies that digitalization, such as adopting smart technologies, automation, and data-driven environmental strategies, contributes to a firm's ability to achieve better sustainability outcomes.

H1b: Sustainability Initiatives Have a Positive Impact on Firm Environmental Performance
The regression results show a significant positive relationship between sustainability initiatives and firm environmental performance, with a coefficient of 0.259 and a p-value of less than 0.001. This supports H1b, indicating that firms implementing sustainability-focused strategies, such as green energy adoption, waste reduction, and corporate social responsibility (CSR) programs, experience enhanced environmental performance. This suggests that sustainability initiatives play a crucial role in driving ecological improvements within firms.

H2a: Digital Initiatives Positively Influence Firm Capabilities
The coefficient for the relationship between digital initiatives and firm capabilities is 0.279, but the p-value is 0.083, which is above the conventional significance level of 0.05. While the coefficient is positive, suggesting that digital initiatives may contribute to enhancing firm capabilities, the lack of statistical significance means there is insufficient evidence to confirm H2a. This implies that while digital adoption might support firm capabilities, other factors could be influencing this relationship, requiring further investigation.

H2b: Sustainability Initiatives Positively Influence Firm Capabilities
The regression coefficient for the relationship between sustainability initiatives and firm capabilities is -0.223, with a p-value of 0.104, which is not statistically significant. Surprisingly, the coefficient is negative, suggesting that, in this context, sustainability initiatives do not enhance firm capabilities and might even hinder them. However, since the result is not statistically significant, we cannot conclusively confirm this negative effect. These findings challenge H2b, suggesting that firms investing in sustainability may not necessarily see direct improvements in their operational capabilities. Further research may be needed to explore potential indirect benefits or external factors affecting this relationship.

H3: Firm Capabilities Positively Influence Firm Environmental Performance
The regression results show a positive and significant effect of firm capabilities on environmental performance, with a coefficient of 0.206 and a p-value of less than 0.001. This confirms H3, indicating that firms with stronger capabilities—such as technological expertise, resource management, and strategic planning—are better positioned to achieve superior environmental performance. This highlights the importance of developing internal capabilities to enhance a firm's ability to implement sustainable practices effectively.
The findings provide strong support for H1a, H1b, and H3, confirming that digital and sustainability initiatives directly improve environmental performance and that firm capabilities further enhance it. However, H2a and H2b are not supported, indicating that digital and sustainability initiatives may not directly improve firm capabilities in this dataset. These results suggest that while digital and sustainability initiatives are crucial for environmental outcomes, their impact on internal firm capabilities may depend on additional factors.

**Table 5.13 Mediating effect of education**

| Path | Direct effects | Indirect effects | Total effects | Conclusion |
|---|---|---|---|---|
| Digital initiative >Firm capabilities > firm env. performance | 0.168* | 0.040* | 0.221** | Supported |
| Sustainability initiative >Firm capabilities > firm env. performance | 0.148* | 0.015* | 0.163* | Supported |

*****p<0.001, **p < 0.01, *, p < 0.05**

Digital Initiatives → Firm Capabilities → Firm Environmental Performance:

Both direct and indirect consequences demonstrate the connection between digital activities, business capabilities, and firm environmental performance. Digital initiatives had an indirect effect of 0.040*, mediated by company capabilities, and a direct effect of 0.168* on environmental performance, for a total effect of 0.221 ($p < 0.01$). Digital transformation improves environmental performance both directly and through capability development, as seen by the considerable indirect effect, which implies that company capacities partially mediate this link. Likewise, through business capabilities, sustainability activities also impact firm environmental performance.

Sustainability Initiatives → Firm Capabilities → Firm Environmental Performance:

Sustainability initiatives had an indirect effect of 0.015* and a direct effect of 0.148* on environmental performance, for a total effect of 0.163* ($p < 0.05$). Although the relatively minor indirect effect implies that sustainability programs may have a bigger direct impact than an indirect one through capability development, the significant indirect effect emphasizes the mediation importance of company capacities. In general, sustainability and digital activities both lead to better environmental performance, and business skills act as a partial mediator in these connections.

H4: R&D Investment Moderates the Relationship Between Digital Initiatives and Firm Environmental Performance

The regression results show that R&D investment significantly affects firm environmental performance ($\beta = 1.002$, $p < 0.001$) and is also influenced by digital initiatives ($\beta = 0.221$, $p = 0.002$). This suggests that R&D investment strengthens the relationship between digital initiatives and environmental performance. Firms that invest in R&D are likely to develop innovative digital solutions that optimize energy use, reduce waste, and enhance sustainability. Thus, H4 is supported.

H5: Institutional Pressure Moderates the Relationship Between Digital Initiatives and Firm Environmental Performance

The regression coefficient for institutional pressure on environmental performance is **-**0.134 ($p = 0.104$), indicating an insignificant effect. This suggests that institutional pressure, such as government regulations, industry norms, or stakeholder demands, does not significantly influence the impact of digital initiatives on environmental performance. It is possible that firms react to institutional pressures in varied ways, leading to inconsistent effects. Thus, H5 is not supported.

**Summary and Conclusion**

The findings highlight the importance of digital and sustainability initiatives in driving environmental performance. While **H1a, H1b, H3, and H4 are supported**, suggesting that digitalization, sustainability efforts, and R&D investment contribute to environmental outcomes, **H2a, H2b, and H5 are not supported**, indicating that firm capabilities do not significantly benefit from these initiatives, and institutional pressure does not moderate the digital-environmental relationship. Moreover, the mediation analysis confirms that firm capabilities act as a partial mediator, reinforcing the role of internal resources in sustaining environmental improvements. These findings provide valuable insights for businesses and policymakers aiming to enhance sustainability through digital transformation and innovation.

This study concludes that business capabilities influence the effects of sustainability and digital activities on environmental performance. The findings, however, cast doubt on the notion that sustainability and digitization initiatives inevitably improve business capacities and emphasize the need for more research. Furthermore, institutional pressure does not seem to have a major impact on the sustainability benefits of digitization, even though R&D spending enhances these benefits.

## CHAPTER ONE: INTRODUCTION

This is the first chapter of the study. The introduction section presents background to the research study, statement of the problem, research objectives and question, significance of the study, scope and overview of the research methodology and technical roadmap of the whole thesis.

### 1.1 Background of the Study

Steel is everywhere in our lives and homes. It has built the modern world and would be essential product as more mega infrastructure are being designed. In 2023, 97.65% of steel industry raw materials were converted into steel products or co-products (World Steel Association, 2023). The world's steel production has seen tremendous increase since 1950. In the 2023, 1892 million tonnes of steel were produced, while 1890 million tonnes was produced in 2022. According to the World Steel Association (2023) steel-producing companies rank, ArcekirMittal, a Kazakhstan company emerged as the second largest producer of steel in million tonnes (68.52) with China Baowu Group being ranked the number one. Globally, Kazakhstan is ranked 37$^{th}$ in terms of major steel production worldwide, and it produced 3.9million tonnes of steel in 2023 (WSA, 2024)

However, in recent years, the global steel industry has faced increasing pressure to adopt more sustainable practices and integrate innovative digital solutions. For instance, the number of injuries per million hours worked was 0.76 for employees and contractors combine in 2023 (World Steel Association, 2024). Also, the World Steel Association sustainability indicator revealed that in 2022, 1.91 tonnes of CO2 were emitted per tonne of crude steel cast, while the material efficiency and environmental management system represent 67.67% and 83.15% respectively. Moreover, United Nation's (2023) sustainability report discovered that steel production accounted for 7%- 9% of global $CO_2$ emissions.

Meanwhile, the steel sector, known for its resource-intensive processes and high carbon footprint, is now seeking pathways to improve efficiency, reduce environmental impact, and enhance competitiveness in an evolving industrial landscape (Miskiewicz & Wolniak, 2020). One major practical application has been the industry 4.0 and 5.0 concepts in the improving steel production strategies. Sarfraz et al. (2022) explored pathways to sustain steel production performance with innovative capabilities, green process and digital leadership. Their results have identified a significant correlation between innovation capabilities, green process innovation, and sustainable performance. Miskiewicz and Wolniak (2020) concluded that implementation of new solution based on digitalization caused increased energy and material efficiency in steel operations. Gajdzik and Wolniak (2021) established that digitalization determines the creation of new or modified products, processes, techniques and expansion of Poland Steel company's infrastructure and sustainability.

### 1.2 Statement of the Problem

Researchers (Grabowska & Saniuk, 2022; Stock & Seliger, 2016) on innovation and sustainability in the steel production is gaining attention, the but era of digital transformation is too dynamic. This requires regular and intense investigation on new strategies to meet the changing landscape of digitalization in steel production sector. For example, the growing environmental regulations, energy price volatility, and societal demands for responsible corporate practices, there is a need for steel manufacturers to innovate by adopting more sustainable methods. ArcelorMittal Temirtau, like many others in the sector, must strike a balance between increasing production efficiency and reducing environmental harm. Despite the global trend toward sustainability and digital transformation, limited research has been done on how these changes are being implemented in the steel industry in Central Asia, particularly Kazakhstan. This study will address the knowledge gap by exploring how ArcelorMittal is leveraging digitalization to drive innovation and sustainability in the steel manufacturing sector.

### 1.3 Research Objective

The primary objectives of this study are:

I. To analyze the key innovation strategies adopted by ArcelorMittal Temirtau in its transition toward sustainability.
II. To explore the role of digital technologies in transforming production processes at ArcelorMittal Temirtau.
III. To evaluate the impact of ArcelorMittal Temirtau's sustainability and digitalization initiatives on environmental performance.

### 1.4 Research Question

This research will seek to answer the following questions:

I. What innovation strategies has ArcelorMittal Temirtau implemented to enhance sustainability?
II. How is ArcelorMittal Temirtau utilizing digital technologies to improve production processes?
III. What is the environmental impact of these digitalization and sustainability initiatives?

### 1.5 Importance of the Study

It is no doubt that a firm's innovation capabilities and strategies are essential for its survival in the business world (Sarfraz et al., 2022). In the era of industry 5.0, digital transformation is core part of growing and international organization. This makes this research significant as it contributes to:

- **Practical Contributions:** It will provide insights into how digitalization and sustainability can be integrated in resource-heavy industries like steel manufacturing, which will benefit industrial managers, policymakers, and sustainability advocates.
- **Industry Impact:** The findings can help steel manufacturers and other heavy industries understand the benefits and challenges of implementing digital transformation strategies, particularly in the context of sustainability.
- **Academic Contribution:** The research will contribute to the growing body of literature on digital innovation and sustainability within the industrial manufacturing sector, particularly in emerging markets like Kazakhstan.
- **Environmental Impact:** The study will highlight the potential environmental benefits of adopting sustainable production processes in a traditionally resource-intensive industry, aligning with global sustainability goals.

### 1.6 Scope of the Study

The study focuses on exploring the digital transformation and sustainability initiatives at ArcelorMittal Temirtau, specifically on its operations and performance in Kazakhstan. The research examines innovation strategies within the context of the steel manufacturing industry, using ArcelorMittal Temirtau as a representative single case. However, the recommendations from the study will have broader implications for the global steel industry.

### 1.7 Overview of the Research Methodology

This study employs an explanatory case study design, focusing on ArcelorMittal Temirtau's ((a steel manufacturing company) digitalization and sustainability initiatives in Kazakhstan. The case study approach allows for an in-depth examination of causal links between digital transformation, sustainability policies, and operational efficiency. The study applies Innovation Diffusion

Theory (IDT), Resource-Based View (RBV), and Institutional Theory to analyze the impact of digitalization and sustainability initiatives. The population consists of employees directly involved in digitalization and sustainability projects, including senior management, R&D personnel, operations managers, and environmental compliance officers. A purposive sampling technique ensures the selection of relevant experts, with 123 participants drawn from key departments. The study also applies inclusion criteria, requiring respondents to have at least three years of relevant experience. A structured questionnaire is the primary data collection tool. It consists of four sections covering respondent demographics, innovative strategies, digital transformation, and key research hypotheses. A 5-point Likert scale is used for measurement. The survey is administered online for convenience, with pilot testing conducted to ensure clarity and reliability. For data analysis, responses are screened using Excel and analyzed with SPSS and AMOS. Statistical techniques such as Cronbach's alpha reliability test, exploratory factor analysis (EFA), confirmatory factor analysis (CFA), structural equation modeling (SEM), and correlation analysis are applied. Ethical considerations include informed consent, confidentiality, and data protection. Participants are assured anonymity, and the organization will receive a copy of the final research findings.

### 1.8 Technical Roadmap of the Research

The study applies three theories and draw insights from empirical literature to answer the research questions and hypotheses. The research outlines plan to complete the study by involving departments, experts and employees within the ArcelorMittal Temirtau's. Overall, the project is grouped under six (6) main chapters.

Chapter 1 Introduction: The introduction section presents background to the research study, statement of the problem, research objectives and question, significance of the study, scope and overview of the research methodology and technical roadmap of the whole thesis.

**CHAPTER 2 LITERATURE REVIEW**

This chapter reviews relevant literature based on the key themes and research objectives. The literature is grouped under subsections such as conceptual and empirical review, review of theories and hypothesis development.

Chapter 3 ArcelorMittal Temirtau Profile: This section presents the background of ArcelorMittal Temirtau Company. It presents its steel operations and performance within the industry as well as innovative strategies. This section also helps to understand the company and the scope of the case study.

Chapter 4 Research Methodology: The fourth chapter outlines the research methodology for achieving the results. It comprises of the research design, population and sample size, data source and instrumentation, data collection procedure and analytical process.

Chapter 5 Results and Discussion: The fifth chapter analysis, present and discuss the data and results of the findings. Here, tables, charts and robust statistical analysis are used to present the key findings and answers to the research questions. The discussion draws comparison with existing literature and come out with new trends and innovative practices.

Chapter 6 Conclusion: This is the final chapter which provides general conclusion, summary and recommendation of the study. This section also presents the research limitations and suggest areas for further research and improvement.

## Chapter 2. Literature Review

This chapter reviews relevant literature based on the key themes and research objectives. The literature is grouped under subsections such as conceptual and empirical review, review of theories and hypothesis development.

### 2.1 Conceptual and Empirical Review

This section review and presents literature on the major concepts and articles on key thematic areas that the study focuses. The review includes explaining existing terminologies, variables, inconsistencies, major findings, methodologies and previous studies pattern of conclusion that are essential to build a theoretical justification for this research.

#### 2.1.1 Digital Transformation in the Steel Manufacturing

Digital transformation (DT) has emerged as a critical driver of innovation and competitiveness in the steel manufacturing industry. This review synthesizes insights from existing literature to explore the key themes, challenges, and opportunities associated with DT in this sector. The discussion is organized around dynamic capabilities, challenges and strategies, regional differences, and sustainability considerations.

Digital transformation (DT) is changing the organization's needs and strategies succeed. DT has been defined as "changes in ways of working, roles, and business offering caused by the adoption of digital technologies in an organization, or in the operation environment of the organization" (Parviainen et al., 2017). Indeed, DT can lead to profound changes in organizational operations, products, processes, and business models, which also require a change in organizational culture, leadership, mindsets, attitudes toward risks, and the propensity to accept ambiguity and constant change (Kane et al., 2015; Kraus et al., 2022). The concept of "Digital Transformation" is often associated with the impact of new disruptive technologies, such as Internet of Things, Augmented Reality, Virtual Reality, and Artificial Intelligence (Bonnet & Westerman, 2021). While digitalization involves the adoption of new technologies in the organization, DT represents the road map to successfully implement the organizational changes needed to effectively integrate technologies into organizational and business processes with the final aim to create value and increase

productivity (Verhoef et al., 2021).
In this context, it is increasingly important for steel manufacturers to proactively develop their strategies and capabilities to meet the changing business and regulatory requirements (Ostmeier & Strobel, 2022). According to Vial (2019), DT is a process that "aims to improve an entity by triggering significant changes to its properties through combinations of information, computing, communication, and connectivity technologies". Several studies highlight that DT is a multidimensional and multi-level process of radical changes that takes place through the combination of various enabling technologies that can influence both organization structure and processes (Nadkarni & Prügl, 2021; Van & Vanthienen, 2021). Accordingly, companies should adopt a holistic view to effectively understand and manage DT (Tekic & Koroteev, 2019).
Grabowska and Saniuk (2022) identified that Steel Manufacturers are implementing digital technologies such as Big Data, cloud computing, system integration, and technologies that support cybersecurity and all the pillars of Industry 4.0. Also, Gajdzik and Wolniak (2021) studied on the practical solutions of Industry 4.0 as applied in the Steel Company (Re Alloys company). They found that Steel Companies are implementing the new standards of Industry 4.0, such as production process digitalization or cloud computing, in order to improve production processes. Zhou (2015) asserted that the connection of machines and devices via the Internet and the digitalization of all production processes is crucial in the steel manufacturing process.
Digital technologies in the Polish metallurgical plants monitor the work in selected sections of production and operate basic technological equipment (monitor the parameters of equipment operation and control the work of equipment). The blast furnace is supervised and controlled by IT systems. Equipment in steel mills and rolling mills is equipped with sensors, which provide data on the processes and facilitate their control. In integrated steel mills (with BF + BOF technology), equipment with sensors forms network structures, called the Blast Furnace Network (Zhong et al., 2017).
For long-term resilience, process optimisation systems are based on maintenance schedules and on maximising resource availability and efficiency. Information systems used for resource intensity analysis are proactively oriented, i.e., they enable anticipation of upcoming problems (Gajdzik & Slaska, 2020). IC technologies also enhance collaboration between end users and original equipment manufacturers (OEM). In resource management, steel mills use IC systems with multiple modules. Systems, such as ERP, MES and CRM, provide data on resources, production, machine operation, products and customers. Expanded IC systems (ERP, CAx) are equipped with applications for documentation management, project management, production planning and scheduling and Business Intelligence (Gajdzik, 2014).
On the path to steelworks, IC technologies assist steelmakers in their roles. The examples of those roles are connected with for example fully and semi-autonomous robots, increased use of artificial intelligence, drones, augmented and mixed reality, virtual, 3D and 4D printing, digital twins and ever more innovative methods to transform organization (Gajdzik & Wolniak, 2021).
In the literature, there are many studies that indicate the positive effects of digitalization on steel manufacturing firms (Grabowska & Saniuk, 2022). The implementation of digitalization in an organization can achieve increased energy efficiency.
#### 2.1.1.1 Dynamic Capabilities and Digital Transformation
Dynamic capabilities are essential for steel manufacturing companies to successfully navigate the complexities of digital transformation. These capabilities enable firms to adapt to rapidly changing market conditions and customer needs (Park & Lee, 2024). A study on global steel companies identified specific dynamic capabilities, such as sensing, seizing, and reconfiguring opportunities, as critical for achieving digital transformation outcomes (Park & Lee, 2024). These capabilities are not only about adopting new technologies but also about fostering organizational agility and innovation. For instance, sensing capabilities involve monitoring market trends and customer demands, while seizing capabilities focus on leveraging digital tools to capitalize on opportunities. Reconfiguring capabilities ensure that firms can adapt their resources and processes to align with digital strategies (Park & Lee, 2024). These findings underscore the importance of building and maintaining dynamic capabilities to sustain competitiveness in the steel industry.
#### 2.1.1.2 Challenges and Strategies for Digital Transformation
The implementation of digital transformation in steel manufacturing is not without challenges. Common barriers include technological ambiguity, slow adoption rates, and the lack of a systematic implementation framework (Chirumalla et al., 2025). Many companies are still in the early stages of DT adoption, struggling to integrate digital technologies into their operations effectively (Chirumalla et al., 2025). Scholars have argued that the ARTO model, which categorizes critical factors into four groups: Awareness-related, Readiness-related, Technology Selection-related, and Operations-related factors (Chirumalla et al., 2025). This model provides a structured approach for companies to identify and address barriers to DT. For example, awareness-related factors emphasize the need for clear communication of DT goals and benefits, while readiness-related factors focus on developing the necessary organizational skills and infrastructure (Chirumalla et al., 2025).
#### 2.1.1.3 Regional Differences in Digital Transformation
Regional disparities play a significant role in the digital transformation of steel manufacturing companies, particularly in China. A systematic literature review highlights significant variations in digital progress across regions, with factors such as economic development, technological infrastructure, and government policies influencing the pace of DT adoption (Zou & Ali, 2024). For instance, companies in the eastern coastal regions of China tend to have better access to advanced technologies and digital

infrastructure compared to their counterparts in central and western regions (Zou & Ali, 2024). Studies have suggest that area-specific policies and targeted investments are essential. These measures can help create a more balanced growth trajectory and enhance the overall competitiveness of the Chinese manufacturing industry (Zou & Ali, 2024). Additionally, fostering collaboration between regions and leveraging shared resources can accelerate the digital transformation process.

**2.1.1.4 Sustainability and Digital Transformation**

The digitalization of manufacturing systems offers significant opportunities for improving sustainability in the steel industry. Digital technologies, such as smart sensors and data analytics, can enhance resource efficiency and reduce environmental impacts by optimizing production processes (Tomaschko et al., 2024). However, the adoption of these technologies also raises concerns about their life-cycle sustainability, including energy consumption and raw material usage (Tomaschko et al., 2024). Some researchers emphasize the need for holistic sustainability assessments that consider both the economic and environmental dimensions of digitalization (Tomaschko et al., 2024). Such assessments can help companies make informed decisions about technology adoption and ensure that digital transformation aligns with broader sustainability goals.

**2.1.1.5 Industry 4.0 and Digital Transformation in Steel Distribution**

The concept of Industry 4.0 has been instrumental in driving digital transformation in the steel distribution sector. A study focusing on Polish steel product distributors highlights the importance of Industry 4.0 pillars, such as cyber-physical systems and smart factories, in improving distribution processes and communication with customers (Gajdzik et al., 2023). Respondents in the study highly valued the role of Industry 4.0 technologies in enhancing storage and distribution efficiency (Gajdzik et al., 2023). The integration of Industry 4.0 technologies, such as artificial intelligence and process digitization, has also been shown to support business management processes in the steel industry. These technologies enable faster decision-making, improve information transparency, and promote strategic planning (Chrusciak et al., 2023). Table 2.2 provides a brief factors influencing digital transformation in the steel manufacturing sector.

**Table 2.2 Factors influencing digital transformation in steel manufacturing**

| Factors | Details | Source |
|---|---|---|
| Dynamic Capabilities | Sensing, seizing, and reconfiguring opportunities to adapt to market changes. | (Park & Lee, 2024 |
| Regional Disparities | Economic development, technological infrastructure, and government policies influence DT adoption. | Zou & Ali, 2024) |
| Sustainability Assessments | Holistic methods linking economic and environmental dimensions of digitalization. | (Tomaschko et al., 2024 |

**2.1.2 Innovation Strategies in the Steel Industry**

The steel industry is a cornerstone of modern industrial development, playing a critical role in infrastructure, construction, and manufacturing. However, the sector faces significant challenges, including environmental concerns, competitive pressures, and the need for sustainable practices (Khosravi et al., 2019). Innovation has emerged as a key driver for addressing these challenges and ensuring the industry's long-term viability. According to Nonaka (1991), innovation management factors consist of transformational leadership, resource management, organizational learning, school innovation, and the improvement of organizational performance. Azanaw (2025) referred to innovation strategies as the deliberate plans and approaches organizations use to develop and implement new ideas, products, services, or processes to gain a competitive advantage. Innovation management is a structured process that enables an organization to perceive new ways to create value. Innovation management could be analyzed in terms of the "ability to effectively acquire and exploit new information" (Chaston, Badger, & Sadler-Smith, 2001). According to Damanpour and Aravind (2012), managerial innovations are "new approaches in knowledge for performing the work of management and new processes that produce changes in the organization's strategy, structure, administrative procedures, and systems." Policymakers and management of today's institutions and enterprises need to leave a legacy of innovative ideas and pass them on to the next generation. But the question is "through which mechanisms"? this is a significant concern because the sustainability and improvement of today's innovation will be at risk if not correctly cultured. Scholars are increasingly researching models and structures to sustain innovation management across the globe. For instance, Khosravi et al. (2019) opined that managerial innovation had gained increased popularity in research and practice because of its positive effects on organizational renewal and performance. The significance of innovation management is unparalleled. Innovation management contributes to a longer-lasting competitive advantage that is difficult to replicate (Pisano & Teece, 2007).

**2.1.2.1 Technological Advancements**

Azanaw (2025) specifically mentioned that technological advancements have been at the forefront of innovation in the steel industry. These innovations aim to improve efficiency, reduce environmental impact, and enhance the quality of steel products. Manufacturers and academics have placed a lot of emphasis on creating high-performance steel alloys. Because of their exceptional strength, resilience, and adaptability, these alloys can be used in a variety of fields, such as renewable energy infrastructure, aircraft, and construction. For example, as a sustainable substitute for conventional materials, the fabrication of high-performance steel alloys from carbonized waste products, such as slag from coal-fired power plants, has been investigated (Azanaw, 2025). Prefabrication and modular construction techniques have gained traction in the steel industry as they offer improved efficiency and reduced waste. These methods involve the assembly of steel components in a factory before being transported to construction sites, where they are rapidly assembled. This approach not only reduces construction time but also minimizes the environmental impact by optimizing resource use (Azanaw, 2025). Moreover, digital twin technologies, which involve the creation of virtual models of physical assets, have revolutionized the steel industry. These technologies enable real-time monitoring, predictive maintenance, and optimized production processes. By integrating AI and machine learning, Digital Twin systems can predict potential failures, reduce downtime, and improve overall operational efficiency (Azanaw, 2025). Qian et al. (2024) researched on the use of hydrogen-based steelmaking which has emerged as a promising alternative to traditional blast furnace-basic oxygen furnace (BF-BOF) production routes. This method significantly reduces carbon emissions by using hydrogen instead of coal or natural gas in the reduction process. While the technology is still in its developmental stages, it holds the potential to transform the steel industry into a more sustainable sector (Qian et al., 2024).

**2.1.2.2 Sustainability and Environmental Innovations**

Today's steel innovation strategies do not focus on the technological aspect only. The innovation strategies take into consideration sustainable actions and environmental protection mechanisms. With a fact-finding research indicating that the steel industry is one of the largest contributors to greenhouse gas (GHG) emissions worldwide, making sustainability a critical focus area for innovation. Researchers and industry leaders have explored various strategies to reduce the environmental impact of steel production and consumption.

Carbon capture, utilization, and storage (CCUS) systems have been identified as a key technology for reducing GHG emissions in the steel industry. These systems capture carbon dioxide emissions during the steelmaking process and either store them underground or utilize them in other industrial applications. While the economic viability and scalability of CCUS technologies remain challenges, they offer a promising pathway toward a low-carbon future (Qian et al., 2024). Moreover, Xinfa et al. (2025) asserted that the adoption of circular economy principles has gained momentum in the steel industry, with a focus on recycling and reusing materials. Scrap steel recycling, for instance, has been identified as a critical component of sustainable steel production. By increasing the use of recycled materials, the industry can significantly reduce its reliance on virgin raw materials and lower its carbon footprint. Scholars have found government subsidies and policy incentives have help promote sustainable and healthy environmental practices in the steel industry (Cheung et al., 2021; Arens et al., 2018). For example, subsidies for low-carbon production methods and green technologies have encouraged steel manufacturers to adopt environmentally friendly practices. These incentives have been particularly effective in China, where the government has implemented policies to encourage the use of recycled materials and reduce carbon emissions (Xinfa et al., 2025).

**2.1.2.3 Digitalization and Industry 4.0 Innovations**

Digitalization has transformed the steel industry by enabling the integration of advanced technologies such as artificial intelligence, big data, and the Internet of Things (IoT). These technologies have enhanced operational efficiency, improved product quality, and facilitated the development of new business models. Gajdzik & Wolniak (2021) used secondary data to examine digitalisation and innovation in the steel industry in Poland. They established that cyber-physical systems (CPS) has been instrumental in driving digitalization in the steel industry. CPS involves the integration of physical systems with computational and communication capabilities, enabling real-time monitoring and control of production processes. This approach has been particularly effective in optimizing resource use and reducing waste. Agazu and Kero (2024) asserted that the

use of big data and analytics has revolutionized decision-making processes in the steel industry. By leveraging data from various sources, including sensors, machines, and supply chains, manufacturers can identify trends, predict potential issues, and make informed decisions. This data-driven approach has been critical in improving operational efficiency and reducing costs (Gajdzik & Wolniak, 2021). Companies that adopt digital technologies are better positioned to compete in a rapidly changing market. For instance, the use of digital tools has enabled companies to develop new products, improve customer relationships, and enhance their overall competitiveness (Agazu & Kero, 2024)

**2.1.2.4 Supply Chain and Operational Innovations**

Innovation in the steel industry is not limited to production processes; it also extends to supply chain management and operational practices. Nowadays, manufacturing firms use agile supply chain innovation strategies aim to improve efficiency, reduce costs, and enhance customer satisfaction. Tizroo et al. (2017) proposed agile supply chain strategies as a means of responding to the dynamic and ever-changing needs of the market. These strategies involve the integration of balance scorecard (BSC) and interpretive structural modeling (ISM) frameworks to identify and prioritize agility factors in the supply chain. Steel companies can improve their responsiveness to market demands and enhance their overall performance (Tizroo et al., 2017). In the perspective of Hakanen (2015), collaborative innovation has emerged as a key driver of success in the steel industry. By working together with customers, suppliers, and other stakeholders, companies can identify new opportunities for innovation and develop tailored solutions to meet specific needs. This approach has been particularly effective in driving the development of high-value-added steel products. Thirdly, studies have found that lean manufacturing principles have been widely adopted in the steel industry as a means of reducing waste and improving efficiency. This approach is about focusing on continuous improvement and eliminating non-value-adding activities, companies can optimize their production processes and reduce costs. Lean manufacturing has been particularly effective in improving the overall competitiveness of steel companies (Ananthapadmanaban, 2023).

Innovation has emerged as a key driver of success in the steel industry, enabling companies to address challenges, improve efficiency, and enhance competitiveness. Technological, sustainability, digital, and business model innovations have been at the forefront of this transformation. The future of the steel industry will be shaped by a combination of technological, strategic, and operational innovations. In Table 2.1, the study summarizes the main innovation strategies that could improve steel manufacturing industry.

**Table 2.1 Innovation strategies in the steel manufacturing industry**

| Innovation Strategy | Description | Source |
|---|---|---|
| High-Performance Steel Alloys | Development of alloys with superior strength and durability for diverse applications | (Azanaw, 2025) |
| Hydrogen-Based Steelmaking | Reduction of carbon emissions through the use of hydrogen in steel production | (Qian et al., 2024) |
| Digital Twin Technologies | Real-time monitoring and predictive maintenance using AI and machine learning | (Azanaw, 2025) |
| Circular Economy and Recycling | Promotion of recycling and reuse of materials to reduce waste and emissions | (Xinfa et al., 2025) (Qian et al., 2024) |
| Agile Supply Chain Strategies | Improved responsiveness to market demands through agile practices | (Tizroo et al., 2017) |
| Value-Added Differentiation | Development of specialized steel products to differentiate in the market | (Blitz, 2017) |
| Government Subsidies and Policies | Incentives for low-carbon production and green technologies | (Xinfa et al., 2025) |

### 2.1.3 Sustainability Strategies and Initiatives in the Steel Production

The steel industry is a critical component in the modern infrastructure development, yet it production process contributes to 7-9% of global emissions (Adhikari & Khanam, 2024; Qian et al., 2024). The imperative to transition toward sustainable steel production has led to a proliferation of research and initiatives aimed at reducing environmental impact while maintaining economic viability. This review synthesizes the latest literature on sustainability strategies and initiatives in the steel production sector, focusing on decarbonization, energy efficiency, circular economy principles, and the integration of environmental, social, and governance (ESG) frameworks.

In the current environment, firms' viable innovative resources are critical regarding a country's ability to achieve progress sustain in the international market. Sazfraz et al. (2022) study found that an increasing environmental concerns have made it necessary for manufacturing firms to adopt sustainable innovation practices. As such, the literature suggests that the high ecological demand has encouraged organizations to practice green innovation (e.g. process and product) to sustain their viability in the fast-growing business environment (Chien et al., 2021).

Hilkenmeier et al. (2021) suggests that organizations have widely realized the significance of innovative offerings (capabilities) as the engine for an organization's growth. According to Chien et al. (2021), firms have therefore developed innovation capabilities as a vital source of incrementing their business success and sustainability. An organization's innovative resources play a strategic role in fostering its progress. Indeed, to ensure sustainability in the current business environment, a study from Pakistan shows that innovative services significantly accelerate a firm's performance (Kiani et al, 2019; Abdullah et al., 2019). Firms have fostered their innovation capabilities based on a sustainability paradigm. The firms' innovation capabilities offset the burdens of ecological vulnerabilities, thus exhibiting sustainable strategies and performance. The innovation capabilities create potential value for the firms' process, leading to firms' sustainable performance (Tseng et al., 2019). Meanwhile, the firms' innovation capabilities ensure the company's successful functioning. The concept of fostering the firms' innovation encourages the firms to integrate novel capabilities (e.g., strategic and technological), bolstering firms' long-term sustainability and digital transformation (Ajaz et al., 2020). The review of several articles point out that considerable attention has been given to firms' innovation capability that establishes their performance and long-term survival. This cut across several industries and sectors of which the steel sector matters equally.

#### 2.1.3.1 Decarbonization Strategies

Decarbonization is a central theme in the quest for sustainable steel production. The steel industry's reliance on fossil fuels, particularly coal, in traditional blast furnace-basic oxygen furnace (BF-BOF) processes, makes it a significant emitter of CO2. Recent advancements in decarbonization strategies include the use of hydrogen as a reducing agent, carbon capture, utilization, and storage (CCUS) technologies, and the adoption of electric arc furnace (EAF) and direct reduced iron (DRI) processes (Roos, 2024;

Diez et al., 2023).
Green hydrogen, produced using renewable energy, has emerged as a promising alternative to conventional fossil fuels in DRI production. Studies indicate that green hydrogen can reduce CO2 emissions by up to 90% compared to traditional methods (Roos, 2024) (Diez et al., 2023). However, challenges such as high production costs, energy efficiency concerns, and infrastructure limitations hinder widespread adoption. Addressing these barriers requires significant investment in infrastructure and research (Johnson et al., 2023). Also, Diez et al. (2023) emphasized on Carbon Capture, Utilization, and Storage (CCUS) technologies for reducing emissions from existing steel plants. These systems capture CO2 emissions, utilize them in industrial processes, or store them underground. While CCUS is effective, its scalability and economic viability remain uncertain, particularly in developing regions. Roos (2024) suggest that Electric Arc Furnace (EAF) and Direct Reduced Iron (DRI) Processes offer lower carbon footprints compared to BF-BOF processes. For instance, DRI production using green hydrogen achieves over 90% CO2 reduction per ton of DRI (Diez et al., 2023). These technologies are increasingly being adopted as part of the transition to green steel.
Similar approach, energy efficiency is another critical area of focus for sustainable steel production. Enhancing energy efficiency not only reduces emissions but also lowers production costs. Recent advancements include process optimization, waste heat recovery, and the integration of renewable energy sources (Yuan et al., 2024). Modern steel plants are increasingly adopting advanced process control systems and waste heat recovery technologies to minimize energy consumption. For example, waste heat from blast furnaces can be reused in power generation or other industrial processes, significantly improving overall energy efficiency (Yuan et al., 2024). The use of renewable energy, such as wind and solar power, is being explored to reduce dependence on fossil fuels. However, the intermittent nature of renewable energy poses challenges for continuous steel production, necessitating the development of energy storage solutions (Adhikari & Khanam, 2024; Yuan et al., 2024).

**2.1.3.2 Circular Economy and Recycling**

The circular economy concept is gaining space in the steel industry, emphasizing resource efficiency and waste reduction. Recycling and the reuse of steel scrap are key strategies for reducing the environmental footprint of steel production (Vaz et al., 2023; Andreotti et al., 2023). Recycling steel scrap reduces the need for virgin raw materials and lowers energy consumption. Advanced sorting and melting technologies are being developed to improve the quality and usability of recycled steel (Vaz et al., 2023). For example, slag, a byproduct of steel production, can be repurposed as a raw material in construction and other industries. In other methods,

**2.1.3.3 Environmental, Social, and Governance (ESG**

Environmental, Social, and Governance (ESG) principles into steel production is essential for achieving long-term sustainability. ESG frameworks address not only environmental concerns but also social and governance issues, ensuring that steel production aligns with global sustainability goals (Andreotti et al., 2023). These green steel refers to steel produced with minimal environmental impact, primarily through the use of renewable energy and low-carbon technologies. Leading steel producers are committing to green steel production as part of their ESG strategies (Vaz et al., 2023). ESG reporting in the annual Company’s report is becoming increasingly important for stakeholders, including investors and regulators. Wastewater management is another critical aspect of sustainability in the steel industry. Steel production generates large volumes of wastewater containing hazardous pollutants, which must be treated effectively to prevent environmental harm (Chalaris et al., 2023).

**2.1.3.4 Sustainable Development Goals (SDGs)**

The steel industry plays a pivotal role in achieving the United Nations' Sustainable Development Goals (SDGs), particularly SDG 6 (Clean Water), SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation, and Infrastructure), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action) (Andreotti et al., 2023). The European Union (EU) has initiated several programs to align the steel industry with SDG targets. These include roadmapping initiatives, eco-labelling, and R&D projects focused on sustainability (Andreotti et al., 2023). Despite progress, significant barriers to SDG implementation exist, including technological limitations, economic constraints, and regulatory challenges. Addressing these issues requires a coordinated effort from industry stakeholders, policymakers, and researchers (Andreotti et al., 2023).

Several frameworks and models have been proposed to guide the integration of sustainability and digitalization. For instance, the concept of "digital-sustainable business models" emphasizes the need for organizations to manage digitalization in a way that aligns with sustainability goals (Palmié et al., 2024). This approach involves balancing value creation, value delivery, and value capture while addressing the triple bottom line of economic, environmental, and social sustainability (Palmié et al., 2024). Another notable framework is the "digital sustainability paradigm," which identifies key dimensions such as strategy, innovation, technology, people, organization, and ecosystem partnerships (Hoang & Ho, 2024). These dimensions provide a foundation for understanding how digital transformation can contribute to sustainability and vice versa. Table 2.3 depicts sustainability strategies in the steel sector.

**Table 2.3: Comparison of Key Sustainability Strategies in Steel Production**

| Strategy | Description | Citation |
|---|---|---|
| Green Hydrogen | Reduces CO2 emissions by up to 90% in DRI production | (Roos, 2024) (Diez et al., 2023) |
| CCUS Technologies | Captures and utilizes CO2 emissions for industrial processes | (Qian et al., 2024) (Diez et al., 2023) |

| | | |
|---|---|---|
| EAF and DRI Processes | Lowers carbon footprint compared to BF-BOF processes | (Qian et al., 2024) (Diez et al., 2023) |
| Circular Economy | Emphasizes recycling and resource efficiency in steel production | (Vaz et al., 2023) (Andreotti et al., 2023) |
| ESG Principles | Integrates environmental, social, and governance practices into steel production | (Vaz et al., 2023) (Andreotti et al., 2023) |
| Advanced Wastewater Treatment | Removes hazardous pollutants with high efficiency | (Chalaris et al., 2023) |

### 2.1.4 Operational and Environmental Performance in Steel Manufacturing

The development towards Industry 4.0 has presently a substantial influence on the manufacturing industry. It is based on the establishment of smart factories, smart products and smart services embedded in an internet of things and of services also called industrial internet. In a manufacturing system, the intelligent cross-linking is realized by the application of so-called Cyber-Physical Systems (CPS) which are operating in a self-organized and decentralized manner (Stock & Seliger, 2016). The 4.0 framework examines the integration of advanced digital technologies, such as the Internet of Things (IoT), Artificial Intelligence (AI), and Big Data, into manufacturing processes to enhance efficiency and innovation. Studies have shown that Industry 4.0 adoption can lead to significant improvements in operational performance (Martinez et al., 2021).

In the 1930s and 1940s, the United States undertook the first attempts to quantify industry R&D operations as an economic phenomena. In 1953, industry started conducting regular statistical surveys of research and development (R&D) (Baranowski 2017). The creation of an architecture of reporting on R&D in numerous nations' sectors marked the conclusion of the previous century. Innovative research conducted in businesses was first reported statistically in the latter half of the 20th century. The OECD assumed responsibility for organizing the standards of data collecting in the 1960s. Guidelines for measuring and interpreting data on innovation activities were first developed by this group. Innovation metrics, including the Global Innovation Index (GII) were used to measure the activity levels of firms. The Innovation Union Scoreboard, formerly known as the European Innovation Scoreboard until 2009, is used within the EU. In certain industries, differentiating measures has also been implemented. The World Economic Forum's Global Competitiveness Report ranking serves as one illustration. Government, industry, or sector organizations create their own rankings or compilations based on innovation measures and indices, using information on businesses' R&D efforts. The rankings assess innovation activity at several economic levels, ranging from macro to micro. However, go-economies are not uniformly constructed; rather, development typically occurs unevenly within them, and research and development efforts are typically concentrated in specific areas, such as industry sectors. The dynamics of change in certain industrial sectors are fascinating, particularly in areas like steel that are crucial to the growth of countries.

#### 2.1.4.1 Lean Management and Operational Excellence

Lean management has emerged as a critical approach to enhancing operational efficiency and sustainability in the steel industry. Research indicates that lean practices, such as waste reduction and process optimization, can significantly improve environmental outcomes. For instance, lean waste management practices, supported by employee engagement, have been shown to enhance sustainable performance, aligning with ESG indicators and the Sustainable Development Goals (SDGs) (Thawornsujaritkul & Boonnual, 2024). However, the effectiveness of lean management is not without its complexities. Studies reveal that while high-performing employees can directly contribute to sustainability, their operational efficiency may reduce the measurable impact of lean practices on sustainability outcomes (Thawornsujaritkul & Boonnual, 2024).

#### 2.1.4.2 The Role of Employee Performance

Employee performance is a critical factor in achieving operational and environmental excellence. Studies demonstrate that employee engagement and continuous improvement practices can significantly enhance sustainability outcomes (Thawornsujaritkul & Boonnual, 2024). However, the moderating role of employee performance on the relationship between lean management and sustainability highlights the complexity of human factors in operational strategies (Thawornsujaritkul & Boonnual, 2024).

#### 2.1.4.3 Standardized Sustainability Metrics

The development of standardized environmental sustainability indicators is essential for assessing and improving performance in the steel industry. Research emphasizes the importance of transparent and standardized metrics to ensure accountability and stakeholder trust (Tolettini & Maria, 2023). These indicators should be integrated into supply chain practices to foster collaboration and drive sustainability efforts.

#### 2.1.4.4 Energy Efficiency and Operational Optimization

Improving energy efficiency is a direct and cost-effective approach to reducing emissions and achieving sustainability in steel production. Various methods, including process simulation, production planning, and scheduling, have been explored to optimize energy use (Zhaojun et al., 2021) (Yuan et al., 2024). However, the fragmented nature of these techniques underscores the need for a more integrated and systematic approach to energy management.

### 2.1.5 Technological Innovations for Sustainability

Technological advancements, such as the use of hydrogen as a renewable fuel and the adoption of Industry 4.0, offer promising solutions to the environmental challenges faced by the steel industry. A systematic review highlights the potential of these technologies to reduce harmful emissions and improve resource efficiency ("Sustainability of the Steel Industry: A Systematic Review", 2023). Additionally, the integration of artificial intelligence and smart energy systems can optimize production processes, leading to better environmental outcomes (Yuan et al., 2024).

Furthermore, **s**ustainable supply chain management (SSCM) plays a pivotal role in enhancing environmental performance in the steel industry. Research identifies scrap recycling and resource-efficient product design as key criteria for SSCM performance. These practices not only reduce resource consumption but also align with broader sustainability goals. The implementation of SSCM is particularly critical in emerging economies, where steel manufacturing is a significant contributor to economic development.

## 2.2 Theoretical Review

This study uses the innovation diffusion theory, resources-based view theory, and industry 4.0 digital transformation concept to explain innovation and sustainability strategies in Steel manufacturing ArcelorMittal in Kazakhstan.

### 2.2.1 Innovation Diffusion Theory

Over the past two decades, the IDT theory has been one of the most applied theoretical models used to investigate the organizational adoption of IS innovation in different disciplines (Akin et al., 2014). This theory believes that innovation adoption in an organization is affected by characteristics of innovation and institutional features. On the other hand, the IDT framework was proposed to explain the process of innovation adoption of different types of innovations in the organizational level (Baragash & Al-Samarraie, 2018). Theorists of this framework introduced three main organizational determinants that facilitate the adoption of new technologies in organizations which includes the environmental context, the technological context and the organizational context (Al-Samarraie & Saeed, 2018). The Innovation Diffusion Theory can be applied to assess how quickly digitalization and sustainability innovations are adopted within ArcelorMittal Temirtau. It helps to explore how innovation spreads throughout the company and whether employees or stakeholders act as early adopters or laggards.

ArcelorMittal Temirtau, a leading steel producer in Kazakhstan, has increasingly embraced sustainability and digitalization initiatives to enhance operational efficiency and environmental performance. The adoption of digital technologies (e.g., automation, artificial intelligence, and predictive analytics) and sustainable practices (e.g., carbon footprint reduction, energy-efficient production) represents a significant transformation in the company's operations. To analyze the adoption process and impact of these innovations, Innovation Diffusion Theory (IDT) (Rogers, 1962) provides a useful framework. IDT explains how new ideas, technologies, and practices spread within an organization or society, emphasizing key factors influencing their adoption. This paper explores the relevance of IDT in understanding the adoption of sustainability and digitalization strategies at ArcelorMittal Temirtau and their implications for operational efficiency and environmental performance. Innovation Diffusion Theory (IDT), developed by Everett Rogers (1962), explains how innovations spread within an organization or across a social system. According to IDT, the adoption of an innovation depends on five key attributes:

a) **Relative Advantage** – The perceived benefits of the innovation compared to existing practices.
b) **Compatibility** – How well the innovation aligns with existing values, processes, and infrastructure.
c) **Complexity** – The ease or difficulty of understanding and using the innovation.
d) **Trialability** – The extent to which an innovation can be tested before full implementation.
e) **Observability** – The visibility of an innovation's benefits to potential adopters

Digitalization and sustainability technologies are spreading throughout the industrial sector in accordance with IDT-predicted trends. The steel industry's ability to successfully deploy AI-driven automation, green technology, and smart production hinges on how companies like ArcelorMittal Temirtau view, test, and embrace these breakthroughs. Digitalization spreads in stages, with certain businesses adopting cutting-edge technologies sooner than others, according to research on Industry 4.0 adoption (Schwab, 2016). Research shows that businesses who use IoT-based monitoring systems and AI-driven predictive maintenance report lower downtime and higher efficiency (Frank et al., 2019). In terms of complexity, employee training issues and upfront implementation expenses are obstacles to high-tech adoption (Sony & Naik, 2020). In the aspect of trialability and observability, businesses can evaluate viability with the use of pilot initiatives like digital twins and automation trials (Kagermann et al., 2013).

### 2.2.2 Resource-based View

RBV focuses on a company's internal resources and capabilities as key drivers of competitive advantage. A major premise of the resource-based theory is that competitive advantage is a function of the resources and capabilities of the firm (Wernerfelt, 1984; Conner, 1991). In the context of ArcelorMittal Temirtau, the company's ability to leverage internal assets (e.g., technological infrastructure, skilled workforce) is critical for successfully implementing digital transformation and sustainability strategies. This theory can explain how the firm's technological capabilities and human resources contribute to innovations that enhance sustainability and operational efficiency.

The Resource-Based View (RBV) theory, proposed by Barney (1991), is relevant to this study as it focuses on how a firm's internal resources and capabilities contribute to competitive advantage and operational efficiency. In the context of ArcelorMittal Temirtau, the company's digitalization and sustainability initiatives can be considered valuable, rare, inimitable, and non-substitutable (VRIN) resources that enhance efficiency and environmental sustainability. According to the RBV theory, a company's performance is influenced by its internal resources, which can be both material (like technology and infrastructure) and immaterial (like knowledge and innovation culture). Research indicates that companies with a focus on sustainability that use digital technology as a strategic tool do better than their rivals in terms of productivity and adherence to regulations (Hart & Dowell, 2011).

Several authors have investigated on digitalization as a rare resource for today's firms that compete global. Teece's (2018) research indicates that companies that invest in digital capabilities (such as big data analytics and the Internet of Things) acquire a long-term competitive edge by improving operational efficiency and agility. Also, the ability to sustain valuable resources and compete is uncommon. As an extension of RBV, Hart (1995) presented the Natural Resource-Based View (NRBV), which highlights that businesses that implement green practices save money, reduce emissions, and achieve long-term sustainability. A study by Jabbour et al. (2020) revealed that businesses that use digital sustainability frameworks improve environmental impact and productivity.

**2.2.3 Institutional Theory**

The concept of institution was for a long time considered a mainstay in the field of sociology (Barley & Tolbert, 1997), but it was not until the end of the 1970s that it began to attract the attention of organizational researchers (Meyer and Rowan, 1977; Zucker, 1977, 1983; DiMaggio and Powell, 1983, 1991). The institutional theory explains how an organization's behaviors and actions work. According to institutional theory, the external environment, actions, and behaviors such as law and regulation, values and norms, and culture and expectations, have a significant impact on businesses (DiMaggio & Powell, 1983) (Heugens & Lander, 2009). According to the theoretical framework, organizations are ingrained in a web of values, norms, rules, and beliefs that guide their behavior and practices. These cultural elements (institutions) are, in fact, social constructions that stabilize over time and provide legitimate action scripts (Badar, 2020). Researchers Meyer and Rowan laid the ground rules on institutional theory, and their research found out that when organizations align their structures with the institutional context, they gain legitimacy, resources, stability, and a better chance of survival (Meyer & Rowan, 1977).

Moreover, The Institutional Theory (DiMaggio & Powell, 1983) describes how businesses respond to external constraints from society, regulatory agencies, and market expectations by implementing sustainability and digitization initiatives. ArcelorMittal Temirtau's adoption of sustainability and digitization initiatives can be viewed as a reaction to institutional factors rather than merely an internal strategy decision, given that the company operates in the highly regulated steel industry. The extent of firms or organization's respond depends on the institutional pressures, which varies in nature and can be classified as coercive, normative, or mimetic. Furthermore, these pressures may come from various stakeholders, including government agencies, suppliers, customers, and non-governmental organizations. The research done by Dimaggio and Powell (1983) divided into the three mechanisms classified above (normative, coercive, and mimetic pressures). Regarding agriculture and farmers, research on institutional pressures has primarily been made about green practices to protect the environment (Saeed, Jun, Nubuor, Priyankara, & Jayasuriya, 2018) (Li, 2014). With the existence of regulatory (coercive), market (normative), and competitive (mimetic) pressures, small agricultural businesses are being required to think beyond traditional production processes and organizational boundaries by integrating new concerns into their operations (Gricelda Juárez-Luis 1, 2018).

**2.2.3.1 Normative pressure**

Normative pressures are social pressures placed on organizations and members to conform to certain norms. The importance given to the phenomenon of professionalization; distinguishes normative pressure from the rest at the analytical level. Professionalization is defined here as all of the collective efforts of members of a profession to define their working conditions and methods and establish a legal basis for their activities, ensuring them a sufficient degree of autonomy. DiMaggio and Powell proposed that normative pressures are generated by various groups associated with professionalization, such as educational institutions promoting cognitive behavior, professionals from industry groups and associations, or nongovernmental organizations with interest in a specific industry. However, a growing body of empirical evidence suggests that clients are a crucial component of these pressures because they have a direct or indirect interest in the organization (Saeed, Jun, Nubuor, Priyankara, & Jayasuriya, 2018).

**2.2.3.2 Coercive pressure**

Coercive pressures are a collection of formal and informal pressures applied to an organization by other organizations on which it is dependent and cultural and societal expectations (DiMaggio & Powell, 1983). Coercive pressure is exerted by external stakeholders like government authorities and non-governmental organizations. These pressures are frequently associated with formal institutions such as regulations or laws, but they can also be informal expectations placed on organizations. According to this viewpoint, new political and legislative rules are more likely to enforce organizational change; for example, implementing new environmental regulations frequently forces organizations to innovate. Governments have however let down the African smallholder farmers as efforts to support this sector most of the time fail to meet the needs and demands.

**2.2.3.3 Mimetic pressure**

Mimetic pressure arises when companies compete for superior performance (DiMaggio & Powell, 1983). Mimetic pressures are demands for organizations to imitate other organizations in order to deal with uncertainty. Meyer and Rowan (1977), writing a few years before DiMaggio and Powell, observed that nothing beats the repetition of behaviors that have previously been perceived as efficient by the market; companies responding to mimetic pressures can obtain economic benefits by being more competitive. Mimetic pressures are thus expected to produce effective solutions at a lower cost.

### 2.3 Theoretical Application and Hypothesis Development

#### 2.3.1 Application of RBV, IDT and Institutional Theory to this Study

According to the Resource-Based View (RBV) paradigm, a company's internal resources both material (like technology and infrastructure) and immaterial (such knowledge and a culture that values innovation) have a big impact on how well it performs. According to research, companies that prioritize sustainability and use digital technology as a strategic asset typically outperform rivals in terms of productivity and adherence to regulations (Hart & Dowell, 2011). Teece (2018) emphasizes digitalization as a resource, contending that businesses that engage in digital capabilities like big data analytics and the Internet of Things gain a long-term competitive edge by increasing operational efficiency and agility. The Natural Resource-Based View (NRBV), which Hart (1995) adds to the RBV paradigm, highlights that businesses that use green practices can save money, reduce emissions, and achieve long-term sustainability. According to Jabbour et al. (2020), companies that use digital sustainability frameworks increase productivity while lowering their environmental effect, which lends more credence to this integration.

Furthermore, the Institutional Theory suggests that firms conform to external norms and regulations to gain legitimacy and ensure long-term survival (Scott, 2005). This research focuses on the **r**egulatory influence on sustainability, and digitalization as a response to institutional pressure. Empirical **r**esearch by Bansal & Roth (2000) highlights how industries with stringent environmental regulations adopt green strategies to comply with legal frameworks and avoid penalties. A study by Martin et al. (2019) found that steel and manufacturing firms integrate digital technologies (AI, IoT, blockchain) to meet global sustainability targets and operational efficiency benchmarks. Also, Wu et al. (2022) demonstrated that steel firms in China adopt eco-friendly digitalization measures due to government incentives and pressure from environmental watchdogs. Applying institutional theory to ArcelorMittal Temirtau, this study evaluates whether its sustainability and digitalization measures are driven by internal efficiency goals (RBV) or external compliance pressures (Institutional Theory)**.**

Digitalization and sustainability technologies are spreading throughout the industrial sector in accordance with IDT-predicted trends. The steel industry's ability to successfully deploy AI-driven automation, green technology, and smart production hinges on how companies like ArcelorMittal Temirtau view, test, and embrace these breakthroughs. Digitalization spreads in stages, with certain businesses adopting cutting-edge technologies sooner than others, according to research on Industry 4.0 adoption (Schwab, 2016). Research shows that businesses who use IoT-based monitoring systems and AI-driven predictive maintenance report lower downtime and higher efficiency (Frank et al., 2019). In terms of complexity, employee training issues and upfront implementation expenses are obstacles to high-tech adoption (Sony & Naik, 2020). In the aspect of trialability and observability, businesses can evaluate viability with the use of pilot initiatives like digital twins and automation trials (Kagermann et al., 2013).

#### 2.3.2 Theoretical Framework and Hypotheses Development

ArcelorMittal Temirtau, one of Kazakhstan's largest steel producers, has increasingly integrated sustainability and digitalization initiatives to improve operational efficiency and environmental performance**.** As industries globally transition toward smart manufacturing and green operations, understanding the impact of these initiatives is essential for business sustainability, regulatory compliance, and long-term competitive advantage. This study integrates three theoretical perspectives**:** Innovation Diffusion Theory (IDT), Resource-Based View (RBV), and Institutional Theory**.** IDT explains the adoption process of technological innovations. In the context of ArcelorMittal Temirtau, digitalization (e.g., artificial intelligence, automation, IoT-based monitoring) and sustainability initiatives (e.g., carbon capture technologies, green energy adoption) represent innovations whose diffusion follows IDT patterns. This theory is essential for the study as it explains how quickly and effectively ArcelorMittal Temirtau integrates digital and sustainable technologies into its production processes. Previous research has demonstrated that firms that adopt digital technologies early tend to achieve greater operational efficiency and environmental compliance (Frank et al., 2019). Therefore, IDT helps assess whether ArcelorMittal's adoption rate of digitalization and sustainability practices influences efficiency gains and environmental outcomes.

RBV highlights how internal resources shape efficiency, and Institutional Theory emphasizes external pressures driving organizational change. By combining these theories, the study presents a holistic framework to analyze how sustainability and digitalization affect ArcelorMittal Temirtau's performance. From an RBV perspective, digital transformation and sustainable practices can be seen as strategic resources that enhance operational performance. The VRIN framework (Valuable, Rare, Inimitable, and Non-substitutable) explains how firms like ArcelorMittal Temirtau can leverage digitalization and green technology as key assets to improve productivity, reduce waste, and lower costs. RBV is crucial in this study because it highlights the firm-specific capabilities that enhance both efficiency and sustainability. Firms that successfully integrate AI-driven manufacturing, energy-efficient furnaces, and digital supply chain management gain operational advantages that are difficult for competitors to replicate (Hart & Dowell, 2011). Therefore, RBV provides a framework to examine how ArcelorMittal leverages its internal digital and sustainability capabilities to drive efficiency and reduce environmental impact.

Institutional Theory (DiMaggio & Powell, 1983) explains how external pressures—regulatory, normative, and mimetic forces—drive organizational changes. The steel industry is heavily regulated, requiring firms to comply with emissions laws, environmental policies, and digital transformation mandates. Institutional forces also influence corporate social responsibility (CSR) commitments, forcing firms to adopt sustainable and digital solutions even when they are not purely profit-driven.

Institutional Theory is relevant because it explains why ArcelorMittal Temirtau adopts digitalization and sustainability measures beyond just efficiency improvements. Regulatory pressures (government policies, international standards), normative pressures (industry best practices), and mimetic pressures (competitor actions) all shape the company's decision-making process. Prior studies have shown that firms in environmentally sensitive industries adopt green and digital strategies due to increasing compliance requirements and stakeholder expectations (Bansal & Roth, 2000). Therefore, Institutional Theory helps analyze whether external pressures significantly drive ArcelorMittal's sustainability and digitalization efforts.

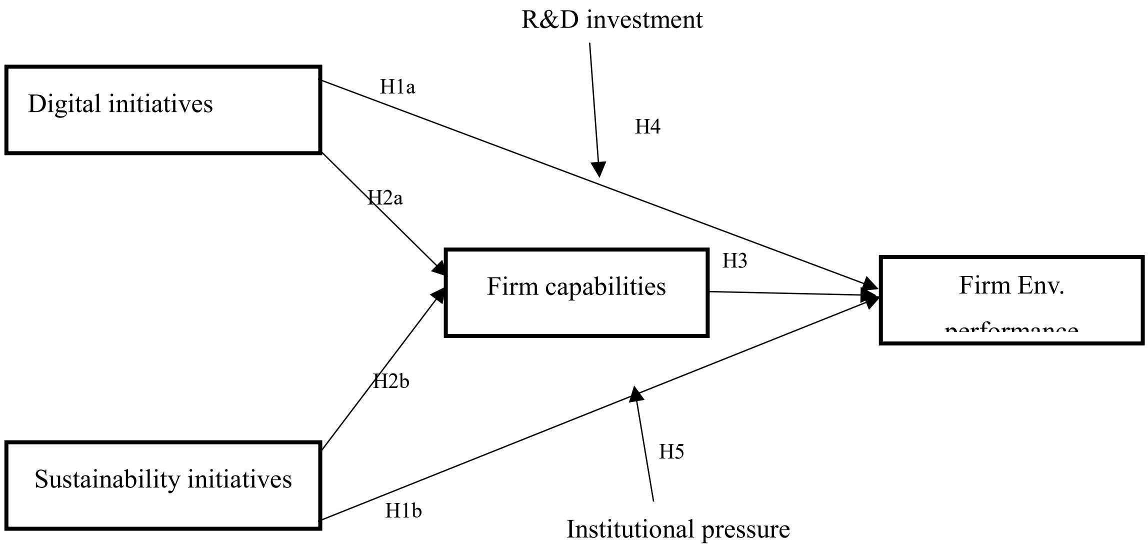



**Figure 2.1 Reseai**

Hypotheses

**H1a**: Digital initiatives have a positive impact on firm environmental performance.

**H1b**: Sustainability initiatives have a positive impact on firm environmental performance.

**H2a**: Digital initiatives positively influence firm capabilities.

**H2b**: Sustainability initiatives positively influence firm capabilities.

**H3**: Firm capabilities positively influence firm environmental performance.

**H4**: R&D investment moderates the relationship between digital initiatives and firm environmental performance

**H5**: Institutional pressure moderates the relationship between digital initiatives and firm environmental performance.

### 2.3.4 Operationalization of Constructs

The study empirically evaluates the impact of digitalization and sustainability on performance using these independent, dependent and moderating variables. The independent variables were digital initiatives and sustainability initiatives. The moderating factors include R&D investment and institutional pressure. Firm capability mediates the relationships between digital initiatives, sustainability initiatives and firm environmental performance. The main dependent variable is environmental performance. These variables were used to evaluates the company's performance by using statistical models, regression analysis, and case study insights to determine the relationships between digitalization, and sustainability.

The constructs were operationalize based on previous validated adoption questions and scale from scholarly literature. For instance, digitalization initiative was measured with Venkatesh et al., 2003, innovation diffusion theory guide, Bansal and Roth (2000) Corporate Environmental Sustainability Framework was used to operationalize sustainability initiatives. Also, DiMaggio & Powell (1983) Institutional Theory was the basis for formulating institutional pressure questions. Hsu et al. (2016) environmental performance index, Oslo manual on innovation measurement were used to measure R&D investment. Also, the study measures firm capabilities using Teece et al. (1997) dynamic capabilities framework.

Using reputable sources and accepted theoretical frameworks, Table xx offers a systematic questionnaire for evaluating firm-specific competences, R&D investment, institutional pressures, sustainability, digitization, and environmental performance.

| Variable | Question Item | Source |
|---|---|---|
| **Digitalization Initiatives** | Our company has adopted AI-driven technologies to optimize production processes. | Venkatesh et al. (2003) – UTAUT Model |
| | Automation has significantly improved our operational efficiency and reduced manual intervention. | |
| **Sustainability Initiatives** | Sustainability initiatives are integrated into our long-term business strategy. | Bansal & Roth (2000) – Corporate Environmental Sustainability Framework |
| | Renewable energy sources, such as solar and wind, are increasingly used in our operations. | |
| | The company has effective waste management policies to reduce environmental impact. | |
| **Institutional Pressures** | Regulatory requirements strongly influence our company's sustainability and digitalization strategies. | DiMaggio & Powell (1983) – Institutional Theory |
| | The company actively adjusts its operations to comply with environmental laws and policies. | |
| **Environmental Performance** | Our company has successfully reduced emissions through innovative sustainability practices. | Hsu et al. (2016) – Environmental Performance Index |
| | Energy efficiency improvements have led to measurable reductions in resource consumption. | |
| **R&D Investment** | Our firm collaborates with research institutions to enhance digital and sustainable solutions. | OECD (2005) – Oslo Manual on Innovation Measurement |
| | R&D efforts focus on developing environmentally friendly technologies. | |
| **Firm-Specific Capabilities** | Training programs are provided to enhance digital and environmental competencies. | Teece et al. (1997) – Dynamic Capabilities Framework |
| | Employees possess the skills required to manage and operate sustainable technologies. | |

## CHAPTER 3. ARCELORMITTAL TEMIRTAU STEEL INNOVATION

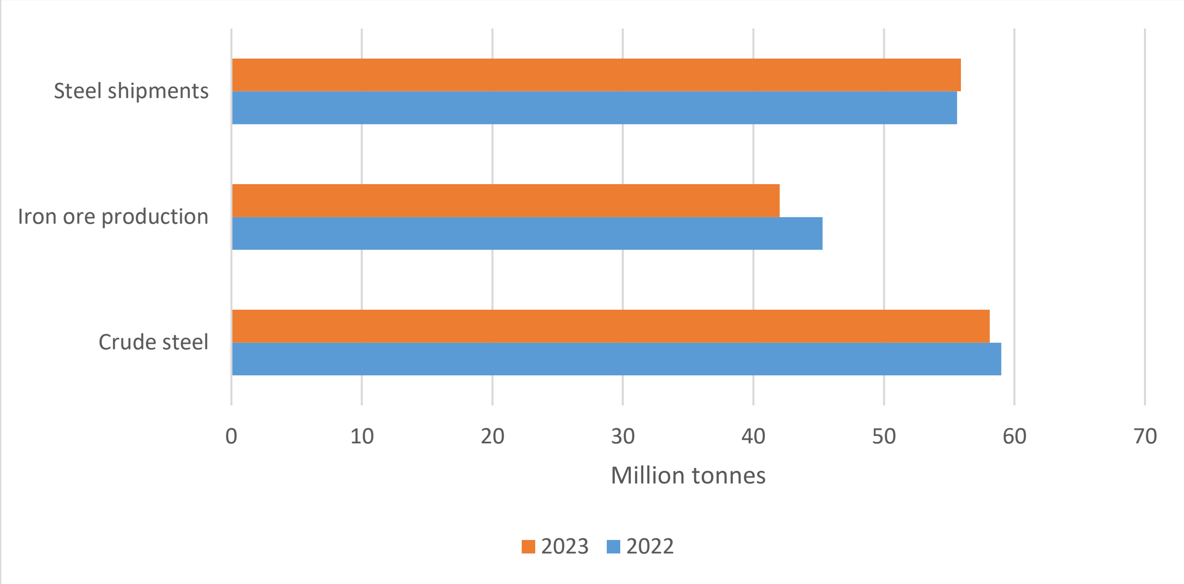
This section presents the background of ArcelorMittal Temirtau Company. It presents its steel operations and performance within the industry as well as innovative strategies. This section also helps to understand the company and the scope of the case study.

### 3.1 Company Background

This study focuses on a steel manufacturing firm in Kazakhstan called ArcelorMittal. The Company is one of the world's leading integrated steel and mining companies. ArcelorMittal is the largest steel producer in Europe and among the largest in the Americas, and a growing presence in Asia including India through its joint venture AMNS India. ArcelorMittal results from the merger in 2007 of its predecessor companies Mittal Steel Company N.V. and Arcelor, each of which had grown through acquisitions over many years. Since its creation ArcelorMittal has experienced periods of external growth as well as consolidation and deleveraging (including through divestment).

The foundation of ArcelorMittal's success is its adherence to the fundamental principles of sustainability, safety, quality, and leadership, as well as the entrepreneurial audacity that enabled it to become the first genuinely worldwide steel and mining corporation. The company has adjusted its footprint to the new demand realities, increased its efforts to control costs, and repositioned its operations with the goal of outperforming its competitors because it recognizes that a combination of structural issues and macroeconomic conditions will continue to challenge returns in its sector. ArcelorMittal has a robust capacity for research and development, which comprises a number of significant research facilities and solid academic alliances with academic institutions and other scientific associations. In light of this, ArcelorMittal's approach consists of utilizing four unique qualities that will allow it to seize top spots in the most desirable segments of the steel industry's value chain, from mining at one end to distribution and initial processing at the other: global reach and breadth; exceptional technological prowess; a varied steel and mining-related business portfolio; and financial capacity.

ArcelorMittal has steel-making operations in 15 countries, including 37 integrated and mini-mill steel-making facilities. As of December 31, 2023, ArcelorMittal had approximately 126,756 employees. ArcelorMittal produces a broad range of high-quality finished and semi-finished steel products (ArcelorMittal Annual Report, 2023).




**Source: ArcelorMitta Annual Report, 2023**

### 3.2 Sustainability Efforts

ArcelorMittal is dedicated to spearheading the sector's decarbonization initiatives and contributing to the global push to achieve net-zero emissions by 2050. The company has established a group goal to reduce its CO2 emissions intensity by 25% by 2030 and in its European operations by 35% by 2030 (scope 1 and 2 emissions) as a milestone to its 2050 net-zero ambition. Since the company places a strong emphasis on research and development ("R&D") to make sure ArcelorMittal is at the forefront of the evolution of steelmaking processes and products, innovation is essential to its success. To this end, the company has created the most comprehensive and adaptable suite of low-emissions steelmaking technologies in the industry, integrating them into two pathways: Innovative-DRI and Smart Carbon.

### 3.3 Digitalization and Innovation of ArcelorMittal Temirtau

Digitalization in steel production involves integrating advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data analytics, and automation to optimize manufacturing processes. According to Xu et al. (2020), digitalization enhances real-time monitoring, predictive maintenance, and quality control, leading to improved production efficiency. The adoption of smart manufacturing in steel industries has been widely recognized as a strategy to remain competitive in the evolving industrial landscape (Jin et al., 2021). According to recent studies, digitalization is revolutionizing industrial value chains by enabling predictive analytics, data-driven decision-making, and the adoption of smart manufacturing practices (Parida et al., 2019) (Branca et al., 2020). In the steel sector, digitalization focuses on two main areas: optimizing production chains and advancing low-carbon production technologies (Branca et al., 2020). The European steel industry, in particular, has embraced digitalization to enhance production efficiency and sustainability. Research indicates that digitalization is expected to play a pivotal role in achieving Industry 4.0 goals, which emphasize automation, connectivity, and data exchange (Herzog et al., 2017) (Branca et al., 2020). For instance, the use of IoT and advanced automation technologies has enabled real-time monitoring and control of production processes, leading to improved product quality and reduced costs (Herzog et al., 2017) (Skriko et al., 2022).

ArcelorMittal Temirtau has embraced Industry 4.0 technologies to improve its production capabilities. The company has invested in automated systems, real-time data analytics, and energy-efficient production processes to enhance operational efficiency and reduce environmental impact (Smith & Brown, 2022). One of the key innovations includes the deployment of machine learning algorithms to predict equipment failures, thus minimizing downtime and maintenance costs (Kumar et al., 2023). Additionally, the use of digital twins—virtual replicas of physical assets—has been integrated into the plant's operations to simulate and optimize production processes before implementation. Research by Miller (2022) highlights that digital twin technology enables manufacturers to enhance efficiency, reduce waste, and improve product quality in steel production. Sustainability is a critical focus for the steel industry, given its high energy consumption and carbon emissions. ArcelorMittal Temirtau has leveraged digitalization to optimize energy use and minimize environmental impact. Research by Zhang et al. (2021) suggests that AI-driven energy management systems can significantly reduce energy consumption and emissions in steel production. By integrating green technologies such as hydrogen-based steelmaking and carbon capture, ArcelorMittal Temirtau aims to align with global sustainability goals (Johnson & Lee, 2023). Despite the advantages of digitalization, challenges such as high implementation costs, cybersecurity risks, and workforce adaptation hinder full-scale adoption. According to Anderson et al. (2023), digital transformation in steel manufacturing requires significant investment in infrastructure and workforce training. Future research should focus on strategies to mitigate these challenges and further enhance digital integration in steel production. Digitalization and innovation are reshaping ArcelorMittal Temirtau's steel production, enhancing efficiency, sustainability, and competitiveness. While challenges persist, continued investment in smart manufacturing and emerging technologies will drive the company towards a more sustainable and technologically advanced future.

## CHAPTER 4. RESEARCH METHODOLOGY

The fourth chapter outline the research methodology for achieving the results. It comprises of the research design, population and sample size, data source and instrumentation, data collection procedure and analytical process.

### 4.1 Research Design

Tharenou et al. (2007) asserted that the research design is the overall plan to answer the research objectives. It forms an integral part of the research process. The main research designs include case study, action research, survey (correlational) experiments and others. Yin (2012) advised scholars to choose a design that suits the particular research questions. In this study, the research employs a case study, particularly an explanatory case study design that focuses on ArcelorMittal Temirtau's sustainability and digitalization initiatives on operational efficiency and environmental performance in Kazakhstan. A case study is "an empirical inquiry that investigates a contemporary phenomenon within its real-life context," (Yin, 2003). Case studies are empirical investigations that are carried out to analyze and explain processes involving units as small as individuals (e.g., medical case studies) or as large as nations (e.g. medical case studies). According to Lee et al. (1999) a case can be persons, groups, organisations, or non-human objects (e.g., products, policies,

Cases are frequently used in management research to examine occurrences that are unique, notable, unknown, and entail change (McCutcheon & Meredith, 1993). When unusual or extreme situations like organizational downsizing, mergers, or acquisitions need to be analyzed for their underlying processes, case studies can be helpful. It is also possible to conduct several case studies of these kinds of events to comprehend their mechanisms. In situations where there is a temporal dimension—where changes take place over time—cases are frequently used (Sommer & Sommer, 1991). The case study gives the researcher the chance to examine social processes as they take place in organizations since it frequently focuses on the processes of change.

#### 4.1.1 Justification of the Research Design

This research is especially well-suited for an explanatory case study since it enables a thorough examination of the causal links between performance outcomes, digital transformation, and sustainability policies. Given the intricacy of digitalization and industrial sustainability, this method offers a methodical framework for investigating the ways in which particular initiatives like automation, energy efficiency, and emission reduction technologies contribute to environmental sustainability and operational enhancements. Kazakhstan's industrial sector, which faces particular regulatory, environmental, and economic issues, might benefit from the context-specific insights this study captures. A thorough analysis of how company sustainability initiatives fit within national and international environmental regulations is made possible by the case study technique, which also provides insightful lessons for other industries operating in comparable environments.

This focus on causality distinguishes it from exploratory case studies, which are more concerned with generating hypotheses or understanding phenomena in a preliminary way (Haverland & Blatter, 2012). And this study focuses on a single organization to help obtain deeper understanding of the sustainability and digitalization issues within the organization as well as Kazakstan's industrial sector. The use of single case is very common. For Ray (2023), the single-case studies are typically used when the case is unique or when the researcher wants to gain an in-depth understanding of a particular phenomenon whereas multiple-case studies allow for cross-case comparisons and can enhance the generalizability of the findings.

Moreover, the application of three theories in this study champions an explanatory case study. Scholars have argued that explanatory case studies frequently use preexisting ideas as a framework for their research. Hypotheses are developed and the case analysis is organized using theoretical frameworks. This method enables researchers to evaluate theories' suitability in practical settings and to improve or develop them in light of the results (Blatter & Haverland, 2012). Similarly, this study integrates Innovation Diffusion Theory (IDT), Resource-Based View (RBV), and Institutional Theory to examine how digitalization and sustainability initiatives impact operational efficiency and environmental performance at ArcelorMittal Temirtau. Furthermore, explanatory case studies provide first-hand explanation to a phenomenon offering empirical support for the efficacy of ArcelorMittal Temirtau's sustainability initiatives, the study's conclusions will also provide useful suggestions for researchers, industry executives, and policymakers interested in sustainable industrial practices in Kazakhstan and elsewhere.

### 4.2 Population and Sampling

According to Agyedu et al. (2007), population refers to the complete set of individuals (subjects), objects, or events having common observable characteristics which the researcher is interested in studying. The research population for this study consists of employees within ArcelorMittal Temirtau, a steel manufacturing company in Kazakhstan, who are directly or indirectly involved in the implementation of digitalization and sustainability initiatives. The employees (workers) referred to in this research include senior management, sustainability officers, digital transformation teams, R&D personnel, operations managers, environmental compliance officers, and financial analysts within the organization umbrella.

### 4.3 Sampling Technique

Given the complexity and specificity of the study, a purposive sampling approach is employed. The researcher adopted this purposive approach to choose the participants because they are likely to generate useful data for the project. According to Bricki and Green (2018), purposive sampling ensures that the sample is credible, and covers the main groups in which the researcher is interested. This non-probability sampling method ensures that only key individuals with relevant expertise and experience in digital transformation, sustainability initiatives, and firm performance are selected for the study. The rationale behind using purposive sampling is to collect rich, context-specific data that would provide meaningful insights into the relationships between digitalization, sustainability, and environmental performance. Two levels of sampling are used in the study to guarantee a thorough viewpoint. First is the firm-level sampling where ArcelorMittal Temirtau is chosen as the sole case study since it is a prominent steel manufacturer in Kazakhstan that has implemented noteworthy digitalization and sustainability projects. An appropriate subject for assessing how these initiatives affect performance is the organization. Second applies to the respondent-level sampling. In the second level, expert participants are chosen from within the organization based on their participation in R&D, digital transformation, sustainability policies, and operational efficiency enhancements.

In the respondent sampling approach, the study adopted the inclusion and exclusion criteria to help gather reliable and credible information. The following are requirements for respondents to be included (a) three years or more of experience in pertinent positions within the organization; (b) and active participation in the formulation or execution of digitalization and sustainability projects; and (c) understanding how institutional and regulatory pressures impact the company's environmental performance. Despite the inclusion criteria set, a multi-stage sampling procedure is used to guarantee a targeted yet varied participant selection. First, the research identifies key departments within the company. The study identifies key departments that are essential to the operation of the business, including operations, finance, R&D, environmental sustainability, and digital transformation. Also, based on their areas of competence, volunteers are chosen from these departments using purposive sampling. If more pertinent experts are found during the data collection process, snowball sampling might be employed.

**Table 4.1 Sampling method and size**

| Department-focused | Purposive |
|---|---|
| Operations, R&D | 31 |
| Information and communications | 24 |
| Management /head | 15 |
| Technical staff | 32 |
| Legal, Finance and Human Resource | 21 |
| Total | 123 |

To ensure that only people with pertinent experience in digitalization, sustainability, and firm performance are involved, this study uses a purposive sampling technique to choose participants from important departments within ArcelorMittal Temirtau. There are 123 participants in all, spread throughout five important departments. With 31 responders, the Operations and R&D department provides the greatest percentage, indicating its crucial role in putting sustainability and digital efforts into action. Given its participation in digital transformation initiatives, the Information and Communications department comes in second with 24 participants. With 15 members, the management and executive leadership team offers strategic insights into institutional pressures and decision-making. This diverse yet targeted sample guarantees a thorough assessment of how digitalization and sustainability impact operational efficiency and environmental performance within the company. The Technical staff, which is in charge of implementing digital and environmental solutions, comprises 32 respondents, while the Legal, Finance, and Human Resource departments contribute 21 participants, offering perspectives on regulatory compliance, financial investment in sustainability, and workforce adaptation to digitalization.

### 4.4 Data Source

The instrument used to measure data largely depends on the type of data the researcher seeks to collect (Tharenou et al., 2007). While some information could be retrieved from online, organizational websites, company report, memorandum and published papers, some can be collected via original owner. Researchers thus group research data into secondary and primary data. Primary data is a first-hand (original) data directly from the owner (respondents). Such information is new and has not been used before or elsewhere. On the contrary, secondary data are re-used information, they are not first-time data. While both are equally useful depending on the research process, this study uses the primary source of data by employing structured questionnaire to collect the appropriate data from workers in ArcelorMittal Temirtau.

### 4.5 Questionnaire

Questionnaires usually used in data collection for the purpose of asking questions to ascertain people’s idea or thoughts and feelings about issues, events and behaviors (Tharenou et al. 2007). Tharenou et al. (2007) argued that questionnaires are highly structured instruments composed of pre-set standardised questions. According to Bryman (2004), questionnaires are tools that respondents themselves fill out. A common term for them is self-administered questionnaires. The most popular tool for gathering data in management research is the questionnaire. For assessing intangible constructs like attitudes, beliefs and preferences, intents, and personalities, they are frequently the most believable substitute and are reasonably simple to utilize and affordable (Moorman & Podsakoff, 1992). This study uses questionnaires as it can also be administered by hand or conducted online or by email making it more convenient. The data collection instrument (questionnaire) employed is suitable to generate quantitative data from the respondents or sample to test research questions and/or hypotheses set in this study.

The questionnaire instrument consists of four main parts [Section A-D] to address the research objectives. Section A is about the background of the respondents and study. It comprises of six (6) main question items with different response scale. Some of the variables include age of respondents, gender, education, number of years working, participation in the company's digitalization and sustainability initiatives. Section B presents questions on the innovative strategies of the ArcelorMittal Company. There are five question items [KS1-KS5] with 5-point response scale. In the Section C of the questionnaire, it explores the role of digital technologies in transforming production process at the Company using five question items [DT1 to DT5]. Lastly, Section D presents the questionnaires to evaluate the research hypotheses. The variables are six (6) categorical (digitalization, sustainability, firm capability, firm performance, institutional pressure, and R&D) and each variable is operationalized with five question items. The study uses 5-point Likert Response Scale as the keys.

### 4.6 Data Collection Procedure

In order to guarantee validity and reliability, the data collecting for this study is done in a methodical manner. Given the study's emphasis on ArcelorMittal Temirtau's digitization and sustainability activities, the main technique for gathering data is giving structured questionnaires to staff members in different departments. To guarantee effectiveness, accessibility, and convenience for participants, the survey will be administered online. In order to ensure that the questionnaire link reaches the intended responders while upholding professionalism and secrecy, it will be sent through official corporate emails and internal communication platforms. Prior to complete deployment, pilot testing will also be carried out to assess the questionnaire's efficacy, dependability, and clarity. For piloting, a small group of respondents ideally five employees from various departments were chosen. The questionnaire was modified as needed to increase its relevance and clarity in light of their input. To find more important people who fit the study's inclusion requirements but weren't initially chosen, snowball sampling may also be used. Responses to the online survey was accepted for four weeks, during which time there were follow-ups and reminders to promote participation.

### 4.7 Data Analytical Process

After the online survey was closed (not accepting responses any longer), the researcher screens the respondents' data with Ms. Excel and exported the data to Statistical Package for Social Science (SPSS). The research utilizes a quantitative data analysis methodology to extract significant insights from the gathered responses. Prior to statistical analysis, the information gathered via the questionnaire was cleansed and coded in SPSS. Demographic and category variables were summarized using descriptive statistics like mean, standard deviation, and frequency distributions to draw key insights. A robust quantitative analysis was conducted using several inferential statistical methods, such as Cronbach alpha reliability test, confirmatory factor analysis (CFA), exploratory factor analysis (EFA), structural equation method (SEM), and correlation analysis, to investigate the connections among environmental performance, operational efficiency, sustainability, and digitization. The questionnaire's constructs were validated by factor analysis. For data analysis, statistical software like SPSS and Analytical Moment of Structure (AMOS) were used to run all the required tests and statistical analysis. The interpretation, charts, tables and major findings were reported in APA 7th edition style.

### 4.8 Research Ethical Consideration

When conducting studies involving human subjects, researchers must adhere to recognized ethical standards and academic guidelines (Atkinson & Coffey, 1997). They asserted that scholars must brief and debrief participants of the option to refuse or discontinue their involvement in a research study. Researchers have argued that it utmost important to protect the integrity of the study by shredding and disposing of information that could link the organization, departments and respondents to the research project (Damianakis & Woodford, 2012; Fleming, 2015; Yin, 2012). Like other research design, case study research designs pose ethical issues and challenges to the investigation of people, and it ought to be concerned about guaranteeing that the interest of those participating in a study is not harmed or hurt (Halai, 2006). In the application of research ethical issues in the study, a coherent protocol was followed.

Sanchini et al. (2014) stated that an informed consent form outlines the procedures for obtaining the Company and respondents' willful and autonomous choice and understanding to participate in studies. First, informed consent were obtained from all participants before they complete the questionnaire. A clear introduction explains the study's purpose, objectives, voluntary participation, and the right to withdraw at any point without repercussions. Participants were assured that their responses remain confidential and used solely for academic purposes. Personal identifiers will be anonymized to protect the identities of respondents. Also, Pinfield (2014) revealed that researchers must use a process that avoids ethical and legal consequences when storing and securing sensitive research data. Bias and conflicts of interest will be minimized by ensuring that the data is objectively analyzed and reported. Finally, all findings will be presented transparently, and no data will be manipulated to favor specific outcomes, maintaining the credibility and integrity of the research. Robinson (2014) revealed that incentives could help motivate respondents. Zhao and Zhu (2014) declared that respondents could achieve intrinsic incentives when the expected research outcome is beneficial to the respondents. In this study, the participants and the Company were promised to get a copy of the final research project. This could lead to contributions to future research and practices of digitalization and sustainability the Company as well as steel manufacturing industry.

## CHAPTER 5 RESULTS AND DISCUSSION

This chapter presents the results of the questionnaire data analysis. The study uses descriptive statistics (mean, frequency, percent, standard deviation) and structural equation model (SEM) to analysis the data quantitatively. The study presents the analysis based on the research objectives and close guidance from the questionnaire. The results are grouped into background of the participants, descriptive analysis of research objective one and two, SEM analysis of research objective three and finally the discussion of the major findings or results.

### 5.1 Background Information of the Study

This section presents the background data of the participants and research environment. The main items discussed are respondents' biodata and background of employees' knowledge on sustainability in the Company or industry under consideration.

#### 5.1.1 Participants' biodata

The study presents detail information on participants' gender, age, educational level and number of years working in the industry/company. The major findings are shown in Table 5.1.

**Table 5.1 Respondents' background description**

| Variables | Items | Frequency | Percent (%) |
|---|---|---|---|
| Gender | Male | 63 | 51.2 |
| | Female | 60 | 48.8 |
| Age | 18-25 years | 16 | 13.0 |
| | 26-35 years | 73 | 59.3 |
| | 36-45 years' | 23 | 18.7 |
| | 46-55 years | 11 | 8.9 |
| Highest level of education | High school diploma/Certificate | 16 | 13.0 |
| | Bachelor degree | 73 | 59.3 |
| | Master's degree | 23 | 18.7 |
| | Doctorate Degree | 11 | 8.9 |
| Years of working in the industry | Less than 1 Year | 10 | 8.1 |
| | 1-5 years | 13 | 10.6 |
| | 6-10 years | 60 | 48.8 |
| | 11-15 years | 40 | 32.5 |

N=123

The demographic profile of the respondents, as presented in Table 5.1, reveals a nearly equal gender distribution, with 51.2% of the participants being male and 48.8% being female. The majority of respondents (59.3%) fall within the 26–35 years age bracket, followed by 18.7% in the 36–45 years category. A smaller proportion, 13.0%, are aged between 18 and 25 years, while the least represented age group is 46–55 years, comprising 8.9% of the sample. In terms of educational qualifications, the highest proportion of respondents (59.3%) hold a bachelor's degree, while 18.7% possess a master's degree. Additionally, 13.0% of participants have obtained a high school diploma or certificate, and 8.9% hold a doctorate degree. Regarding industry experience, nearly half of the respondents (48.8%) have worked in the sector for 6–10 years, while 32.5% have between 11 and 15 years of experience. A smaller percentage (10.6%) have worked for 1–5 years, and 8.1% have less than one year of industry experience.

#### 5.1.2 Involvement in Digitalization and Sustainability Initiatives

Table 5.2 illustrates the level of involvement of respondents in digitalization and sustainability initiatives. The data indicates that 51.2% of participants are directly engaged in the implementation of such initiatives, while 48.0% are occasionally involved in related projects. Only a negligible proportion (0.8%) are aware of these initiatives but not actively involved. This distribution suggests a high level of engagement among respondents in digitalization and sustainability efforts, with nearly all participants contributing in some capacity.

**Table 5.2 Involvement in Digitalization and Sustainability Initiatives**

| Items | Frequency | Percent |
|---|---|---|
| Directly involved in implementation | 63 | 51.2 |
| Occasionally involved in related projects | 59 | 48.0 |
| Aware but not actively involved | 1 | .8 |
| Total | 123 | 100.0 |

### 5.1.3 Participation in Training on Digitalization and Sustainability

As shown in Table 5.3, a significant proportion of respondents have undergone training on digitalization and sustainability. Specifically, 44.7% have participated in such training multiple times, while 54.5% have attended at least once. Only 0.8% of participants have not received any training but have expressed an interest in it. These findings indicate a strong awareness and engagement in capacity-building efforts related to digitalization and sustainability, highlighting the importance placed on continuous learning and professional development in this field.

**Table 5.3 Participation in training on digitalization and sustainability**

| Response items | Frequency | Percent |
|---|---|---|
| Yes, multiple times | 55 | 44.7 |
| Yes, once | 67 | 54.5 |
| No, but I am interested | 1 | .8 |
| Total | 123 | 100.0 |

## 5.2 Analyzing Innovation Strategies and Role of Technologies in ArcelorMittal

The descriptive mean statistics method is employed to analyze the responses related to innovation strategies and digital transformation initiatives roles at ArcelorMittal Temirtau. This method measures the central tendency of responses using the mean (average) value while also considering the standard deviation (SD) to indicate variability among respondents. The mean provides a numerical representation of how strongly respondents agree or disagree with specific statements, with higher values suggesting stronger agreement. Meanwhile, the standard deviation reflects the level of consensus among respondents, with lower values indicating greater consistency in responses. The use of descriptive mean statistics is justified in this study as it enables a straightforward interpretation of participants' perceptions regarding sustainability and digitalization initiatives.

### 5.2.1 Key innovation strategies adopted by ArcelorMittal Temirtau in its transition toward sustainability

As presented in Table 5.4, the mean values for all the key innovation strategies range between 3.81 and 3.91, indicating a generally positive perception of the company's sustainability initiatives. The highest-rated strategy is collaboration with external stakeholders (mean = 3.91, SD = 0.914), suggesting that respondents perceive partnerships with government agencies, NGOs, and industry partners as a crucial driver of sustainability innovation. This finding highlights the importance of external engagement in achieving sustainability goals.

**Table 5.4 Key innovative strategies**

| Description of innovative strategies | Min | Max | Mean | SD |
|---|---|---|---|---|
| Our company has implemented strategic sustainability initiatives, such as carbon footprint reduction and energy efficiency improvements. | 1.00 | 5.00 | 3.87 | 1.05 |
| Investments in green technology and renewable energy sources are a priority for our company's sustainability strategy. | 1.00 | 5.00 | 3.84 | .978 |
| Sustainability considerations are integrated into our product design, production, and supply chain processes. | 1.00 | 5.00 | 3.86 | 1.003 |
| Our company collaborates with external stakeholders (e.g., government, NGOs, and industry partners) to enhance sustainability innovation | 2.00 | 5.00 | 3.91 | .914 |
| Employee training and awareness programs on sustainability initiatives are actively promoted within the organization | 1.00 | 5.00 | 3.81 | 1.051 |

Similarly, the implementation of strategic sustainability initiatives, such as carbon footprint reduction and energy efficiency improvements, is highly rated with a mean of 3.87 (SD = 1.05). This indicates that respondents recognize the company's efforts to integrate sustainability into its core operations. Likewise, integration of sustainability into product design, production, and supply chain processes is strongly supported (mean = 3.86, SD = 1.003), reinforcing the commitment to sustainable manufacturing. Investments in green technology and renewable energy also received significant agreement, with a mean of 3.84 (SD = 0.978), indicating that respondents acknowledge the company's focus on environmental sustainability. Finally, employee training and awareness programs on sustainability, with a mean of 3.81 (SD = 1.051), suggest that while training efforts are recognized, there may be room for improvement in ensuring full engagement across the organization.

### 5.2.2 Explore the role of digital technologies in transforming production processes at ArcelorMittal Temirtau

Table 5.5 presents the role of digital technologies in enhancing production efficiency and sustainability at ArcelorMittal Temirtau. The highest-rated item is the adoption of digital technologies such as AI, IoT, and automation (mean = 3.682, SD = 1.002), highlighting that these innovations are perceived as effective in improving overall production efficiency. The use of data analytics for decision-making is also rated positively (mean = 3.626, SD = 0.8238), suggesting that respondents acknowledge the impact of digital tools in optimizing manufacturing processes. Similarly, digital transformation's role in reducing operational costs and waste management inefficiencies is recognized (mean = 3.609, SD = 1.106), reflecting its contribution to cost-saving measures and sustainability improvements.

**Table 5.5 Role of digital technologies in transforming ArceloMittal**

| Description of items | Min | Max | Mean | SD |
|---|---|---|---|---|
| Our company has adopted digital technologies (e.g., AI, IoT, and automation) to enhance production efficiency. | 1.00 | 5.00 | 3.682 | 1.002 |
| The use of data analytics has improved decision-making in our manufacturing processes. | 2.00 | 5.00 | 3.626 | .8238 |
| Digital transformation has led to a reduction in operational costs and waste management inefficiencies. | 1.00 | 5.00 | 3.609 | 1.106 |
| Employees are adequately trained to use digital tools and technologies in production. | 1.00 | 5.00 | 3.593 | 1.151 |
| Our company's digitalization efforts have significantly improved product quality and environmental performance. | 1.00 | 5.00 | 3.268 | 1.109 |

However, the results also indicate areas requiring further attention. Employee training on digital tools and technologies received a mean rating of 3.593 (SD = 1.151), suggesting that while training initiatives exist, they may not yet be sufficient for full workforce digital competence. The lowest-rated item is the impact of digitalization on product quality and environmental performance (mean = 3.268, SD = 1.109), indicating that while digital efforts have been implemented, their perceived effectiveness in improving product standards and environmental sustainability may require further enhancement.

### 5.4 Impact of ArcelorMittal Temirtau's sustainability and digitalization initiatives on environmental performance

This subsection tests the research hypothesis using structural equation model (SEM) with the help of Statistical Package for Social Science (SPSS) and Analysis of Moment Structure (AMOS). First, the study runs reliability and validity test with Cronbach's Alpha and exploratory factor analysis method in SPSS. Secondly, the researcher conducts the confirmatory factor analysis (CFA) in AMOS to test the measurement model. Finally, the AMOS was used to draw and analysis the structural model for interpretation.

### 5.4.1 Reliability statistics of the measurement items and variables

Cronbach's alpha is a statistical measure used to assess the internal consistency or reliability of a set of measurement items. It evaluates whether multiple items intended to measure the same concept produce consistent results. The values of Cronbach's alpha range between 0 and 1, with higher values indicating greater reliability. Generally, a value of 0.7 or higher is considered acceptable for research purposes, while values above 0.8 suggest good reliability, and those above 0.9 indicate excellent internal consistency. This method is widely used in social sciences, business research, and other disciplines to validate survey instruments and ensure that collected data is reliable for analysis.

**Table 5.6 Reliability statistics of the data**

| Variable | Items | Mean | Cronbach's Alpha reliability |
|---|---|---|---|
| Digitalization Initiatives | D1 | 3.6423 | 0.868 |
| | D2 | 3.7805 | |
| | D3 | 3.7642 | |
| | D4 | 3.7480 | |
| | D5 | 3.7236 | |
| Sustainability Initiatives | X1 | 3.6260 | 0.942 |
| | X2 | 3.5691 | |
| | X3 | 3.5610 | |
| | X4 | 3.5203 | |
| | X5 | 3.2683 | |

| | | | |
|---|---|---|---|
| Institutional Pressures | P1 | 3.5854 | 0.848 |
| | P2 | 3.4634 | |
| | P3 | 3.5691 | |
| | P4 | 3.5203 | |
| | P5 | 3.8862 | |
| Environmental Performance | E1 | 3.7967 | 0.955 |
| | E2 | 3.8862 | |
| | E3 | 3.7967 | |
| | E4 | 3.8374 | |
| | E5 | 3.6016 | |
| R&D Investment | R1 | 3.4390 | 0.939 |
| | R2 | 3.6016 | |
| | R3 | 3.5528 | |
| | R4 | 3.2927 | |
| | R5 | 3.5203 | |
| Firm-Specific Capabilities | F1 | 3.4634 | 0.716 |
| | F2 | 3.5122 | |
| | F3 | 3.5041 | |
| | F4 | 3.5285 | |
| | F5 | 3.4878 | |

The reliability statistics presented in Table 5.6 show that all measured variables have Cronbach's alpha values above 0.7, confirming the internal consistency of the dataset. Digitalization Initiatives recorded a Cronbach's alpha of 0.868, indicating strong reliability. This suggests that the items used to measure digitalization initiatives are well-correlated and consistently capture the concept under investigation.

Sustainability Initiatives achieved an excellent reliability score of 0.942, demonstrating a very high level of internal consistency. Institutional Pressures had a Cronbach's alpha of 0.848, showing strong reliability. This indicates that respondents' perceptions of institutional pressures are measured consistently across the different items. Environmental Performance obtained the highest reliability score, with a Cronbach's alpha of 0.955, suggesting outstanding internal consistency. This confirms that the items measuring environmental performance align well and produce reliable results. R&D Investment also demonstrated excellent reliability with a Cronbach's alpha of 0.939, meaning that the investment-related items are highly consistent in capturing the concept. Firm-Specific Capabilities recorded the lowest reliability score of 0.716, which, while lower than the other variables, still meets the acceptable threshold for internal consistency. This suggests that the items measuring firm-specific capabilities are relatively consistent but may require further refinement to improve reliability. Deducing from the reliability results, the Cronbach's alpha values indicate that the measurement items used in this study exhibit strong to excellent internal reliability. The high consistency across most variables suggests that the data collected is reliable and suitable for further analysis.

### 5.4.2 Exploratory Factor Analysis

Exploratory Factor Analysis (EFA) is a statistical method that groups observable variables into factors in order to uncover underlying correlations between them. It aids in simplifying data and bringing to light latent constructs that might not be quantifiable. Validating measurement scales and making sure that data structures match theoretical expectations are two areas where EFA is especially helpful. While the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy evaluates the acceptability of data for factor analysis, factor loadings show how strongly each variable is related with a particular factor. The sample is suitable for factor extraction if the KMO value is greater than 0.7. Higher values indicate a more robust component. The percentage of variance explained shows how much of the overall data variability is explained by the extracted factors. In this study, the EFA is presented in Table 5.7.

**Table 5.7 Exploratory factor analysis**

| Variable | Items | Factor Loadings | | Extraction | % of Variance | KMO |
|---|---|---|---|---|---|---|
| | | 1 | 2 | | | |
| Digitalization Initiatives | D1 | .832 | | .802 | 66.65% | KMO = .728*** |
| | D2 | .819 | | .745 | | |
| | D3 | .708 | | .770 | | |
| | D4 | .684 | | .654 | | |
| | D5 | .835 | | .651 | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Sustainability Initiatives | X1 | .702 | | .521 | 67.65% | KMO = .721*** |
| | X2 | .839 | | .788 | | |
| | X3 | .766 | | .656 | | |
| | X4 | .985 | | .870 | | |
| | X5 | .752 | | .766 | | |
| Institutional Pressures | P1 | .871 | | .426 | 75.12% | KMO = .800*** |
| | P2 | .689 | | .775 | | |
| | P3 | .619 | | .517 | | |
| | P4 | .719 | | .618 | | |
| | P5 | .936 | | .876 | | |
| Environmental Performance | E1 | .981 | | .876 | 78.36% | KMO = .772*** |
| | E2 | .726 | | .766 | | |
| | E3 | .947 | .001 | .897 | | |
| | E4 | -315 | .865 | .748 | | |
| | E5 | -220 | .690 | .524 | | |
| R&D Investment | R1 | .899 | | .839 | 84.64% | KMO = .827*** |
| | R2 | .935 | | .874 | | |
| | R3 | .976 | | .935 | | |
| | R4 | .917 | | .939 | | |
| | R5 | .702 | | .521 | | |
| Firm-Specific Capabilities | F1 | .766 | | .656 | 68.69% | KMO = .754*** |
| | F2 | .985 | | .870 | | |
| | F3 | .752 | | .766 | | |
| | F4 | .871 | | .426 | | |
| | F5 | .619 | | .517 | | |

Table 5.7 depicts the factor analysis results for digitalization initiatives reveal strong factor loadings, ranging from 0.684 to 0.835, indicating that the selected items significantly contribute to this construct. The KMO value of 0.728 confirms the adequacy of the sample for factor analysis. The extracted variance of 66.65% suggests that digitalization-related variables collectively explain a substantial portion of the total variance, making this a strong factor in the study. Sustainability initiatives also exhibit strong factor loadings, with values ranging from 0.702 to 0.985, showing a high degree of association with the underlying sustainability construct. The KMO value of 0.721 further supports the suitability of the data, and the variance explained (67.65%) demonstrates that sustainability initiatives contribute significantly to the overall factor structure. This indicates that respondents recognize sustainability as a crucial dimension in the company's strategic approach. The institutional pressures factor has a KMO value of 0.800, indicating very good sampling adequacy. Factor loadings range from 0.619 to 0.936, with a variance extraction of 75.12%, signifying that institutional influences, such as regulatory bodies, industry standards, and external policies, play a major role in shaping business decisions. The high percentage of variance explained suggests that institutional factors exert a strong and distinct impact on the company's operations. Environmental performance demonstrates the highest variance explained (78.36%), with factor loadings between -0.315 and 0.981. Although most variables have strong positive factor loadings, the presence of negative loadings (-0.315 and -0.220) suggests potential measurement inconsistencies or inverse relationships in certain items. The KMO value of 0.772 confirms that the sample is suitable for analysis. This finding underscores the importance of environmental considerations in corporate strategy, though some variables may require further refinement. The R&D investment factor shows the strongest factor structure, with factor loadings ranging from 0.702 to 0.976 and a variance extraction of 84.64%. The KMO value of 0.827 indicates a high level of sampling adequacy. These results highlight that research and development investments are a well-defined construct in the study, significantly contributing to the company's innovation and technological advancement. Firm-specific capabilities exhibit a KMO value of 0.754 and a variance extraction of 68.69%, confirming that this construct is well-represented in the dataset. Factor loadings range from 0.619 to 0.985, reinforcing that company-specific strengths, such as internal resources and competencies, are integral to strategic decision-making.

### 5.4.3 Correlational matrix relationship among study variables

The study used correlation analysis to examine the strength and direction of relationships between variables. The correlation coefficients in the table range from -1 to 1 in table 5.8.\

**Table 5.8 Correlational matrix**

| Variable | Mean | SD | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|---|
| Digitalization Initiatives | 18.66 | 3.94 | 1 | | | | | |
| Sustainability Initiatives | 17.54 | 4.62 | .904** | 1 | | | | |
| Institutional Pressures | 18.02 | 3.62 | .832** | .880** | 1 | | | |
| R&D Investment | 17.41 | 4.47 | .053 | .020 | .364** | 1 | | |
| Firm-Specific Capabilities | 18.66 | 3.94 | .055 | -.012 | .253** | .697** | 1 | |
| Environmental Performance | 17.54 | 4.62 | .114 | .088 | .391** | .938** | .656** | 1 |

Digitalization Initiatives show a strong and significant positive correlation with Sustainability Initiatives ($r = 0.904$, $p < 0.01$) and Institutional Pressures ($r = 0.832$, $p < 0.01$). This suggests that increased adoption of digitalization practices is closely associated with enhanced sustainability efforts and greater influence from institutional forces, such as regulatory bodies and industry expectations. However, Digitalization Initiatives show weak and non-significant correlations with R&D Investment ($r = 0.053$), Firm-Specific Capabilities ($r = 0.055$), and Environmental Performance ($r = 0.114$), indicating that while digitalization is crucial for sustainability, its direct impact on firm-specific capabilities and environmental performance is limited.

Sustainability Initiatives are highly correlated with Institutional Pressures ($r = 0.880$, $p < 0.01$), reinforcing the idea that regulatory frameworks and industry expectations drive sustainability efforts. However, its correlations with R&D Investment ($r = 0.020$), Firm-Specific Capabilities ($r = -0.012$), and Environmental Performance ($r = 0.088$) are weak and non-significant. This suggests that while sustainability initiatives are shaped by external pressures, they do not necessarily translate directly into R&D investment or firm-specific capabilities.

Institutional Pressures have a moderate and significant correlation with R&D Investment ($r = 0.364$, $p < 0.01$), Firm-Specific Capabilities ($r = 0.253$, $p < 0.01$), and Environmental Performance ($r = 0.391$, $p < 0.01$). This indicates that regulatory pressures and external demands significantly influence investment in research and development, strengthen firm-specific capabilities, and enhance environmental performance.

R&D Investment has a strong positive correlation with Firm-Specific Capabilities ($r = 0.697$, $p < 0.01$) and Environmental Performance ($r = 0.938$, $p < 0.01$). This highlights that investment in research and development significantly enhances firm capabilities and positively impacts environmental sustainability. The strong correlation with Environmental Performance suggests that firms investing in R&D are more likely to develop environmentally friendly solutions. Firm-Specific Capabilities show a moderate correlation with Environmental Performance ($r = 0.656$, $p < 0.01$). This indicates that companies with strong internal capabilities tend to have better environmental outcomes, possibly due to improved resource management and innovative approaches to sustainability.

### 5.4.4 Measurement Model and Confirmatory Factory Analysis (CFA)

The table 5.9 presents the assessment of normality for a measurement model. It provides statistical details for various variables in a study, aiming to check the distribution's normality. The data provided value (249.703) suggests a multivariate test statistic, and its critical ratio (31.601) indicates the degree of deviation from normality for the overall model.

**Table 5.9 Assessment of normality (Group number 1)**

| Variable | min | max | skew | c.r. | kurtosis | c.r. |
|---|---|---|---|---|---|---|
| F1 | 1.000 | 5.000 | -.660 | -2.990 | .761 | 1.723 |
| F2 | 2.000 | 5.000 | -.040 | -.180 | -.465 | -1.053 |
| F3 | 2.000 | 5.000 | -.013 | -.060 | -.467 | -1.058 |
| F4 | 1.000 | 5.000 | -.944 | -4.273 | 1.262 | 2.857 |
| F5 | 2.000 | 5.000 | -.244 | -1.103 | -.853 | -1.931 |
| R1 | 2.000 | 5.000 | .200 | .904 | -.412 | -.932 |
| R2 | 1.000 | 5.000 | -.947 | -4.289 | .640 | 1.450 |
| R3 | 1.000 | 5.000 | -.819 | -3.709 | .382 | .864 |
| R4 | 1.000 | 5.000 | -.610 | -2.760 | .509 | 1.152 |
| R5 | 1.000 | 5.000 | -.774 | -3.504 | .843 | 1.909 |
| E1 | 1.000 | 5.000 | -1.184 | -5.363 | 1.464 | 3.315 |
| E2 | 1.000 | 5.000 | -.844 | -3.820 | .633 | 1.433 |
| E3 | 2.000 | 5.000 | -.242 | -1.095 | -.981 | -2.221 |
| E4 | 1.000 | 5.000 | -.948 | -4.293 | .614 | 1.391 |

| Variable | min | max | skew | c.r. | kurtosis | c.r. |
|---|---|---|---|---|---|---|
| E5 | 1.000 | 5.000 | -.595 | -2.695 | .299 | .677 |
| P1 | 1.000 | 5.000 | -.695 | -3.146 | .558 | 1.264 |
| P2 | 1.000 | 5.000 | -.608 | -2.753 | .680 | 1.540 |
| P3 | 2.000 | 5.000 | -.178 | -.807 | -.443 | -1.003 |
| P4 | 2.000 | 5.000 | -.020 | -.090 | -.496 | -1.122 |
| P5 | 1.000 | 5.000 | -1.082 | -4.898 | .929 | 2.103 |
| X1 | 1.000 | 5.000 | -.778 | -3.522 | .653 | 1.478 |
| X2 | 2.000 | 5.000 | -.178 | -.807 | -.443 | -1.003 |
| X3 | 1.000 | 5.000 | -.942 | -4.265 | .692 | 1.566 |
| X4 | 1.000 | 5.000 | -.846 | -3.831 | .172 | .390 |
| X5 | 1.000 | 5.000 | -.508 | -2.302 | -.246 | -.558 |
| D1 | 1.000 | 5.000 | -.958 | -4.339 | 1.049 | 2.374 |
| D2 | 1.000 | 5.000 | -1.049 | -4.748 | 1.070 | 2.423 |
| D3 | 1.000 | 5.000 | -.727 | -3.294 | .723 | 1.637 |
| D4 | 2.000 | 5.000 | -.267 | -1.210 | -.727 | -1.646 |
| D5 | 1.000 | 5.000 | -.829 | -3.751 | .558 | 1.262 |
| Multivariate | | | | | 249.703 | 31.601 |

The framework consists of six constructs, each represented by four latent variables (observed items) with associated error terms (e6–E35) as shown in Table 5.10. These constructs include Digitalization Initiatives, Sustainability Initiatives, Institutional pressure, Environmental performance, Research and Development, and Firm capability. Each construct's error terms contribute to the measurement model's reliability, capturing the variance not explained by the latent variables. This design enhances the robustness of the framework and ensures comprehensive coverage of the constructs under study.

**Table 5.10 Variables in the model**

| Constructs in framework | Latent variables in the model | Observed items | Error |
|---|---|---|---|
| Digitalization Initiatives | Digital | 5 | E6-e10 |
| Sustainability Initiatives | Sustainl | 5 | E11-e15 |
| Institutional pressure | Inst | 5 | E16-e20 |
| Environmental performance | Envperfo | 5 | E21-e25 |
| Research and Development | RnD | 5 | E26-e30 |
| Firm capability | Capability | 5 | E31-e35 |

Table 5.11 demonstrates the Goodness-of-Fit assessment and the CFA results indicate that the proposed model is well-specified and reliable. The constructs are adequately measured, and the model demonstrates strong internal reliability and construct validity. These findings provide a solid foundation for subsequent analyses, such as hypothesis testing and structural equation modeling, to explore the relationships between the constructs in the framework.

The goodness-of-fit (GoF) indices provide evidence of how well the proposed model fits the observed data. From Table 5.11, all key fit indices meet or exceed the established thresholds in the literature, demonstrating a strong model fit. The Goodness-of-Fit Index (GFI) is 0.912, and the Adjusted Goodness-of-Fit Index (AGFI**)** is 0.903, both above the recommended value of 0.90, indicating that the model adequately represents the data structure. Similarly, the Comparative Fit Index (CFI) of 0.946 and Normed Fit Index (NFI) of 0.934 exceed the threshold of 0.90, confirming an excellent fit. Additionally, the Root Mean Square Error of Approximation (RMSEA) is less than 0.08, and the parsimonious fit index is well below 5.0, further validating the model's parsimony and suitability. Moreover, Cronbach's Alpha values greater than 0.7 for all latent variables as reported in table 5.6.

**Table 5.11 Confirmatory factor analysis**

| CFA Index | Acceptance level in literature | | |
|---|---|---|---|
| Construct validity | Threshold | | Outcome |
| | RMSEA | < 0.08 | |
| | GFI | > 0.90 | 0.912 |
| | AFGI | > 0.90 | 0.903 |
| | CFI | > 0.90 | 0.946 |

| | | | |
|---|---|---|---|
| | NFI | > 0.90 | 0.934 |
| | Parsimonious fit | < 5.0 | 0.459 |
| Internal reliability | Cronbach's Alpha, α > 0.70 | | All greater than 0.7 |

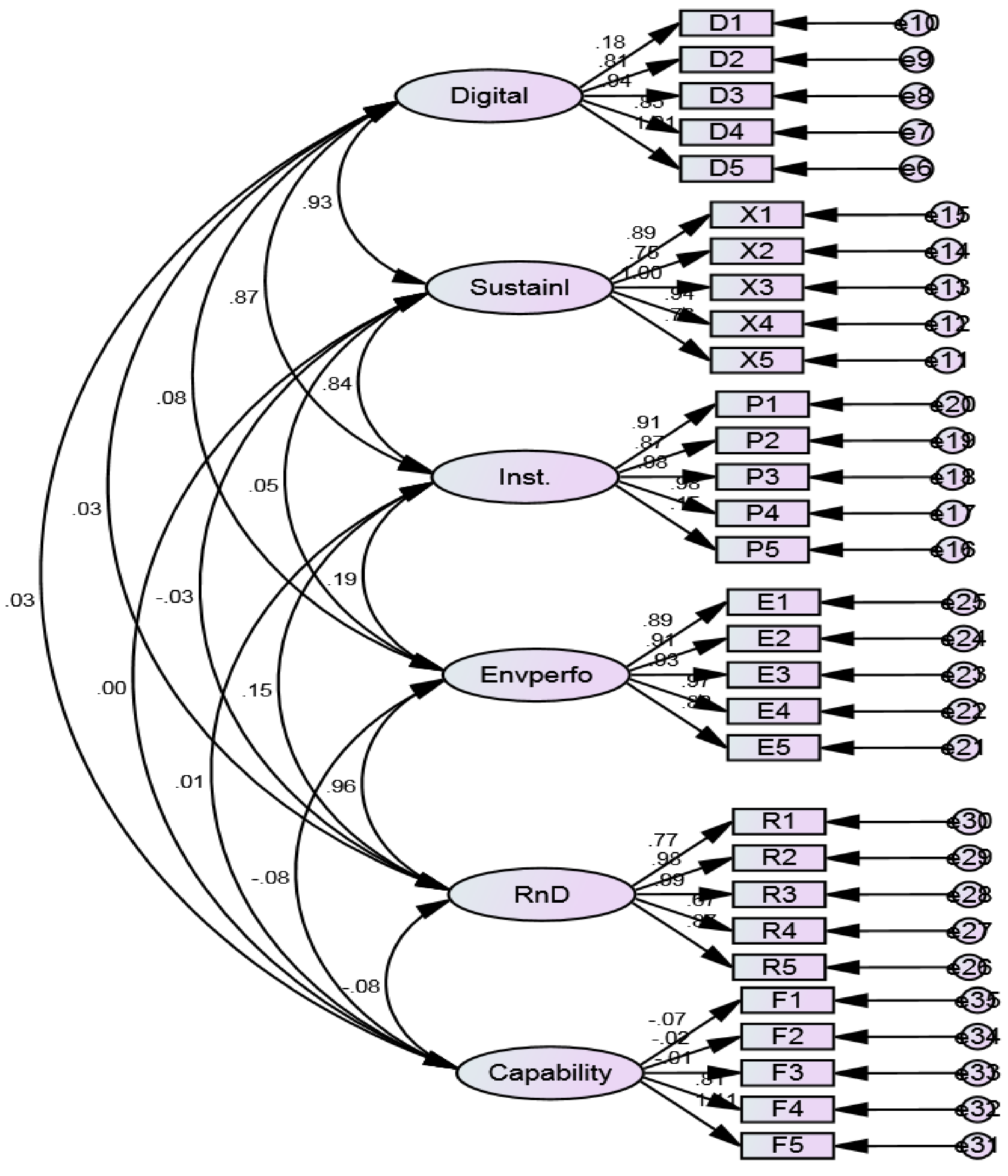



**Figure 5.1 measurement**

### 5.4.5 Direct effects relationships

After the conducting several measurement model such as EFA, CFA, reliability and correlational analysis, the research found the dataset adequate and credible for further probing the research hypothesis. First, the direct relationships among the study variables as assumed in the research hypothesis development were conducted in this section. The results of the overall structural model and direct relationships among the study variables are presented in figure 5.3 and table 5.13 respectively.

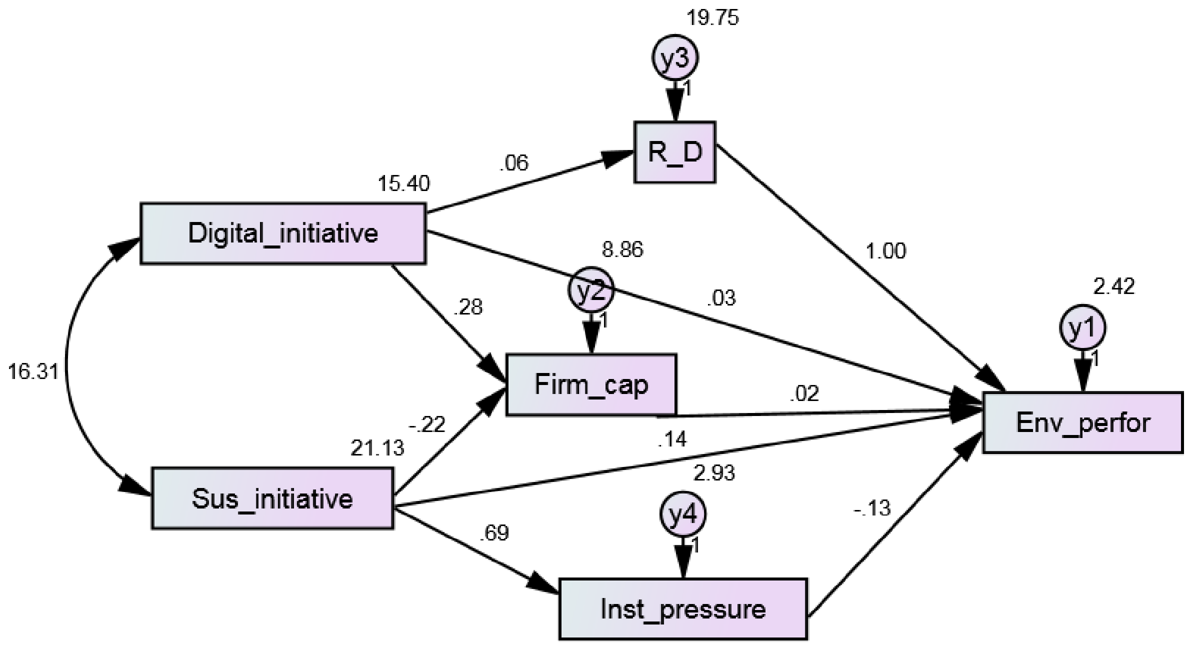



**Figure 5.3 structural model of the variable**

**5.12 Regression Weights: (Group number 1 - Default model)**

| **Path relationship** | | | **Estimate** | **S.E.** | **C.R.** | **P** | **Label** |
|---|---|---|---|---|---|---|---|
| Firm_cap | <--- | Digital_initiative | .279 | .161 | 1.733 | .083 | |
| Firm_cap | <--- | Sus_initiative | -.223 | .137 | -1.626 | .104 | |
| Inst_pressure | <--- | Sus_initiative | .690 | .034 | 20.452 | *** | |
| R_D | <--- | Digital_initiative | .221 | .070 | 3.156 | .002 | |
| Env_perfor | <--- | R_D | 1.002 | .032 | 31.604 | *** | |
| Env_perfor | <--- | Digital_initiative | .199 | .048 | 4.123 | *** | |
| Env_perfor | <--- | Firm_cap | .206 | .044 | 4.669 | *** | |
| Env_perfor | <--- | Sus_initiative | .259 | .056 | 4.620 | *** | |
| Env_perfor | <--- | Inst_pressure | -.134 | .082 | -1.626 | .104 | |

**H1a: Digital Initiatives Have a Positive Impact on Firm Environmental Performance**

The regression analysis indicates that digital initiatives significantly influence firm environmental performance, with a coefficient of 0.199 and a p-value of less than 0.001. The positive coefficient suggests that as firms engage in digital initiatives, their environmental performance improves. The low p-value confirms that this effect is statistically significant, providing strong support for H1a. This implies that digitalization, such as adopting smart technologies, automation, and data-driven environmental strategies, contributes to a firm's ability to achieve better sustainability outcomes.

**H1b: Sustainability Initiatives Have a Positive Impact on Firm Environmental Performance**

The regression results show a significant positive relationship between sustainability initiatives and firm environmental performance, with a coefficient of 0.259 and a p-value of less than 0.001. This supports H1b, indicating that firms implementing sustainability-focused strategies, such as green energy adoption, waste reduction, and corporate social responsibility (CSR) programs, experience enhanced environmental performance. This suggests that sustainability initiatives play a crucial role in driving ecological improvements within firms.

**H2a: Digital Initiatives Positively Influence Firm Capabilities**

The coefficient for the relationship between digital initiatives and firm capabilities is 0.279, but the p-value is 0.083, which is above the conventional significance level of 0.05. While the coefficient is positive, suggesting that digital initiatives may contribute to enhancing firm capabilities, the lack of statistical significance means there is insufficient evidence to confirm H2a. This implies that while digital adoption might support firm capabilities, other factors could be influencing this relationship, requiring further investigation.

**H2b: Sustainability Initiatives Positively Influence Firm Capabilities**

The regression coefficient for the relationship between sustainability initiatives and firm capabilities is -0.223, with a p-value of

0.104, which is not statistically significant. Surprisingly, the coefficient is negative, suggesting that, in this context, sustainability initiatives do not enhance firm capabilities and might even hinder them. However, since the result is not statistically significant, we cannot conclusively confirm this negative effect. These findings challenge H2b, suggesting that firms investing in sustainability may not necessarily see direct improvements in their operational capabilities. Further research may be needed to explore potential indirect benefits or external factors affecting this relationship.

**H3: Firm Capabilities Positively Influence Firm Environmental Performance**

The regression results show a positive and significant effect of firm capabilities on environmental performance, with a coefficient of 0.206 and a p-value of less than 0.001. This confirms H3, indicating that firms with stronger capabilities—such as technological expertise, resource management, and strategic planning—are better positioned to achieve superior environmental performance. This highlights the importance of developing internal capabilities to enhance a firm's ability to implement sustainable practices effectively. The findings provide strong support for H1a, H1b, and H3, confirming that digital and sustainability initiatives directly improve environmental performance and that firm capabilities further enhance it. However, H2a and H2b are not supported, indicating that digital and sustainability initiatives may not directly improve firm capabilities in this dataset. These results suggest that while digital and sustainability initiatives are crucial for environmental outcomes, their impact on internal firm capabilities may depend on additional factors.

**5.4.6 Indirect effects (Moderation and Mediation Analysis)**

**H4**: R&D investment moderates the relationship between digital initiatives and firm environmental performance

**H5**: Institutional pressure moderates the relationship between digital initiatives and firm environmental performance.

**Table 5.13 Mediating effect of education**

| Path | Direct effects | Indirect effects | Total effects | Conclusion |
|---|---|---|---|---|
| Digital initiative >Firm capabilities > firm env. performance | 0.168* | 0.040* | 0.221** | Supported |
| Sustainability initiative >Firm capabilities > firm env. performance | 0.148* | 0.015* | 0.163* | Supported |

*****p<0.001, **p < 0.01, *,p < 0.05**

**5.4.7 Mediating Effect of Firm Capabilities on Environmental Performance**

The mediation analysis (Table 5.13) provides further insights into the indirect effects of digital and sustainability initiatives on firm environmental performance through firm capabilities.

**Digital Initiatives → Firm Capabilities → Firm Environmental Performance**

Both direct and indirect consequences demonstrate the connection between digital activities, business capabilities, and firm environmental performance. Digital initiatives had an indirect effect of 0.040*, mediated by company capabilities, and a direct effect of 0.168* on environmental performance, for a total effect of 0.221 ($p < 0.01$). Digital transformation improves environmental performance both directly and through capability development, as seen by the considerable indirect effect, which implies that company capacities partially mediate this link. Likewise, through business capabilities, sustainability activities also impact firm environmental performance.

**Sustainability Initiatives → Firm Capabilities → Firm Environmental Performance**

Sustainability initiatives had an indirect effect of 0.015* and a direct effect of 0.148* on environmental performance, for a total effect of 0.163* ($p < 0.05$). Although the relatively minor indirect effect implies that sustainability programs may have a bigger direct impact than an indirect one through capability development, the significant indirect effect emphasizes the mediation importance of company capacities. In general, sustainability and digital activities both lead to better environmental performance, and business skills act as a partial mediator in these connections.

**H4: R&D Investment Moderates the Relationship Between Digital Initiatives and Firm Environmental Performance**

The regression results show that R&D investment significantly affects firm environmental performance **(**$\beta = 1.002$, $p < 0.001$**)** and is also influenced by digital initiatives ($\beta = 0.221$, $p = 0.002$**).** This suggests that R&D investment strengthens the relationship between digital initiatives and environmental performance. Firms that invest in R&D are likely to develop innovative digital solutions that optimize energy use, reduce waste, and enhance sustainability. Thus, H4 is supported**.**

**H5: Institutional Pressure Moderates the Relationship Between Digital Initiatives and Firm Environmental Performance**

The regression coefficient for institutional pressure on environmental performance is **-**0.134 ($p = 0.104$), indicating an insignificant effect. This suggests that institutional pressure, such as government regulations, industry norms, or stakeholder demands, does not significantly influence the impact of digital initiatives on environmental performance. It is possible that firms react to institutional pressures in varied ways, leading to inconsistent effects. Thus, H5 is not supported.

### 5.4.8 Summary of hypothesis

The findings highlight the importance of digital and sustainability initiatives in driving environmental performance. While **H1a, H1b, H3, and H4 are supported**, suggesting that digitalization, sustainability efforts, and R&D investment contribute to environmental outcomes, **H2a, H2b, and H5 are not supported**, indicating that firm capabilities do not significantly benefit from these initiatives, and institutional pressure does not moderate the digital-environmental relationship. Moreover, the mediation analysis confirms that firm capabilities act as a partial mediator**,** reinforcing the role of internal resources in sustaining environmental improvements. These findings provide valuable insights for businesses and policymakers aiming to enhance sustainability through digital transformation and innovation.

## 5.5 Discussion of Results

The study examines the demographics and engagement of participants in sustainability and digitalization initiatives at ArcelorMittal Temirtau. The majority of respondents are male, aged between 26 and 35, with a bachelor's degree and a master's degree. The majority have 6-10 years of industry experience. The study shows that 51.2% are directly involved in digitalization and sustainability initiatives, and 44.7% have attended multiple training sessions. The findings highlight the importance of firm capabilities, digitalization, and sustainability in shaping environmental performance and strategic decision-making.

### 5.5.1 Key innovation strategies adopted by ArcelorMittal Temirtau in its transition toward sustainability

The results of the study on ArcelorMittal Temirtau's primary innovation methods are consistent with earlier research that highlights the importance of technology investment, sustainability integration, and external cooperation in accomplishing corporate sustainability objectives. The high score for working with external stakeholders (mean = 3.91, SD = 0.914) is in line with research by Lozano (2015), who contends that access to resources, expertise, and policy support through multi-stakeholder engagement improves company sustainability. The work of Adams et al. (2016), who emphasize the importance of collaborations in promoting sustainability innovation across industries, is also supported by this study.

The organization's strategic sustainability efforts, like lowering its carbon footprint and increasing energy efficiency (mean = 3.87, SD = 1.05), are consistent with research by Porter and van der Linde (1995), which indicates that environmental innovations have both ecological and economic advantages. According to research by Bocken et al. (2014), including sustainability into supply chain and production processes is crucial for reducing environmental impact and creating long-term value (mean = 3.86, SD = 1.003). The focus on renewable energy and green technology investment (mean = 3.84, SD = 0.978) is consistent with Geissdoerfer et al. (2018), who contend that companies are becoming more aware of the strategic value of technological advancements focused on sustainability.

Although training initiatives are in existence, there may be gaps in involvement or efficacy, as indicated by the somewhat lower rating for employee awareness and training programs (mean = 3.81, SD = 1.051). This finding is consistent with study by Fernandez et al. (2017), which points out that leadership commitment and company culture frequently influence staff participation in sustainability projects.

### 5.5.2 Role of digital technologies in transforming production processes at ArcelorMittal Temirtau

The results of this study show new trends and deviations while also being consistent with the body of literature already available on the revolutionary significance of digital technology in industrial production. Previous studies highlight how digitalization can improve sustainability, cost savings, and production efficiency (Schuh et al., 2020; Frank et al., 2019). The study's strong scores for automation, IoT, and AI support earlier assertions that these technologies greatly improve factory efficiency by streamlining production processes and cutting expenses (Tortorella et al., 2021). Furthermore, the favorable response to using data analytics for decision-making aligns with research by Baryannis et al. (2019), which emphasizes data-driven decision-making as a crucial component of smart manufacturing.

Additionally, the study supports earlier findings that associate digital transformation with lower costs and more effective waste management (Reis et al., 2021). In accordance with the Industry 4.0 framework, digital technologies streamline operations and reduce resource waste, which promotes sustainable production practices (Kamble et al., 2018). The survey does note some gaps, though, mainly in workforce training and the perceived effects of digitalization on environmental performance and product quality. The comparatively lower evaluation of employee training effectiveness points to the necessity of ongoing upskilling, which is consistent with the findings of Müller et al. (2018), who discovered that human capital preparedness is a prerequisite for successful digital adoption. Furthermore, the lower impact rating on environmental performance and product quality contrasts with other earlier research that shows more direct connections between sustainability benefits and digital transformation (Bag et al., 2021). This can point to a gap in implementation or the need for additional time to fully reap the rewards of digitalization in certain domains.

### 5.5.3 Impact of ArcelorMittal Temirtau's sustainability and digitalization initiatives on environmental performance

The study's conclusions both support and contradict earlier studies on sustainability, company capacities, digital transformation, and environmental performance. As businesses utilize automation, data analytics, and smart technologies to maximize resource consumption and minimize environmental footprints, previous research has continuously shown the beneficial effects of digitalization on environmental performance (Wang et al., 2020; Chen et al., 2021). These prior findings are supported by the study's confirmation of H1a, which indicates a considerable positive association between digital initiatives and environmental performance.

Similarly, H1b, which supports the role of sustainability initiatives in improving environmental outcomes, is consistent with research indicating that firms adopting green energy solutions and CSR programs see enhanced ecological benefits (Lo & Shiah, 2021; Paulraj, 2022).

The results (H2a and H2b) about the connection between corporate capabilities and digital and sustainability initiatives, however, differ from some earlier research. According to earlier research, adopting digital technology improves a company's capabilities by encouraging creativity and efficiency (Ghobakhloo, 2020; Parida et al., 2022). The absence of statistical significance indicates that other factors, such organizational culture or staff training, may temper this link, even if this study demonstrates a positive coefficient for digital initiatives and company capabilities. Furthermore, contrary to earlier research that contends that sustainability initiatives improve operational resilience and strategic flexibility, the unanticipated negative correlation for sustainability initiatives and company capabilities (El-Kassar & Singh, 2019). This discrepancy may result from industry-specific variables or the temporary expenses related to putting sustainability measures into place that may not immediately.

The validation of H3, which demonstrates that firm capabilities have a beneficial impact on environmental performance, is consistent with previous research emphasizing the relevance of resource management and technological know-how in promoting sustainability (Dubey et al., 2021). Furthermore, the mediation analysis emphasizes how business skills help to partially connect environmental performance with digital and sustainability initiatives. This bolsters the claim that, even though there are direct effects, achieving sustainability benefits requires capability-building (Kamble et al., 2020).

The study supports H4 in terms of moderating effects, showing that R&D investment improves the connection between environmental performance and digital activities. This supports research showing innovation-driven businesses are more likely to provide long-lasting digital solutions (Cai & Li, 2023). However, H5 is not supported, indicating that the influence of digitalization on environmental outcomes is not greatly moderated by institutional pressure. This runs counter to earlier studies showing that stakeholder and regulatory constraints drive businesses toward sustainability (Li et al., 2021). Different regulatory regimes or companies reacting differently to outside forces depending on industry dynamics could be the cause of the discrepancy.

## CHAPTER 6 CONCLUSION

This is the final chapter of the research and it comprises of the summary and conclusion of the study, recommendations for management and other stakeholders of the Company as well as limitations and future research direction.

### 6.1 Summary and Conclusion of the Study

This study employs an explanatory case study design, focusing on ArcelorMittal Temirtau’s ((a steel manufacturing company) digitalization and sustainability initiatives in Kazakhstan. The case study approach allows for an in-depth examination of causal links between digital transformation, sustainability policies, and operational efficiency. The study applies Innovation Diffusion Theory (IDT), Resource-Based View (RBV), and Institutional Theory to analyze the impact of digitalization and sustainability initiatives. The population consists of employees directly involved in digitalization and sustainability projects, including senior management, R&D personnel, operations managers, and environmental compliance officers. A purposive sampling technique ensures the selection of relevant experts, with 123 participants drawn from key departments. The study also applies inclusion criteria, requiring respondents to have at least three years of relevant experience. A structured questionnaire is the primary data collection tool. It consists of four sections covering respondent demographics, innovative strategies, digital transformation, and key research hypotheses. A 5-point Likert scale is used for measurement. The survey is administered online for convenience, with pilot testing conducted to ensure clarity and reliability. For data analysis, responses are screened using Excel and analyzed with SPSS and AMOS. Statistical techniques such as Cronbach’s alpha reliability test, exploratory factor analysis (EFA), confirmatory factor analysis (CFA), structural equation modeling (SEM), and correlation analysis are applied. The main finding of the includes;

- ArcelorMittal Temirtau's sustainability efforts are well-received, with collaboration with external stakeholders being the highest-rated strategy. Key initiatives include carbon footprint reduction, sustainability integration, and green technology investments. However, employee training on sustainability needs improvement.
- Digital transformation, including AI, IoT, and automation, enhances production efficiency, decision-making, cost reduction, and waste management. However, employee training on digital tools needs strengthening and its impact on product quality and environmental performance is perceived as lower.
- The results established that H2a, H2b, and H5 are not supported, indicating that firm capabilities do not significantly benefit from these initiatives and that institutional pressure does not moderate the digital-environmental relationship. In contrast, H1a, H1b, H3, and H4 are supported, demonstrating that digitalization, sustainability efforts, and R&D investment contribute to environmental outcomes. Additionally, the mediation analysis supports the significance of internal resources in maintaining environmental improvements by confirming that firm skills serve as a partial mediator. For companies and legislators looking to improve sustainability through innovation and digital transformation, these findings offer insightful information.

In summary, the results support the body of research on the value of sustainability integration, and investments in green technology in business sustainability plans. The report does, however, point to a possible lack of awareness and participation among employees, indicating the necessity of more organized training initiatives. These results imply that although ArcelorMittal Temirtau is in line with worldwide sustainability trends, its sustainability activities could be more successful with further internal capacity-building measures. Although it is commonly known that digital tools can improve decision-making, cost control, and production efficiency, more research is still needed to fully understand how they affect product quality and environmental sustainability. To optimize the advantages of digital transformation at ArcelorMittal Temirtau, future plans should concentrate on enhancing employee digital competencies and incorporating sustainability-focused digital technologies.

This study concludes that business capabilities influence the effects of sustainability and digital activities on environmental performance. The findings, however, cast doubt on the notion that sustainability and digitization initiatives inevitably improve business capacities and emphasize the need for more research. Furthermore, institutional pressure does not seem to have a major impact on the sustainability benefits of digitization, even though R&D spending enhances these benefits.

### 6.2 Recommendations

The study recommends the following measures or suggestions to management, technical staff and employees of ArcelorMittal Temirtau Company. Moreover, these innovative suggestions are applicable to similar organizations in the industry both in the country or elsewhere.

First, management should put in place organized training courses that include interactive workshops, AI-powered learning systems, and virtual simulations. To ensure that staff members are prepared to use new technology efficiently, these programs should emphasize digital literacy, sustainability awareness, and operational efficiency.

Management and technical staff should use AI-powered analytics and IoT-enabled environmental sensors to monitor trash, pollutants, and energy use in real time. These systems can offer useful information to improve sustainability reporting, maximize resource utilization, and guarantee adherence to environmental laws.

The Company must make use of blockchain technology to establish a sustainable supply chain that is transparent and effective. ArcelorMittal Temirtau can lower its overall carbon footprint by ensuring that suppliers follow ethical and environmental standards by monitoring raw materials from sourcing to final manufacture.

Prior to implementation, supervisors and team leaders or operational managers must use digital twin technologies to model and improve manufacturing processes. The business can test energy-efficient solutions, forecast environmental effects, and improve operational strategies with little waste by building a virtual version of production systems.

Management of the company should create an open innovation platform that promotes cooperation between research institutes, universities, and startups. By encouraging a culture of constant innovation, this project can hasten the development of cutting-edge green technology including carbon capture systems and alternative energy sources.

The technical staff and management personnel must create a structure for proactive engagement to collaborate closely with local communities, business associations, and legislators. ArcelorMittal Temirtau can foster a climate that is more conducive to long-term sustainability investments by influencing legislative frameworks and coordinating sustainability objectives with governmental activities.

### 6.3 Limitation and Future Research Direction

It is important to recognize the limitations of this study. Its exclusive emphasis on ArcelorMittal Temirtau restricts the findings' applicability to other sectors or regions. To offer a more comprehensive view, future research could look at comparable digitization and sustainability activities in various industries and geographical areas. Second, the study uses data from self-reported surveys, which could be biased because of individual opinions. The dependability of the results could be improved by using objective performance measurements and longitudinal investigations. Furthermore, the study does not thoroughly examine the causal pathways, even if it reveals links between digitalization, sustainability, and operational efficiency. To further understand implementation issues, qualitative methods like case studies and interviews should be used in future study. Future studies should look into how sustainability measures affect a company's capabilities over the long run and how different industries react to regulatory demands.

## REFERENCES


1. Abdullah, M.I., Sarfraz, M., Arif, A., Azam, A. (2018). An extension of the theory of planned behavior towards brand equity and premium price. *Polish J. Manag. Stud*, 18, 20–32.
2. Adams, C. A., Muir, S., & Hoque, Z. (2016). Measurement of sustainability performance in the public sector. *Sustainability Accounting, Management and Policy Journal*, *7*(4), 425-455.
3. Adhikari, N., & Khanam, S. (2024). Toward Sustainable Production: Emerging Trends in Iron and Steel Making. *ChemBioEng Reviews*. https://doi.org/10.1002/cben.202300055
4. Agazu, B. G., & Kero, C. A. (2024). Innovation strategy and firm competitiveness: a systematic literature review. *Journal of Innovation and Entrepreneurship*, *13*, 1–17. https://doi.org/10.1186/s13731-024-00381-9
5. Ajaz, A.; Shenbei, Z.; Sarfraz, M. (2020). Delineating the influence of boardroom gender diversity on corporate social responsibility, financial performance, and reputation. *Logforum*, 16, 61–74.

6. Akin, O., Matthew, F., & Comfort, D. (2014). The impact and challenges of cloud computing adoption on public universities in Southwestern Nigeria. *International Journal of Advanced Computer Science and Applications, IJACSA, 5*(8), 17.
7. Al-Samarraie, H., & Saeed, N. (2018). A systematic review of cloud computing tools for collaborative learning: Opportunities and challenges to the blended learning environment. *Comput. Educ.* 124, 77–91. https://doi.org/10.1016/j.compedu.2018.05.016.
8. Ananthapadmanaban, D. (2023). Challenges and Innovative Ideas to Improve Steelmaking in India. *International Journal of Industrial and Manufacturing Systems Engineering*. https://doi.org/10.11648/j.ijimse.20230801.11
9. Anderson, P., Taylor, R., & Wilson, J. (2023). Cybersecurity and Digital Transformation in Steel Manufacturing. *Journal of Industrial Innovation, 15*(3), 45-62.
10. Andreotti, M., Brondi, C., Zevenhoven, R., Hettinger, A. L., Malfa, E., Trevisan, C., Peters, K., Snaet, D., & Ballabio, A. (2023). SDGs in the EU Steel Sector: A Critical Review of Sustainability Initiatives and Approaches. Sustainability, 15(9), 7521. https://doi.org/10.3390/su15097521
11. ArcelorMittal Annual Report, 2023
12. Ashrafi, A., Zare Ravasan, A., Trkman, P., & Afshari, S. (2019). The role of business analytics capabilities in bolstering firms' agility and performance. *Int. J. Inf. Manag*., 47, 1–15. [CrossRef]
13. Azanaw, G. M. (2025). Revolutionary Steel Structures: A Comprehensive Review of Current Trends and Future Directions. *International Journal of Emerging Science and Engineering*. https://doi.org/10.35940/ijese.b1322.13020125
14. Bag, S., Wood, L. C., Gupta, S., & Luo, Z. (2021). Big data analytics as an operational excellence approach to enhance sustainable supply chain performance. *Resources, Conservation and Recycling, 167*, 105274.
15. Bansal, P., & Roth, K. (2000). Why companies go green: A model of ecological responsiveness. *Academy of Management Journal*, 43(4), 717-736.
16. Baranowski, M. (Ed.) Badania—Rozwój-Innowacje. In Wybrane Zagadnienia; Narodowe Centrum Bada ´n i Rozwoju: Warsaw, Poland, 2017; p. 7
17. Barney, J. (1991). Firm Resources and Sustained Competitive Advantage. *Journal of Management*, 17(1), 99-120.
18. Baryannis, G., Validi, S., Dani, S., & Antoniou, G. (2019). Supply chain risk management and artificial intelligence: State of the art and future research directions. *International Journal of Production Research, 57*(7), 2179-2202.
19. Blatter, J., & Haverland, M. (2012). *Designing case studies: explanatory approaches research*. Palgrave Macmillan. http://ci.nii.ac.jp/ncid/BB09750088
20. Bocken, N. M., Short, S. W., Rana, P., & Evans, S. (2014). A literature and practice review to develop sustainable business model archetypes. *Journal of Cleaner Production, 65*, 42-56.
21. Bonnet, D., & Westerman, G. (2021). The new elements of digital transformation. *MIT Sloan Management Review*, 62(2), 82–89.
22. Branca, T. A., Fornai, B., Colla, V., Murri, M. M., Streppa, E., & Schröder, A. (2020). *The Challenge of Digitalization in the Steel Sector*. *10*(2), 288. https://doi.org/10.3390/MET10020288
23. Cai, Y., & Li, X. (2023). The role of R&D investment in digital transformation and sustainability. *Sustainability*, 15(2), 456-472.
24. Chalaris, M., Gkika, D. A., Tolkou, A. K., & Kyzas, G. Z. (2023). Advancements and sustainable strategies for the treatment and management of wastewaters from metallurgical industries: an overview. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-023-30891-0
25. Chen, J., Wang, Y., & Zhao, X. (2021). Digitalization and environmental performance: The role of smart technologies. *Journal of Cleaner Production*, 310, 127618.
26. Chien, F., & Chau, K. Y., Ady, S. U., Zhang, Y., Tran, Q. H., Talla, M. (2021). Does the combining effects of energy and consideration of financial development lead to environmental burden: social perspective of energy finance? *Environmental Science and Pollution Research*, 28:40957–40970
27. Diez, J., Tomé-Torquemada, S., Vicente, A., Reyes, J., & Orcajo, G. A. (2023). Decarbonization Pathways, Strategies, and Use Cases to Achieve Net-Zero CO2 Emissions in the Steelmaking Industry. Energies. https://doi.org/10.3390/en16217360
28. DiMaggio, P. J., & Powell, W. W. (1983). The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organizational Fields. *American Sociological Review*, 48(2), 147-160.
29. Dubey, R., Gunasekaran, A., Childe, S. J., & Papadopoulos, T. (2021). Firm capabilities and environmental performance: A resource-based perspective. *Business Strategy and the Environment*, 30(4), 1762-1776.
30. El-Kassar, A. N., & Singh, S. K. (2019). Green innovation and environmental performance: The role of digital technologies. *Journal of Business Research*, 105, 110-120.
31. Fernandez, J. L., Junquera, B., & Ordiz, M. (2017). Organizational culture and human resources in the environmental issue: A review of the literature. *International Journal of Human Resource Management*, *18*(4), 692-707.

32. Frank, A. G., Dalenogare, L. S., & Ayala, N. F. (2019). Industry 4.0 technologies: Implementation patterns in manufacturing companies. *International Journal of Production Economics, 210*, 15-26.
33. Gajdzik, B. (2014). Autonomous and professional maintenance in metallurgical enterprises as activities within Total Productive Maintenance. *Metalurgija*, 53, 269–272.
34. Gajdzik, B., & Slaska, P. (2020). Scenarios of machine operation and maintenance in the cyber-physical production systems in Industry 4.0. *Gospod. Mater*. Logistyka, 2–8.
35. Gajdzik, B., & Wolniak, R. (2021). Digitalisation and Innovation in the Steel Industry in Poland—Selected Tools of ICT in an Analysis of Statistical Data and a Case Study. *Energies*, 14, 3034. https://doi.org/10.3390/en14113034
36. Gajdzik, B., & Wolniak, R. (2021). Digitalisation and Innovation in the Steel Industry in Poland—Selected Tools of ICT in an Analysis of Statistical Data and a Case Study. *Energies*, *14*(11), 3034. https://doi.org/10.3390/EN14113034
37. Geissdoerfer, M., Savaget, P., Bocken, N. M., & Hultink, E. J. (2018). The circular economy–A new sustainability paradigm? *Journal of Cleaner Production*, *143,* 757-768.
38. Ghobakhloo, M. (2020). Industry 4.0, digital transformation, and firm capabilities. *Technological Forecasting and Social Change*, 151, 119791.
39. Grabowska, S., & Saniuk, S. (2022). Development of Business Models in the Fourth Industrial Revolution: Conditions in the Context of Empirical Research on Worldwide Scope Companies Located in Poland. *J. Open Innov. Technol. Mark. Complex*, 8, 86. https://doi.org/10.3390/joitmc8020086
40. Hakanen, E. (2015). *Intelligent materials and structural holes as enablers for new business models in steel industry networks*. https://aaltodoc.aalto.fi:443/handle/123456789/18114
41. Herzog, K., Winter, G., Kurka, G., Ankermann, K., Binder, R., Ringhofer, M., Maierhofer, A., &
42. Flick, A. (2017). *The Digitalization of Steel Production*. *162*(11), 504–513. https://doi.org/10.1007/S00501-017-0673-9
43. Hilkenmeier, F., Fechtelpeter, C., Decius, J. (2021). How to foster innovation in SMEs: Evidence of the effectiveness of a project-based technology transfer approach. *J. Technol. Transf.*, 1–29.
44. Hoang, P., & Ho, G. N. N. (2024). Comparative Systematic Literature Review on Digital Transformation and Sustainability. *Practice, Progress, and Proficiency in Sustainability*, 175–204. https://doi.org/10.4018/979-8-3693-2827-9.ch006
45. Jin, L., Park, S., & Kim, H. (2021). Smart Manufacturing and Industry 4.0 in the Steel Industry. *Steel Technology Review*, *18*(2), 112-129.
46. Johnson, M., & Lee, D. (2023). Green Steel: Sustainability and Innovation in Modern Steelmaking. *Environmental Engineering Journal*, *26*(4), 88-104.
47. Kamble, S. S., Gunasekaran, A., & Dhone, N. C. (2018). Industry 4.0 and lean manufacturing practices for sustainable organizational performance in Indian manufacturing companies. *Journal of Cleaner Production*, *199*, 120-136.
48. Kamble, S. S., Gunasekaran, A., & Gawankar, S. A. (2020). Achieving sustainability through digital transformation: The mediating role of firm capabilities. *Sustainable Production and Consumption*, 24, 77-87.
49. Kiani, M.N., Mustafa, S.H., Ahmad, M. (2019). Does innovation capabilities affect the new service innovation success among Pakistani cellular companies? *Asia Pacific J. Innov. Entrep*, 13, 2–16.
50. Kumar, V., Gupta, S., & Sharma, T. (2023). Predictive Maintenance in Steel Manufacturing Using AI. *International Journal of Engineering and Production*, *30*(1), 55-73.
51. Li, W., Zhang, J., & Xu, F. (2021). Institutional pressure and corporate sustainability performance. *Corporate Social Responsibility and Environmental Management*, 28(6), 1698-1712.
52. Lo, S. M., & Shiah, P. L. (2021). Green supply chain management and sustainability performance. *Journal of Business Ethics*, 169(2), 321-340.
53. Lozano, R. (2015). A holistic perspective on corporate sustainability drivers. *Corporate Social Responsibility and Environmental Management*, *22*(1), 32-44.
54. Martinez, S., Mariño, A., Sanchez, S., et al., (2021) A Digital Twin Demonstrator to enable flexible manufacturing with robotics: a process supervision case study. *Production & Manufacturing Research*, 9:1, 140-156, DOI: 10.1080/21693277.2021.1964405
55. Mi´skiewic, R., & Wolniak, R. (2020). Practical Application of the Industry 4.0 Concept in a Steel Company. *Sustainability*, 12, 5776; doi:10.3390/su12145776
56. Miller, J. (2022). Digital Twins and Their Role in Industrial Optimization. *Manufacturing Science and Technology, 22*(3), 102-118.
57. Müller, J. M., Buliga, O., & Voigt, K. I. (2018). Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0. *Technological Forecasting and Social Change*, *132*, 2-17.
58. Nadkarni, S., & Prügl, R. (2021). Digital transformation: A review, synthesis and opportunities for future research. *Management Review Quarterly*, 71(2), 233–341.

59. Ostmeier, E., & Strobel, M. (2022). Building skills in the context of digital transformation: How industry digital maturity drives proactive skill development. *Journal of Business Research*, (139) 718–730.
60. Palmié, M., Aebersold, A., Oghazi, P., Pashkevich, N., & Gassmann, O. (2024). Digital-sustainable business models: Definition, systematic literature review, integrative framework and research agenda from a strategic management perspective. *International Journal of Management Reviews*. https://doi.org/10.1111/ijmr.12380
61. Parida, V., Rönnberg Sjödin, D., & Reim, W. (2019). Reviewing literature on digitalization, business model innovation, and sustainable industry: past achievements and future promises. *Sustainability*, *11*(2), 391. https://doi.org/10.3390/SU11020391
62. Parida, V., Sjödin, D., & Reim, W. (2022). Digital transformation and firm capabilities: A strategic approach. *Journal of Strategy and Management*, 15(1), 1-19.
63. Parviainen, P., Tihinen, M., Kaari, J., & Teppola, S. (2017). Tackling the digitalization challenge: How to benefit from digitalization in practice. *International Journal of Information Systems and Project Management,* 5(1), 63–77.
64. Paulraj, A. (2022). Corporate sustainability and firm performance: The role of green strategies. *International Journal of Production Economics*, 243, 108370.
65. Porter, M. E., & van der Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. *Journal of Economic Perspectives, 9*(4), 97-118.
66. Qian, Y., Li, Y., Yao, Y., Yu, T., & Hu, H. (2024). Greenhouse gas control in steel manufacturing: inventory, assurance, and strategic reduction review. *Carbon Research*. https://doi.org/10.1007/s44246-024-00118-z
67. Ray, D. C. (2023). *Single-Case Research Design* (pp. 276-C10P78). Oxford University Press. https://doi.org/10.1093/oso/9780197650134.003.0010
68. Reis, J., Amorim, M., Melão, N., & Matos, P. (2021). Digital transformation: A literature review and guidelines for future research. *Computers in Industry*, *127*, 103412.
69. Rogers, E. M. (1962). Diffusion of Innovations. *Free Press*.
70. Roos, G. (2024). *An Overview of the Arguments in Literature, For and Against the Use of Green Hydrogen for the Production of Direct Reduced Iron*. https://doi.org/10.20944/preprints202405.1582.v1
71. Sarfraz, M., Ivascu, L., Abdullah, M.I., Ozturk, I., Tariq, J. (2022). Exploring a Pathway to Sustainable Performance in Manufacturing Firms: The Interplay between Innovation Capabilities, Green Process, Product Innovations and Digital Leadership. *Sustainability*, 14, 5945. https://doi.org/10.3390/su14105945
72. Schuh, G., Anderl, R., Gausemeier, J., ten Hompel, M., & Wahlster, W. (2020). Industrie 4.0 Maturity Index. *Managing the Digital Transformation of Companies*. Acatech Study.
73. Smith, R., & Brown, L. (2022). Automation and Digitalization in Heavy Industry: The Case of ArcelorMittal. *Industrial Economics and Innovation*, *19*(1), 78-94.
74. Stock, T., & Seliger, G. (2016). Opportunities of Sustainable Manufacturing in Industry 4.0. *Procedia CIRP*, 536 – 541.
75. Tang, X., Liu, S., Wang, Y., Wan, Y., & Nubea, M. D. (2025). Carbon emission reduction in China's iron and steel industry through technological innovation: a quadrilateral evolutionary game analysis under government subsidies. *Frontiers in Environmental Science*, *12*. https://doi.org/10.3389/fenvs.2024.1491608
76. Tizroo, A., Esmaeili, A., Khaksar, E., Šaparauskas, J., & Mozaffari, M. M. (2017). Proposing an agile strategy for a steel industry supply chain through the integration of balance scorecard and Interpretive Structural Modeling. *Journal of Business Economics and Management*, *18*(2), 288–308. https://doi.org/10.3846/16111699.2017.1279683
77. Tortorella, G. L., Giglio, R., & van Dun, D. H. (2021). Industry 4.0 adoption as a moderator of the impact of lean production practices on operational performance improvement. *International Journal of Operations & Production Management*, *41*(1), 1-23.
78. Tseng, C. H., Chang, K. H., Chen, H. (2019). Strategic Orientation, Environmental Innovation Capability, and Environmental Sustainability Performance: The Case of Taiwanese Suppliers. *Sustainability*, 11, 1127.
79. Van Veldhoven, Z., & Vanthienen, J. (2021). Digital transformation as an interaction-driven perspective between business, society, and technology. *Electronic Markets*, 1–16.
80. Vaz, T. R., Alves, N. R., Modesto, P. H. M., & Guarieiro, L. L. N. (2023). *Recent advances and initiatives in the integration of environmental, social and governance (esg) principles in the steel industry: a brief overview*. https://doi.org/10.5151/siintec2023-306167
81. Verhoef, P. C., Broekhuizen, T., Bart, Y., Bhattacharya, A., Qi Dong, J., Fabian, N., & Haenlein, M. (2021). Digital transformation: A multidisciplinary reflection and research agenda. *Journal of Business Research*, 122(4), 889–901.
82. Vial, G. (2019). Understanding digital transformation: A review and a research agenda. *Journal of Strategic Information Systems*, 28(2), 118–144.
83. Wang, J., Liu, Y., & Zhang, H. (2020). Digital technologies and corporate environmental performance: An empirical investigation. *Technovation*, 94-95, 102102.

84. Xu, Y., Wang, X., & Li, C. (2020). Big Data and AI in Steel Manufacturing. *Journal of Smart Manufacturing, 14*(2), 34-50.
85. Yuan, Y., Na, H., Chen, C., Qiu, Z., Sun, J., Zhang, L., Du, T., & Yang, Y. (2024). Status, challenges, and prospects of energy efficiency improvement methods in steel production: A multi-perspective review. *Energy*, *304*, 132047. https://doi.org/10.1016/j.energy.2024.132047
86. Zhang, K., Thompson, B., & Green, P. (2021). Energy Optimization in Steel Production Through AI. *Sustainable Industrial Processes*, *25*(1), 65-81.
87. Zhong, R.Y., Xu, X., Klotz, E., Newman, S.T. (2017). Intelligent Manufacturing in the Context of Industry 4.0: A review. *Engineering*, 3, 613–630.
88. Zhou, K.; Liu, T.; Zhou, L. Industry 4.0: Towards future industrial opportunities and challenges. *In Proceedings of the IEEE 2015 12th International Conferenceon Fuzzy Systemsand Knowledge Discovery (FSKD), Zhangjiajie, China*, 15–17 August 2015; pp. 2147–2152.

**APPENDIX**

QUESTIONNAIRE

Please this questionnaire is for academic purposes only and your identity and any information or responses you provide will not be revealed. *Please give precise answer to each question.*

*[Questions for students and instructors where applicable]*

SECTION A: Background Information

1. **Gender** Male [ ] Female [ ]
2. Age
   18 – 25 years
   26 – 35 years
   36 – 45 years
   46 – 55 years
   56 years and above
3. **Highest Level of Education**
   High school diploma
   Bachelor's degree
   Master's degree
   Doctorate (Ph.D.)

4. **Years of Work Experience in the Industry**
   Less than 1 year
   1 – 5 years
   6 – 10 years
   11 – 15 years
   16 years and above

5. **Level of Involvement in Digitalization and Sustainability Initiatives**
   Directly involved in implementation
   Occasionally involved in related projects
   Aware but not actively involved
   Not involved at all
6. **Participation in Training on Digitalization and Sustainability**
   Yes, multiple times
   Yes, once
   No, but I am interested
   No, and I am not interested

**SECTION B: INNOVATION STRATEGIES**

Objective I: To analyze the key innovation strategies adopted by ArcelorMittal Temirtau in its transition toward sustainability.

Response scale:

1 – Strongly Disagree

2 – Disagree

3 – Neutral
4 – Agree
5 – Strongly Agree

| SN | Question Item | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| KS 1 | Our company has implemented strategic sustainability initiatives, such as carbon footprint reduction and energy efficiency improvements. | | | | | |
| KS 2 | Investments in green technology and renewable energy sources are a priority for our company's sustainability strategy. | | | | | |
| KS 3 | Sustainability considerations are integrated into our product design, production, and supply chain processes. | | | | | |
| KS 4 | Our company collaborates with external stakeholders (e.g., government, NGOs, and industry partners) to enhance sustainability innovation | | | | | |
| KS 5 | Employee training and awareness programs on sustainability initiatives are actively promoted within the organization | | | | | |

**SECTION C: DIGITAL TECHNOLOGIES**

Objective II: To explore the role of digital technologies in transforming production processes at ArcelorMittal Temirtau.
Response scale:
1 – Strongly Disagree
2 – Disagree
3 – Neutral
4 – Agree
5 – Strongly Agree

| SN | Question Item | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| DT 1 | Our company has adopted digital technologies (e.g., AI, IoT, and automation) to enhance production efficiency. | | | | | |
| DT 2 | The use of data analytics has improved decision-making in our manufacturing processes. | | | | | |
| DT 3 | Digital transformation has led to a reduction in operational costs and waste management inefficiencies. | | | | | |
| DT 4 | Employees are adequately trained to use digital tools and technologies in production. | | | | | |
| DT 5 | Our company's digitalization efforts have significantly improved product quality and environmental performance. | | | | | |

**SECTION D: IMPACT OF DIGITALIZATION ON PERFORMANCE**

These question items are designed to capture the relationship between digitalization, sustainability, and environmental performance, while considering the moderating roles of R&D investment and firm-specific capabilities.

**Response Scale (5-Point Likert Scale)**
1 – Strongly Disagree
2 – Disagree
3 – Neutral
4 – Agree
5 – Strongly Agree

| Variable | | Question Item | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|
| **Digitalization Initiatives** | D1 | Our company has adopted AI-driven technologies to optimize production processes. | | | | | |
| | D2 | Automation has significantly improved our operational efficiency and reduced manual intervention. | | | | | |
| | D3 | Data analytics is effectively used for predictive maintenance and process optimization. | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | D4 | Digitalization has led to a reduction in resource wastage and improved cost efficiency. | | | | | |
| | D5 | Employees receive adequate training to adapt to new digital technologies in the company. | | | | | |
| **Sustainability Initiatives** | X1 | Our company actively invests in carbon footprint reduction strategies. | | | | | |
| | X2 | Renewable energy sources, such as solar and wind, are increasingly used in our operations. | | | | | |
| | X3 | The company has effective waste management policies to reduce environmental impact. | | | | | |
| | X4 | Sustainability initiatives are integrated into our long-term business strategy. | | | | | |
| | X5 | We track and report sustainability metrics to ensure compliance with environmental goals. | | | | | |
| **Institutional Pressures** | P1 | Regulatory requirements strongly influence our company's sustainability and digitalization strategies. | | | | | |
| | P2 | The company actively adjusts its operations to comply with environmental laws and policies. | | | | | |
| | P3 | Competitive market forces push us to innovate in sustainability and digitalization. | | | | | |
| | P4 | Investors and stakeholders demand greater environmental responsibility from our company. | | | | | |
| | P5 | We engage with policymakers and industry associations to stay ahead of regulatory changes. | | | | | |
| **Environmental Performance** | E1 | Our company has successfully reduced emissions through innovative sustainability practices. | | | | | |
| | E2 | Energy efficiency improvements have led to measurable reductions in resource consumption. | | | | | |
| | E3 | The firm has implemented effective waste recycling and reduction programs. | | | | | |
| | E4 | Our environmental performance has improved due to sustainability and digitalization efforts. | | | | | |
| | E5 | We regularly assess and benchmark our environmental performance against industry standards. | | | | | |
| **R&D Investment** | R1 | The company invests significantly in R&D to drive sustainability and digitalization innovations. | | | | | |
| | R2 | R&D efforts focus on developing environmentally friendly technologies. | | | | | |
| | R3 | Our firm collaborates with research institutions to enhance digital and sustainable solutions. | | | | | |
| | R4 | The company's R&D investment directly contributes to operational efficiency improvements. | | | | | |
| | R5 | There is a dedicated budget for continuous research and development in sustainability and technology. | | | | | |
| **Firm-Specific Capabilities** | F1 | Our company has the necessary expertise to implement advanced digitalization strategies. | | | | | |
| | F2 | Employees possess the skills required to manage and operate sustainable technologies. | | | | | |
| | F3 | Training programs are provided to enhance digital and environmental competencies. | | | | | |
| | F4 | Our company effectively integrates digital and sustainability expertise to improve performance. | | | | | |
| | F5 | The firm's leadership actively supports skill development in digitalization and sustainability. | | | | | |