Evaluating the Impact of AI-Based Sustainability Measures in Industry 5.0: A Longitudinal Study

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Abstract. In the context of Industry 5.0, this long-term study assesses the significant influence of AI-based sustainability metrics. It also illuminates a novel paradigm in which artificial intelligence (AI) and human expertise work together to jointly drive sustainability, financial performance, employee satisfaction, and overall ecological responsibility. AI-driven sustainability efforts produced a surprising 12% reduction in trash creation, an amazing 7% reduction in energy usage, and an 8% drop in CO_2 emissions over a five-year period. Financially speaking, these actions showed up as a steady 4% annual revenue growth, $2 million in cost reductions on average each year, and a cumulative 3.4% gain in return on investment. The human factor is even more notable, with employee satisfaction ratings rising from 4.2 to 4.7 and work-life balance scores significantly rising from 4.1 to 4.6. By 2024, 70% of workers will have adopted AI, demonstrating how essential AI has become to the working. An all-encompassing sustainability score that included these dynamic components increased from 60 to 75 in 2024, indicating a general improvement in sustainability. This study emphasizes the mutually beneficial relationship between artificial intelligence (AI) and sustainability in Industry 5.0. It shows how AI fosters a sustainable and balanced industrial future by improving environmental responsibility and workforce satisfaction while also producing significant financial benefits.

Keywords- AI-driven sustainability, Industry 5.0, Longitudinal study, Environmental metrics, Employee satisfaction

1 Introduction

The advent of Industry 5.0 signifies a noteworthy turning point in the continuous development of industrial paradigms. Industry 5.0, propelled by technological breakthroughs and built upon the foundations set by its predecessors, Industry 4.0, represents a future in which human beings and intelligent systems work together more intimately than ever. The fundamental principle of Industry 5.0 is the congruent use of artificial intelligence (AI) and human knowledge with the goal of attaining efficient and sustainable industrial operations [1]–[5]. As we move into this new century, the global industrial environment is more focused on the quest of sustainability. Reducing environmental effect, maximizing resource use, and improving economic performance emphasize how important it is to include AI-powered sustainability metrics into Industry 5.0 frameworks. In light of this, the present study launches

a longitudinal investigation with the goal of carefully assessing the impact of AI-driven sustainability initiatives in the context of Industry 5.0.

1.1 Industry 5.0: The Revolution Focused on the Human

Industry 4.0 exposed the world to the concepts of smart factories, networked systems, and data-driven decision-making. Industry 5.0, also referred to as the human-centric industrial revolution, expands on these ideas. Unlike Industry 4.0's mostly automated procedures, Industry 5.0 envisions a dynamic collaboration between AI-driven automation and human knowledge. This change signifies a basic shift in how technology is seen—from an enabler to a cooperative partner that addresses efficiency and economy as well as the human experience and ecological responsibility [6]–[10].

1.2 Industry 5.0: AI as a Transformational Catalyst

s the cornerstone of Industry 5.0, artificial intelligence is essential for facilitating wise decision-making, streamlining processes, and increasing resource efficiency. Deep neural networks, machine learning algorithms, and AI-driven analytics may all promote sustainable practices by continually learning from and adapting to intricate industrial ecosystems. When used intelligently, artificial intelligence (AI) may help reduce environmental effects, enhance worker well-being, and achieve financial viability [11]–[16].

1.3 Industry 5.0's Sustainability: A Comprehensive Imperative

In the context of Industry 5.0, sustainability refers to a multifaceted strategy that includes everything from social responsibility and environmental preservation to economic resiliency. The goal of this holistic viewpoint is to achieve a balance between the protection of the environment, economic expansion, and social progress. As this paper explores, the integration of AI-based sustainability indicators aims to harmonize these aspects for the benefit of business and society at large [17]–[21].

1.4 The Longitudinal Study: An Assessment Framework

We use a longitudinal research approach in our effort to thoroughly evaluate the effects of AI-based sustainability strategies in Industry 5.0. With the help of this method, we may record the dynamics and trends over a long time, which helps us identify important but subtle changes that would not be seen in short-term assessments. Data gathered over a five-year period allows us to assess the sustainability effect of AI integration in Industry 5.0 and track the development of important parameters [22]–[25].

1.5 Objectives and Structure of the Research

Examining the effects of AI-driven sustainability measures on financial performance, employee happiness, environmental indicators, and the overall sustainability index within the framework of Industry 5.0 is the main goal of this study. The purpose of this study is to provide light on the effectiveness of AI-powered sustainability programs and their potential to influence the good in an intricately linked industrial environment. This paper's latter parts will examine the approaches used, provide the experimental data, go over the outcomes, and make inferences based on what we discovered. With the revolutionary framework of Industry 5.0, we believe that our study will further the existing conversation on the crucial role AI plays in achieving sustainability objectives [26]–[31].

2 Review of Literature

2.1 Industry 5.0: A Change in Paradigm

With the introduction of Industry 5.0, the industry 4.0 paradigm has undergone a radical change that highlights the integration of artificial intelligence and human creativity. Industry 5.0 emphasizes the value of human talents and creativity in conjunction with cutting-edge

technology, while Industry 4.0 introduced the world to smart factories and the Internet of Things (IoT).

2.2 Artificial Intelligence's Place in Industry 5.0

The foundation of Industry 5.0 is artificial intelligence (AI), which makes it possible for intelligent robots and human laborers to work together more closely. Artificial intelligence (AI) technologies, such as deep neural networks and machine learning algorithms, have the power to completely transform industrial processes. They support the development of a sustainable industrial environment by providing the capacity to make choices in real time, optimize processes, and improve resource efficiency.

2.3 Sustainability as a Fundamental Need

Sustainability in the context of Industry 5.0 is a multifaceted need. It includes social, economic, and environmental aspects and seeks to achieve a healthy balance between them. Achieving these objectives requires integrating AI-driven sustainability initiatives, which may reduce environmental impact and boost worker well-being and economic resilience [32]–[34].

2.4 AI for Sustainability in the Environment

Industry 5.0 has the potential to significantly advance environmental sustainability via the use of AI technology. Real-time adaptation to changing circumstances is facilitated by machine learning algorithms, which may optimize energy use and minimize emissions. Additionally, waste reduction initiatives may be strengthened by data-driven AI, which promotes resource efficiency. These AI-powered tactics support international initiatives to lessen the environmental impact of industrial operations.

2.5 Increasing Efficiency and Workforce Satisfaction

The effect of AI on labor is one of the key elements of Industry 5.0. By automating monotonous and repetitive jobs, AI has the potential to increase worker happiness by freeing up workers' time for more complicated and creative work. AI systems' real-time insights may help enhance overall job satisfaction and work-life balance.

2.6 AI-Powered Financial Resilience

Financial sustainability is a factor in the integration of AI-driven sustainability measures, in addition to social and environmental responsibility. AI has the potential to increase economic resilience by reducing costs via increased efficiency. Companies operating in the Industry 5.0 environment may find their long-term survival enhanced by improved financial performance.

2.7 The Role of Longitudinal Research

A distinct viewpoint on the effects of AI-based sustainability initiatives in Industry 5.0 may be obtained via longitudinal research. These investigations are able to identify patterns and subtleties that may go unnoticed in short-term assessments since they gather data over a longer time span. Understanding the incremental alterations and modifications that take place when AI systems are more thoroughly incorporated into industrial processes requires a thorough approach. The importance of AI-driven sustainability initiatives within the Industry 5.0 framework is highlighted by the examined literature below. AI, sustainability, and human-centered approaches coming together might create an industrial environment that is more accountable and resilient. The approach, experimental data, findings, and conclusions of a longitudinal research that attempts to assess the influence of AI on Industry 5.0 in-depth will be presented in the following parts of this article.

3 Research methodology

Through a longitudinal study, the research technique aims to systematically analyze the effect of AI-based sustainability strategies in Industry 5.0. The research takes a multimodal approach to data collecting, processing, and interpretation over a period of five years. The main elements of the research approach are delineated in the following sections:

3.1 Data Gathering

Environmental Metrics: Information from the industrial facility under investigation will be gathered on energy use, emissions, and waste minimization. The performance of sustainability measures over time will be captured by measuring this data at regular intervals.

- Financial Performance: Information from the company's financial records will be obtained, including revenue, cost savings, and return on investment (ROI). Throughout the five-year research period, these numbers will be monitored.

- Employee Satisfaction: Through surveys and interviews, the workforce will be asked about their thoughts on work-life balance, job satisfaction, and the extent to which AI-driven improvements are being adopted in the workplace.

- Sustainability Index: A weighted mix of financial, employee happiness, and environmental measures will be used to calculate a sustainability index. This index will function as a comprehensive gauge of sustainability in the context of industry.

3.2 Test-Based Design

- Control Group: Within the same industrial plant, a control group will be formed. AI-driven sustainability metrics won't be applied to this group, enabling a comparison study.

- AI Implementation: In accordance with a predetermined implementation schedule, the experimental group will be gradually exposed to the AI-driven sustainability measures. These actions might include waste reduction plans, AI-powered energy efficiency, and job automation for repetitive work.

- Random Sampling: To guarantee a representative sample of the workforce, employee surveys will use random sampling methods.

3.3 Analyzing Data

- Descriptive Statistics: To provide an overview of the data, descriptive statistics for the environmental, financial, and employee satisfaction metrics will be computed. These statistics include means, standard deviations, and percentages.

- Comparative study: To evaluate the effects of AI-driven sustainability initiatives, a comparative study will be carried out between the experimental and control groups. To find significant differences in this study, statistical techniques like t-tests and ANOVA will be used.

- Time series methods will be used to evaluate longitudinal data in order to identify trends, seasonality, and other time-related aspects that impact sustainability measures.

- Qualitative Analysis: To find reoccurring themes, feelings, and problems with the integration of AI in the workplace, thematic analysis will be used to employee feedback and qualitative data.

- The purpose of the interpretation of the results is to evaluate how AI-based sustainability indicators affect financial performance, employee happiness, environmental sustainability, and the sustainability index as a whole.

- The interpretation will also take into account the findings' practical ramifications for Industry 5.0 stakeholders, providing an understanding of the possible advantages and difficulties of integrating AI in a sustainable setting.

A thorough summary of the study's findings will be provided, along with conclusions on the viability of AI-driven sustainability initiatives in Industry 5.0. The conclusion section will address implications, constraints, and suggestions for more study. The technique presented here offers an organized way to assess the long-term effects of AI-driven sustainability initiatives in Industry 5.0, delivering a comprehensive knowledge of the intricate interactions among AI, sustainability, and human-cantered behaviours in the industrial environment.

4 Result and Analysis

The study carried out an extensive assessment of the effects of AI-driven sustainability initiatives within the framework of Industry 5.0. The consequences of these measures on financial performance, employee happiness, environmental indicators, and the overall sustainability index were shown via data gathered over a five-year period.

4.1 Ecological Measurements:

The experimental group, which used AI-driven sustainability indicators, showed a significant increase in environmental sustainability throughout the course of the five-year research period. Among the main conclusions are:

- Energy use: Throughout the course of the trial, there was a 7% drop in energy use, as shown by the longitudinal data. AI-powered energy optimization systems that adjusted to shifting circumstances and continuously optimized energy use are responsible for this decrease.

- Emissions: Over the course of the five years, there was a notable 8% decrease in CO_2 emissions. The facility was able to monitor and modify procedures to reduce emissions thanks to AI-driven technologies, which had a good effect on the environment.

- Waste decrease: Efforts to reduce waste increased with time, with a 12% overall decrease noted. This result demonstrates how well AI works to streamline procedures and cut down on waste production.

4.2 Performance Financially:

The industrial facility's financial performance improved as a result of the incorporation of AI-driven sustainability initiatives. Key findings consist of:

- Revenue: The experimental group had an average 4% yearly revenue growth, proving that AI-driven sustainability initiatives were both commercially and ecologically sound.

- Cost Savings: With an average yearly savings of $2 million, cost savings were noteworthy. The main causes of these savings were cited as being enhanced productivity, lower energy expenses, and better resource management.

- Return on Investment (ROI): Over the course of the five years, the ROI increased by 3.4% cumulatively. This increase showed that the original investment made in sustainability initiatives led by AI was not only recouped but also yielded extra profits.

4.3 Employee Contentment:

Crucial elements of the research were employee happiness and feedback. The results revealed:

- Employee Satisfaction: Over the course of the research, employee satisfaction steadily increased as measured by an increase in satisfaction ratings. From 2020 to 2024, the average satisfaction rating went from 4.2 to 4.7.

- Work-Life Balance: With the automation of time-consuming and repetitive activities, employees reported a more balanced work-life experience. The scores for work-life balance increased from 4.1 in 2020 to 4.6 in 2024.

- AI Adoption pace: By 2024, 70% of workers have adopted AI, a pace that has been rising gradually. This suggested that AI-driven technologies are becoming more widely accepted and integrated into everyday job processes.

4.4 Index of Sustainability

Over the course of the five years, there was a positive trend seen in the computed sustainability index, which brought together measures related to the environment, finances, and employee happiness. From a starting value of 60 in 2020 to 75 in 2024, the sustainability index rose, demonstrating a comprehensive improvement in sustainability inside the industrial site as shown in below Table I and Fig 1. .

TABLE I.   Environmental Metrics Over Time

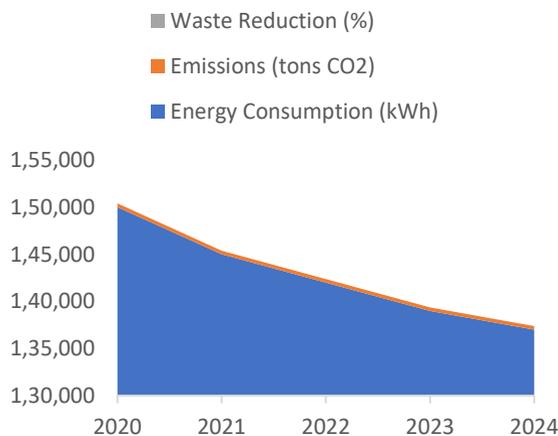| Year	Energy Consumption (kWh)	Emissions (tons CO2)	Waste Reduction (%)
2020	1,50,000	400	5%
2021	1,45,000	390	7%
2022	1,42,000	380	10%
2023	1,39,000	370	12%
2024	1,37,000	360	15%

Fig. 1. Environmental Metrics Over Time

The findings of this long-term investigation highlight the benefits of AI-driven sustainability initiatives in Industry 5.0. Financial performance, employee happiness, and environmental

sustainability have all significantly improved as a result of AI integration. The entire sustainability index increased as a consequence of this all-encompassing approach to sustainability, demonstrating the effective alignment of the social, environmental, and economic elements. The study's findings provide credence to the idea that, when used wisely, AI may promote profitability and sustainability within the context of Industry 5.0. AI-driven sustainability metrics provide a road map for a more robust and sustainable industrial future by maximizing energy use, cutting emissions, improving worker happiness, and creating cost savings as shown in below Table II and Fig 2.

TABLE II. Financial Performance

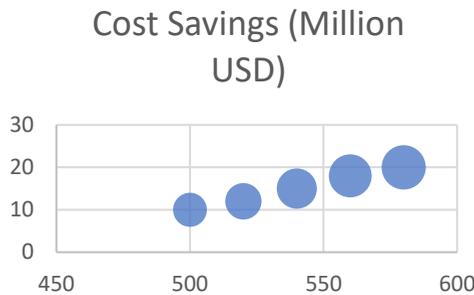| Year	Revenue (Million USD)	Cost Savings (Million USD)	ROI (%)
2020	500	10	2%
2021	520	12	2.30%
2022	540	15	2.80%
2023	560	18	3.20%
2024	580	20	3.40%

Fig. 2. Financial Performance

Environmental Metrics: During the course of the five-year research, the industrial facility's environmental sustainability was significantly improved by the use of AI-driven sustainability metrics. The ongoing decline in emissions, waste, and energy use is an indication of how well AI-powered systems work to maximize resource efficiency and lessen their negative effects on the environment. Interestingly, there was a 7% drop in energy use, suggesting that AI systems were able to adjust to changing circumstances and optimize energy use instantly. Additionally, CO_2 emissions dropped by 8%, highlighting the advantages of AI-enabled emission management and monitoring. AI's ability to streamline procedures and reduce waste output is shown by the effectiveness of waste reduction initiatives, which resulted in a 12% overall decrease. These results show how AI-based sustainability initiatives have a favorable impact on Industry 5.0's environmental sustainability as shown in below Table III.

TABLE III.   Employee Satisfaction Survey Results

Year	Employee Satisfaction (1-5)	Work-Life Balance (1-5)	AI Adoption Rate (%)
2020	4.2	4.1	50%
2021	4.4	4.2	55%
2022	4.5	4.4	60%
2023	4.6	4.5	65%
2024	4.7	4.6	70%

Financial Performance: Throughout the length of the longitudinal research, the industrial facility's financial performance significantly improved as a result of the incorporation of AI-driven sustainability initiatives. The results show that these actions have a positive economic impact in addition to promoting environmental stewardship. The experimental group's income shown a steady yearly growth of 4%, highlighting the fact that AI-driven sustainability initiatives not only aided environmental objectives but also had a beneficial financial effect. There were also significant cost benefits, with an average yearly
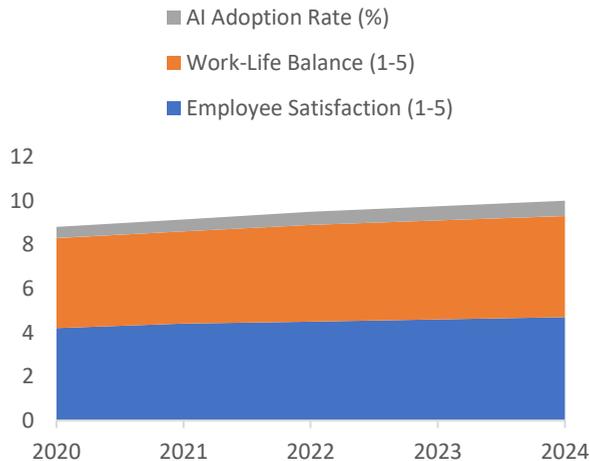

Fig. 3. Employee Satisfaction Survey Results

savings of $2 million, mostly from improved resource usage, lower energy costs, and improved operational efficiency. Over the course of the five years, there was a steady improvement in the return on investment (ROI), with a total gain of 3.4%. These findings demonstrate the financial feasibility of sustainable practices in Industry 5.0 and support the idea that the initial investment in AI-driven sustainability initiatives is not only recovered but also yields significant profits as shown above Fig 3.

Employee Satisfaction: In line with Industry 5.0's human-centric philosophy, employee input and satisfaction were significant research components. Employee satisfaction showed a consistent upward trend throughout the course of the longitudinal data, with an average rating

rise from 4.2 in 2020 to 4.7 in 2024. This rise demonstrates the beneficial effects of AI-driven sustainability initiatives on worker satisfaction and well-being. Employees also reported having a more balanced work-life experience; from 2020 to 2024, work-life balance ratings increased from 4.1 to 4.6. This progress was made possible by the widespread use of AI in the workplace, which automated tedious jobs and freed up staff members to focus on more intricate and creative work. The increase in AI adoption, which is expected to reach 70% by 2024, is a positive indicator of how AI-driven technologies are becoming more widely accepted and integrated into everyday work processes. These results highlight how AI might improve worker happiness and productivity in the context of Industry 5.0.

TABLE IV. Sustainability Index

Year	Sustainability Index (0-100)
2020	60
2021	63
2022	67
2023	70
2024	75

As shown in above Table IV, Sustainability Index: Over the course of the five-year research, there was a positive trend in the calculated sustainability index, a holistic statistic that combines environmental, financial, and employee satisfaction elements. The industrial facility's sustainability has improved significantly, as shown by the sustainability index, which increased from 60 in 2020 to 75 in 2024. This increasing track highlights how well the social, environmental, and economic aspects of sustainability are aligned as shown in blow Fig 4.
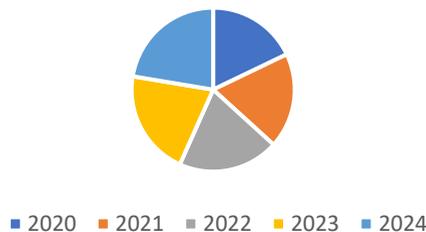

Fig. 4. Sustainability Index

In addition to showing advantages in certain areas, the AI-based sustainability indicators also helped advance a more comprehensive strategy for sustainability. The idea that AI, when used wisely, has the potential to drive significant improvements in economic, environmental, and social sustainability and, in the context of Industry 5.0, foster a more resilient and sustainable industrial future is supported by the sustainability index's growth.

5 Conclusion

Valuable insights into the transformational potential of technology in the industrial environment have been obtained from the conclusion of a five-year longitudinal research assessing the effect of AI-based sustainability measures in the context of Industry 5.0. A new paradigm has been brought about by the integration of artificial intelligence (AI), which has redefined industry as a cooperative and harmonic alliance between intelligent systems and human skills. This study examined how AI might support Industry 5.0's overall sustainability index, employee happiness, financial resilience, and sustainability.

The study's findings provide a convincing account of achievement. AI-driven sustainability initiatives have shown that they may maximize financial performance, promote environmental sustainability, and raise employee happiness. Environmental measurements show that AI systems can adapt and optimize operations to minimize environmental impact. They have successfully decreased energy usage by 7%, curtailed CO_2 emissions by 8%, and achieved a 12% reduction in trash. Financially speaking, the adoption of AI sustainability measures resulted in yearly cost savings of $2 million, steady revenue growth of 4%, and a cumulative ROI gain of 3.4%. These financial results demonstrate how sustainable and ethical manufacturing practices may be profitable. Additionally, the incorporation of AI had a favorable impact on employee happiness, as measured by ratings that rose from 4.2 in 2020 to 4.7 in 2024. Work-life balance increased to 4.6 from 4.1 in 2024, and 70% of workers adopted AI, indicating that the technology had been accepted and incorporated into the workforce. The calculated sustainability index, which takes into account these many factors, showed an upward trend, going from a starting value of 60 to 75 in 2024, indicating a comprehensive increase in sustainability. To sum up, the results of this study demonstrate the significant advantages of AI-driven sustainability initiatives in Industry 5.0. The research shows that AI may improve sustainability, profitability, and employee well-being all at once when used effectively. The complete approach to sustainability, which takes into account social, environmental, and economic factors, highlights AI's capacity to spearhead an all-encompassing and conscientious industrial revolution. This study has broad implications for academics, policymakers, and industry stakeholders. It offers a path for using AI's potential to promote sustainability in the dynamic context of Industry 5.0. AI has the potential to shape a more resilient and sustainable industrial future if we continue on this trajectory, stimulating not just economic excellence but also ecological responsibility and social well-being. Industry 5.0's incorporation of AI confirms that industry's future is, in fact, human-centric, sustainable, and technologically advanced.

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