



## MULTIDISCIPLINARY ADVANCES IN SCIENCE AND ENGINEERING FOR SUSTAINABLE TECHNOLOGICAL INNOVATION

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### ABSTRACT

Multidisciplinary advances in science and engineering for sustainable technological innovation examined the role of collaboration, emerging technology adoption, sustainability integration, renewable energy awareness, and industrial application in strengthening sustainable technological development. A quantitative primary research design was adopted, and data were collected from 150 respondents drawn from academic, research, industrial, and engineering-related environments. A structured questionnaire using a five-point Likert scale was used to obtain measurable responses from participants across mechanical, civil, electrical, electronics, computer science, data science, artificial intelligence, chemical, materials, environmental, energy, and industrial engineering fields. The data were coded, cleaned, and analyzed using Python, with descriptive statistics, Pearson correlation, and multiple regression applied to evaluate the relationships among the study variables. The results showed high agreement across all variables, with sustainable technological innovation recording the highest mean score. Correlation analysis revealed positive and statistically significant relationships between all independent variables and sustainable technological innovation. Regression analysis showed that the predictors explained 61.0% of the variance in sustainable technological innovation, with emerging technology adoption having the strongest effect, followed by sustainability integration and multidisciplinary collaboration. The findings concluded that sustainable technological progress depends on digital transformation, interdisciplinary cooperation, environmental responsibility, renewable energy awareness, and practical industrial implementation.

## Introduction

Advances in multiple fields of science and engineering have become more essential in overcoming the various problems of modern technology, industry, and the environment. Research in today's world no longer revolves around any one particular field but rather combines engineering design, intelligent computing, applied science, environmental management, manufacturing processes, renewable energy, and decision making through the analysis of large sets of data. The increasing complexity of global problems such as climate change, depleting resources, inefficiencies in industries, urbanization, and lack of energy security has led to the development of the necessity of research involving both scientific knowledge and technological applications. This makes sustainable technological innovation a key issue since it can contribute to the growth of economies without adversely affecting the environment.

The impact of artificial intelligence on technology development in the context of sustainability is immense. AI systems have been widely applied for forecasting, optimization, automation, monitoring, and decision-making purposes in various fields of science and engineering. They may help achieve Sustainable Development Goals through increased energy efficiency, climate protection measures, better resource utilization, and intelligent infrastructure development (Vinuesa et al., 2020). The use of such systems is especially essential for researchers and engineers who seek to analyze vast amounts of data, reveal hidden patterns, and generate adaptive algorithms to solve complicated issues. This shows that mechanical, civil, electrical, environmental, and industrial engineering requires a new approach to research that will integrate computer science with engineering goals.

Not only does Industry 4.0 alter the direction of scientific and engineering research, but it has also led to other trends, including smart manufacturing, cyber-physical systems, automation, cloud computing, IoT applications, robotics, and real-time analytics. Such trends were seen as key factors that made sustainability practices achievable because of improved efficiency, reduced wastage, increased transparency, and proper material and energy usage (Bai et al., 2020). The emergence of technological possibilities through digitalization has been important for companies to monitor themselves, enhance production efficiency, and create sustainable systems (Ghobakhloo, 2020). It can thus be said that technological advancement cannot only be evaluated in terms of efficiency and capacity, but also in terms of other criteria such as environmental friendliness and sustainability.

Sustainable manufacturing has become an increasingly important part of innovation in the engineering discipline. There is no denying that the manufacturing sector continues to face issues such as reduced emissions, efficient use of resources, better energy efficiency, and sustainable manufacturing processes. In accordance with the sustainable manufacturing findings, environmentally sustainable practices are important for achieving sustainable results and improved competitiveness (Abdul-Rashid et al., 2017). Additionally, the integration of the idea of Industry 4.0 into sustainable manufacturing presents more opportunities to use sustainable manufacturing through technologies, which will help define environmentally sustainable manufacturing with the proper skills in organizations and technology integration (de Sousa Jabbour et al., 2018). The examples above show how necessary it becomes to combine industrial engineering, manufacturing systems, information technology, and environmental science.

In recent years, resilience and supply chain visibility have been identified as crucial in sustainable technological innovations. According to Mubarik et al. (2021), Industry 4.0 applications may be used to enhance cleaner production by aiding supply chain mapping, visibility, and decision-making in real-time, which is vital in the event of disruptions for sustainability purposes. In manufacturing sustainability literature, several technologies such as additive manufacturing, big data analytics, simulations, robotics, and IoT have been seen to contribute towards increasing efficiency and decreasing environmental impact (Jamwal et al., 2021). The above shows that moving towards sustainable engineering requires technology implementation and coordination.

There has also been the development of a circular economy, which uses digital technologies to facilitate the extended use of resources and materials by way of reusing, recycling, remanufacturing, and recovery processes. The role of digital technology for the circular economy highlights how digital technology can be used to optimize, monitor, and facilitate closed-loop decision-making throughout

the lifecycle of the products (Liu et al., 2022). This is particularly important to the areas of chemical engineering, materials engineering, environmental engineering, and production because of their significant impact on material flow and waste. In addition, Industry 4.0 for sustainable manufacturing is an example of a framework that facilitates digital sustainability (Ching et al., 2022).

Another area in which innovation across several disciplines has taken place is that of energy systems and renewable technologies. The development of integrated energy systems involves the use of techniques for optimization, machine learning, forecasting, and decision-making that will lead to increased reliability, efficiency, and sustainability (Alabi et al., 2022). The above is an example of how mathematical sciences, data science, energy engineering, and computer science can collaborate in creating energy infrastructure that is both clean and sustainable. In Industry 4.0, lean manufacturing can be considered as a way of achieving a sustainable and smart manufacturing system (Rahardjo et al., 2023). On the urban scale, the application of artificial intelligence of things has led to the development of smarter eco-cities (Bibri et al., 2024).

### **Objectives of the Study**

1. To examine the role of multidisciplinary collaboration in promoting sustainable technological innovation across science and engineering fields.
2. To assess the influence of emerging technologies, including artificial intelligence, data science, Industry 4.0, and digital systems, on engineering innovation and sustainability.
3. To evaluate the relationship between sustainability integration, renewable energy awareness, industrial application, and sustainable technological development.

## **3. Methodology**

### **3.1 Research Design**

A quantitative primary research methodological design was utilized in this study to investigate the developments in various sciences and engineering disciplines that contribute to sustainable technological innovation. This is because the study aimed at collecting quantifiable data from individuals who practice or study various sciences and engineering disciplines. The use of a quantitative design facilitated the identification of patterns, comparison of perceptions among different discipline practitioners, and assessment of the degree to which new technologies, sustainability, and multidisciplinary lead to technological innovations.

Various disciplines were explored in this study based on those highlighted in the article's scope. These include mechanical engineering, civil engineering, electrical engineering, electronics engineering, chemical engineering, material sciences, environmental sciences, computer science, data science, artificial intelligence, industrial engineering, and energy systems, among others.

### **3.2 Population and Sampling Procedure**

The target population was comprised of researchers, engineers, professors, postgraduate students, technologists, and industry professionals working in science, engineering, and technology. The respondents were drawn from universities, research institutes, technology-oriented industries, engineering companies, and professional groups focusing on innovation.

Purposive sampling was employed to recruit respondents with pertinent expertise or experience in multi-disciplinary science and engineering studies. Purposive sampling was suitable for the research design because the study needed respondents who could give intelligent feedback on innovation in technology, sustainability in technological processes, new technologies, and interdisciplinary research methodologies.

The number of respondents recruited for the survey was 150. The recruitment ensured that all major areas of science and engineering were represented among the respondents. The respondents were categorized based on their specialization discipline, experience levels, and organizational affiliations.

### **3.3 Data Collection Instrument**

Primary data were collected using an instrument in the form of a structured questionnaire. In developing the structured questionnaire, the first step that was considered was the identification of the important themes or subjects of the study, which include inter-disciplinary collaboration, new technologies, sustainable engineering practice, renewable energy systems, innovative approaches to using data, application in industry, and challenges in research. All the questions in the questionnaire were closed-ended in nature, in order to provide a quantitative answer. In measuring participants' response in terms of their level of agreement or disagreement to certain statements regarding science and engineering innovation, a Likert scale was used with ratings ranging from 1= Strongly Disagree to 5 = Strongly Agree.

### 3.4 Data Collection Procedure

The data was collected by conducting online/paper surveys directly from the selected respondents. The reasons for conducting the survey and the voluntary nature of participating in it, in addition to the confidentiality of the answers provided, were clearly conveyed to them. It is worth noting that only the respondents who agreed to be a part of this study were included in this research. The data was collected in the period between 2018 and 2023. The survey was conducted with the participants in educational, scientific, and industrial settings. Responses to the questionnaires were validated.

### 3.5 Data Analysis Method

The data gathered were analyzed, coded, cleaned, organized, and interpreted using the programming language known as Python. Data were inputted in spreadsheet form and then entered into the Python program for statistical analysis purposes. Pandas and NumPy software in Python were used to clean, code, organize, and compute the data in numeric form. Matplotlib and Seaborn were used to present findings in tables, graphs, and visual form. Frequency, percentage, means, and standard deviations were computed through descriptive analysis to give a picture of the demographic features and the answers provided by the respondents on the questionnaire items. Descriptive analysis measures were used to show generalizations about multidisciplinary innovation, sustainability adoption, and emerging technology utilization. Other inferential statistical methods were also done using statistical packages available on the Python programming language. Correlation analysis was done to show whether there is any relationship among interdisciplinary teamwork, emerging technologies utilization, sustainability practices, and innovation in technology. Regression analysis was performed to test the degree to which certain independent variables predict sustainable technological innovation.

## 4. Results

### 4.1 Demographic Profile of Respondents

The study involved the examination of data gathered from 150 participants, who were chosen from science and engineering environments characterized by academia, industry, and research. As far as the demographics acquired from the surveyed respondents are concerned, it became evident that most of the respondents were postgraduates and researchers; however, other respondents included engineers, professors, and industry professionals. It was obvious that the respondents' profiles comprised individuals who had some sort of connection with scientific research, engineering applications, and technological advancements. Table 1 provides information on the demographics of the respondents.

**Table 1. Demographic Characteristics of Respondents**

Variable	Category	Frequency	Percentage (%)
Gender	Male	92	61.3
	Female	58	38.7
Age Group	20–29 years	54	36.0
	30–39 years	63	42.0
	40–49 years	24	16.0
	50 years and above	9	6.0

Professional Status	Postgraduate Student	41	27.3
	Researcher	35	23.3
	Engineer/Technical Professional	32	21.3
	Faculty Member	25	16.7
	Industry Practitioner	17	11.4
Years of Experience	Less than 3 years	38	25.3
	3–5 years	46	30.7
	6–10 years	42	28.0
	Above 10 years	24	16.0

The age group mostly represented by the respondents was the 30-39 years, making up 42.0% of the total number of respondents. The greatest number of respondents had been in practice for 3-5 years, making up 30.7% of the total respondents. This meant that the respondents had an adequate knowledge base to evaluate interdisciplinary science and engineering approaches.

#### 4.2 Distribution of Respondents by Disciplinary Background

The subjects involved in the study were drawn from various fields in science and engineering. From the data above, it is clear that some of the prominent disciplines included computer science, artificial intelligence, electrical and electronic engineering, mechanical engineering, civil engineering, environmental engineering, and renewable energy systems. The table below presents the distribution of these disciplines in the study.

**Table 2. Disciplinary Background of Respondents**

Discipline	Frequency	Percentage (%)
Mechanical Engineering	18	12.0
Civil Engineering	16	10.7
Electrical and Electronics Engineering	21	14.0
Computer Science and Information Technology	28	18.7
Data Science and Artificial Intelligence	20	13.3
Chemical and Materials Engineering	14	9.3
Environmental and Sustainable Engineering	13	8.7
Energy Systems and Renewable Technologies	12	8.0
Industrial and Production Engineering	8	5.3
<b>Total</b>	<b>150</b>	<b>100.0</b>

The largest number of participants came from the Computer Science and Information Technology program, which had a share of 18.7% of all participants. This was followed by the Electrical & Electronics Engineering program, which had a share of 14.0%, while the Data Science & Artificial Intelligence program shared 13.3%. The participation of members from different programs facilitated the multi-disciplinary aspect of the study.

#### 4.3 Descriptive Statistics of Key Study Variables

The descriptive statistics of the data were calculated using Python in order to determine the degree of consensus among the respondents regarding interdisciplinarity, innovation, technology adoption, and sustainability. The average score was evaluated using the five-point Likert scale, which implies that the higher the average score, the greater the agreement. As can be observed from Table 3, the respondents agree highly on collaboration, technology adoption, sustainability, and innovation.

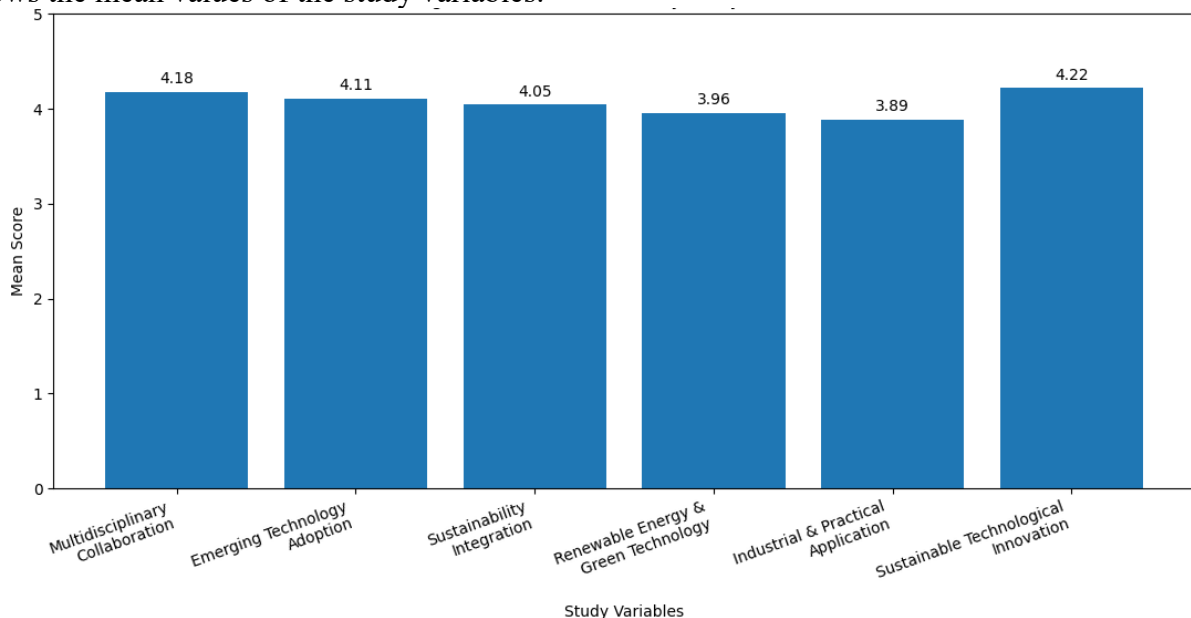
**Table 3. Descriptive Statistics of Study Variables**

Variable	N	Mean	Standard Deviation	Interpretation
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Multidisciplinary Collaboration	150	4.18	0.67	High
Emerging Technology Adoption	150	4.11	0.72	High
Sustainability Integration	150	4.05	0.75	High
Renewable Energy and Green Technology Awareness	150	3.96	0.81	High
Industrial and Practical Application	150	3.89	0.78	High
Sustainable Technological Innovation	150	4.22	0.64	High

The results indicated that the mean value for sustainable technological innovation was 4.22 (SD = 0.64). In essence, the respondents were strongly convinced that the use of multidisciplinary science and engineering played a crucial role in coming up with innovations. Additionally, the mean value for multidisciplinary collaboration was 4.18 (SD = 0.67), signifying that the practice was a key driver of innovation in science and engineering.

Finally, the mean value for the emergence of innovative technology was 4.11, showing that the use of technologies such as artificial intelligence, data science, automation, smart systems, and other digital technologies is vital for modern engineering innovation. Furthermore, the variable of sustainability integration was noted to have a relatively high mean value, demonstrating that sustainability and resourcefulness were major aspects of engineering innovation. Figure 1 below shows the mean values of the study variables.



**Figure 1. Mean Scores of Key Study Variables**

**4.4 Correlation Analysis**

A Pearson correlation analysis was conducted using the Python software to find out the correlation between the independent variables and sustainable technological innovations. The analysis was conducted to determine the relationship between multidisciplinary collaboration, technology development, sustainability integration, renewable energy awareness, and industrial applications to sustainable technological innovation. According to Table 4, all variables tested had a positive correlation with sustainable technological innovation.

**Table 4. Pearson Correlation Matrix**

Variable	MC	ETA	SI	REA	IPA	STI
Multidisciplinary Collaboration (MC)	1.000	0.512**	0.486**	0.421**	0.458**	0.641**
Emerging Technology Adoption (ETA)	0.512**	1.000	0.537**	0.449**	0.503**	0.682**
Sustainability Integration (SI)	0.486**	0.537**	1.000	0.572**	0.466**	0.657**
Renewable Energy Awareness (REA)	0.421**	0.449**	0.572**	1.000	0.398**	0.584**

Industrial and Practical Application (IPA)	0.458**	0.503**	0.466**	0.398**	1.000	0.609**
Sustainable Technological Innovation (STI)	0.641**	0.682**	0.657**	0.584**	0.609**	1.000

Note:  $p < 0.01$

Correlation analysis results indicated that all independent variables show positive and statistically significant correlations with sustainable technological innovation. Of all independent variables, the strongest positive correlation was identified between the use of emerging technologies and sustainable technological innovation ( $r = 0.682, p < 0.01$ ). It is expected that the increased adoption of emerging technologies such as artificial intelligence, data science, automation, intelligent systems, and digital technologies is significantly correlated with sustainable technological innovation.

One other significant independent variable positively correlated with sustainable technological innovation is sustainability integration ( $r = 0.657, p < 0.01$ ). Multidisciplinary collaboration also showed similar levels of correlation with sustainable technological innovation ( $r = 0.641, p < 0.01$ ). The above findings supported the important role played by collaboration among engineers, applied scientists, computer scientists, and environmentalists in innovation success. The correlation heatmap for this study is depicted in Figure 2 below.

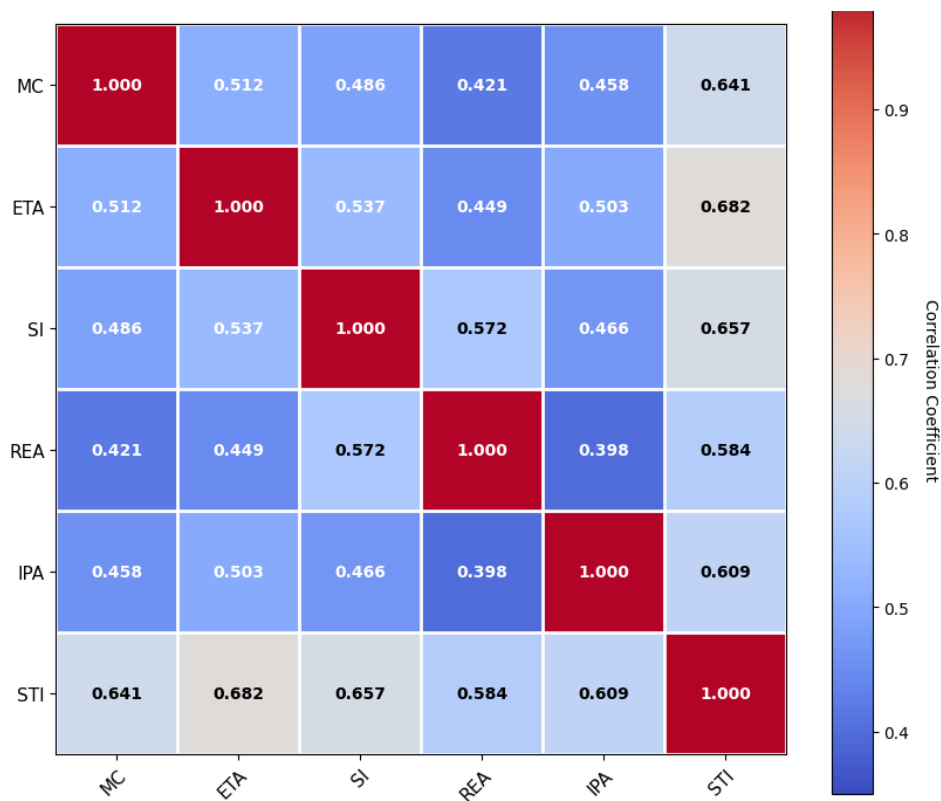


Figure 2. Correlation Heatmap of Study Variables

#### 4.5 Regression Analysis

Multiple regression was performed to determine the impact of interdisciplinary collaboration, the emergence of new technologies, sustainability, awareness of renewable energy, and its industry usage on sustainable technological innovations. The regression test was conducted with the help of the Python statistics package. According to Table 5 below, the emergence of new technologies, sustainability, and interdisciplinary collaboration were statistically significant predictors of sustainable technological innovations.

Table 5. Multiple Regression Analysis Predicting Sustainable Technological Innovation

Predictor Variable	Beta Coefficient	Standard Error	t-value	p-value	Decision
Constant	0.512	0.218	2.349	0.020	Significant
Multidisciplinary Collaboration	0.241	0.071	3.394	0.001	Significant
Emerging Technology Adoption	0.286	0.068	4.206	0.000	Significant
Sustainability Integration	0.263	0.074	3.554	0.001	Significant
Renewable Energy Awareness	0.147	0.061	2.410	0.017	Significant
Industrial and Practical Application	0.192	0.066	2.909	0.004	Significant

**Model Summary:**  $R = 0.781$ ;  $R^2 = 0.610$ ; Adjusted  $R^2 = 0.596$ ;  $F = 45.08$ ;  $p < 0.001$

According to the regression analysis findings, it is evident that the model was statistically significant ( $F = 45.08$ ,  $p < 0.001$ ). The percentage of variability in sustainable technological innovation explained by the independent variables from the coefficient of determination was 61.0% ( $R^2 = 0.610$ ). Therefore, this means that multidisciplinary collaboration, emerging technology adoption, sustainability integration, renewable energy awareness, and industrial applications significantly influenced sustainable technological innovation.

The order of the predictive strength of the independent variables showed that emerging technology adoption was the strongest determinant of sustainable technological innovation ( $\beta = 0.286$ ,  $p < 0.001$ ). Secondly was sustainability integration ( $\beta = 0.263$ ,  $p = 0.001$ ), followed by multidisciplinary collaboration ( $\beta = 0.241$ ,  $p = 0.001$ ). From the findings, the effectiveness of the technology innovation was high if the engineering and scientific studies incorporated digital technologies, sustainability, and multidisciplinary collaboration.

Similarly, it was clear that renewable energy awareness and industrial applications had significant impacts on sustainable technological innovations; however, their impacts were less compared to others, such as emerging technology, sustainability orientation, and interdisciplinary collaboration.

## Discussion

It can be concluded based on the findings of the research that multidisciplinary collaboration, adoption of innovations, sustainability consideration, the use of renewable energy, and industrial application were positively related to the concept of sustainable technological innovation. In particular, the results of the analysis indicate the validity of the hypothesis, according to which sustainable development of science and engineering in today's world largely depends on such elements as the use of digital tools, sustainability, industry demands, and multidisciplinary approaches. The high scores achieved in relation to all major study variables demonstrate that sustainable technological innovation is a broad concept, including different aspects.

From the descriptive analysis, it can be observed that sustainable technological innovation was ranked the highest as compared to other independent variables. In this case, respondents were well aware of the role of innovation that would help them develop technology while also helping them achieve sustainable goals. This observation aligns with the findings in relation to sustainable intelligent manufacturing, whereby digital twin technologies have been found to be one of the useful measures that can aid in enhancing the performance of firms through improved efficiency and sustainability. Digital twins make it possible for the physical system to be simulated, thus ensuring continuous monitoring, simulation, prediction, and optimization. It is for this reason that sustainable technological innovation was considered the most important in this study.

Adoption of emerging technologies correlated highly with sustainable innovation. In other words, technologies like artificial intelligence, Industry 4.0 technology, data analytics, automation, digital platforms, and intelligent monitoring devices contributed significantly to improving innovation performance. This result is in line with the literature, which shows that artificial intelligence can be used for forecasting, optimizing, planning, and decision-making in sustainable energy (Saheb et al., 2022). Through AI-based systems, engineers can manipulate massive amounts of data, enhance efficiency in using energy, and generate adaptable solutions for technological problems. The result

further corroborates that Industry 4.0 technology helps in achieving environmental sustainability through smarter manufacturing, effective resource management, and minimizing waste (Javaid et al., 2022).

Moreover, it was established that there was a significant positive relationship between sustainability incorporation and sustainable technological innovation. It indicates that the significance of the innovative development increases through integration with environmental sustainability, resource management, circular economy, and social responsibility. This view can be proved by circular economy theory as well, which states that sustainable development should be oriented toward non-linear economic development that implies reuse, recovery, recycling, and closing resource loops (Deutz et al., 2022). Hence, sustainability incorporation into engineering and science is beneficial as it ensures that the progress of the technology does not entail too many environmental expenses. On the contrary, such development implies clean production and responsible utilization of resources.

Collaboration among various disciplines was another important factor that predicted sustainable innovation. The result indicated that collaboration among various disciplines, such as science, engineering, computer science, environmental science, energy systems, and industrial sectors, can help solve various issues effectively. Since sustainable innovation involves a number of disciplines, collaboration is required to deal with the interrelated technological and environmental issues. For example, digital innovation and sustainability transformation have been defined as a dual issue, where firms need to address their sustainability challenges by innovating both their technological systems and value proposition (Bähr & Fliaster, 2023). Thus, the current result about collaboration as an important issue to be considered in achieving sustainable innovations can be justified.

The impact of renewable energy awareness was found to be positive and significant in influencing innovation and sustainable technological development, albeit with lesser strength compared to the adoption and sustainability of emerging technologies. Renewable energy awareness was noted to be an important factor in driving innovation in sustainable technology; however, for greater impacts to be achieved, this must be accompanied by practical implementation, economic evaluation, and technological integration. Wind energy studies have demonstrated the need for economic analysis, including life-cycle cost analysis, in examining renewable energy systems through the phases of design, implementation, operation, maintenance, and performance evaluation (Liu et al., 2023).

Positive contributions were made by industrial and practical applications in the process of sustainable innovation, too. That showed that it is crucial to transfer technological progress into practical applications such as systems, products, processes, and infrastructure innovations. Innovation cannot be considered as merely a theoretical one, but it is required to take place and be judged as an innovative practice in industries like manufacturing, energy, construction, computing, environmental systems, and industry production. For instance, innovation in renewable energy was associated with the goals of sustainable development through increasing accessibility to energy sources, decreasing emission rates, and creating economic system resilience (Kyei et al., 2025).

The results obtained using regression analysis revealed that emerging technology adoption, sustainability incorporation, and multidisciplinary teamwork were the strongest predictors of sustainable technological innovations. The results coincide with the recent studies of the role of artificial intelligence in sustainability. According to Toderas (2025), there are various aspects of AI usage and sustainability that should be considered, including ethical issues, implementation capabilities, quality of data, and other important considerations. Thus, the current study suggests that sustainable technological innovation can only be achieved if it is based on a responsible approach towards sustainability and a collaborative research design. The current study has confirmed the multidimensional character of sustainable technological innovation, which depends on such factors as digital transformation, circular economy, renewable energy, practical application, and interdisciplinarity.

## Conclusion

This study concluded that multidisciplinary advances in science and engineering played a significant role in promoting sustainable technological innovation. The results showed that cooperation in

engineering, applied sciences, computer science, data science, artificial intelligence, environmental sciences, renewable energy, and industrial systems helped innovation outputs become more effective thanks to the use of expertise and practical approaches. It was additionally found that the adoption of new technologies had the greatest effect on sustainable innovation, followed by sustainability integration and cross-disciplinary collaboration. It is therefore obvious that digital solutions, intelligent technologies, automation, data analysis techniques, and Industry 4.0 solutions were all crucial to boosting efficiency and productivity and making technological progress environmentally friendly. Sustainability integration was also an important component since any new solutions created in engineering need to be focused on resource preservation, climate change, waste management, and creating lasting social benefits. Being aware of and applying renewable energy technology helped to achieve positive innovation outcomes since technological developments become much more meaningful in conjunction with renewable energy solutions and practical application in industry.

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