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Digital Technologies' Contribution to the Environmental Market's Sustainability

Dr. Akash Kumar Arya[1], Dr. Bhuwan Gupta[2]

[1]Assistant Professor, School of Business Management,
IFTM University, Moradabad, India
[2]Assistant Professor, School of Business Management,
IFTM University, Moradabad, India

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ABSTRACT

Industry 4.0 has transformed manufacturing systems by adopting digital technologies such as big data analytics, cloud computing, and the Internet of Things. This transformation has improved customer service, increased production efficiency, and enhanced product development. Nevertheless, these technologies can put both financial and environmental limitations on businesses. The influence of digital technology on the economic and ecological market is contingent upon multiple elements, including the dynamic nature of the environment. Precision agriculture utilizes Digital Twin and Blockchain technologies to enhance decision-making processes and ensure food security. An integrated research strategy was employed to examine the barriers to implementing digital technology in emerging economies. Industry 4.0 technologies can be utilized in flexible manners, such as monitoring soil conditions, integrating drones, and managing livestock to decrease water usage, optimize the application of fertilizers and nutrients, and enhance social sustainability.

Keywords: Environmental market, Industry 4.0, Digital Twin, Blockchain technology, I4.0 technologies.

1. INTRODUCTION

In academic and professional groups, the emergence and application of digital technologies have provoked lively debates, particularly concerning the emerging period known as Industry 4.0, or I4.0. Within the framework of Industry 4.0, "digital technologies" refers to a range of sophisticated and inventive technologies as well as a paradigm. Automation, communication, and networking are made easier by technological advancements like cloud computing, big data analytics, and the Internet of Things [1]. With the help of these developing cutting-edge technologies, businesses may improve their production systems that are both vertically and horizontally linked [3] and collect data using data-driven methods that cover the entire life cycle of a product, including material quality and process characteristics. In a manufacturing system run by digital technology, this is possible.

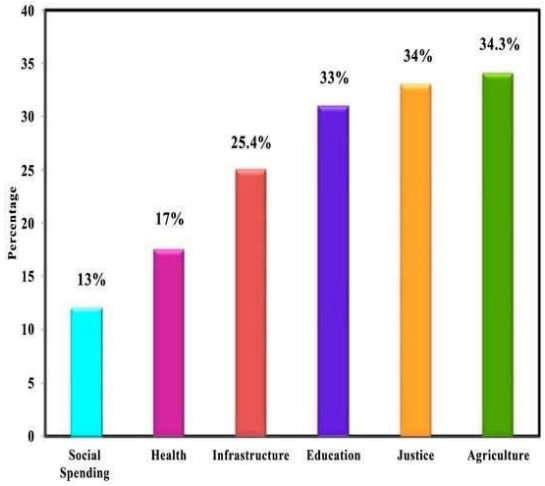

Figure 1: Sustainable development sectors [27]

The advent of digital technologies offers industrial firms advantages as well as difficulties in terms of effectively and sustainably growing their businesses. A digital revolution has been brought about by the widespread adoption of intelligent technologies in the industrial sector. Along with the possibility for improvements in customer service, manufacturing efficiency, and product creation, the revolution has brought about a change in the traditional approaches to production and operations management [4]. Furthermore, these cutting-edge technologies can improve resource distribution more effectively, which will help achieve environmental sustainability [5-7]. On the other hand, industrial organizations may face both financial and environmental constraints as a result of evolving technologies, which can further exacerbate competitive forces in business contexts [8].

In addition, we examine the possible impact of digital technology while accounting for other variable aspects including the dynamic features of the present situation. Information processing technology (IPT) emphasizes how crucial it is to match the information needs and processing capacity of an organization with the business environment [9]. The qualities of the surrounding environment can have an impact on how well supply chain platforms and advanced digital technologies integrate, as said. The primary objective of this study is to examine environmental dynamism, which pertains to the degree of instability or volatility that a firm encounters in its operating environment [10]. According to the study's authors, the degree of environmental dynamism has an impact on how technological innovations and supply chain networks influence both financial and environmental outcomes.

2. Objectives of Study

- To analyze how digital technologies enhance monitoring and reporting of environmental metrics.
- To evaluate the impact of AI and machine learning on sustainable practices.
- To assess the role of blockchain in improving transparency in environmental markets.
- To examine how IoT devices contribute to resource efficiency and conservation efforts.

3. Literature Review

Utilizing digital technologies in this scenario can lead to unforeseen and harmful consequences for sustainable development. It is necessary to give priority to and carry out a comprehensive analysis of the impact of digital technologies on sustainability performance, specifically in terms of economic and environmental aspects.
This study aims to demonstrate the need to use an established supply chain platform in order to understand the impact of technological advances on sustainability results. Prior studies have acknowledged the significance of advanced digital technologies in relation to Industry 4.0, particularly in the setting of supply chain interaction [9-11]. Moreover, the advancement of digital logistics platforms allows for the gathering and elimination of significant amounts of data, as well as effortless integration and cooperation [12]. Manufacturing businesses are strongly advised to form collaborations with their distribution partners in the supply chain and enhance the utilization of digital technologies in order to attain sustainable development [13]. Although academics have made attempts to incorporate digital technologies into logistics networks, there is a lack of research examining the effects of digital technology on sustainability in the economy and the environment by means of online supply chain platforms.

The theoretical basis for our examination is the concept of information process theory (IPT), which serves as the cornerstone of our study of research [14, 15]. Logistics and management of the environment require a significant amount of data [16, 17]. To achieve outstanding performance, an organization must improve both the quality of the information it manages and its capacity to process that information. To do this, one can follow the principles of the data process theory (IPT) [18,19], which considers the entity as a social-economic system that is open. Digital technologies are essential elements of an organization's data framework, demonstrating its ability to manage information. Supply chain platforms facilitate the sharing of information among players in the supply chain, which is seen as a valuable external source of information. Manufacturing businesses can implement eco-friendly practices by utilizing advanced information processing capabilities to examine data acquired from the external supply chain. This study investigates the efficiency of the manufacturing process and the environmental impact of using digital technologies to connect various components of the manufacturing process, with a particular focus on IPT.

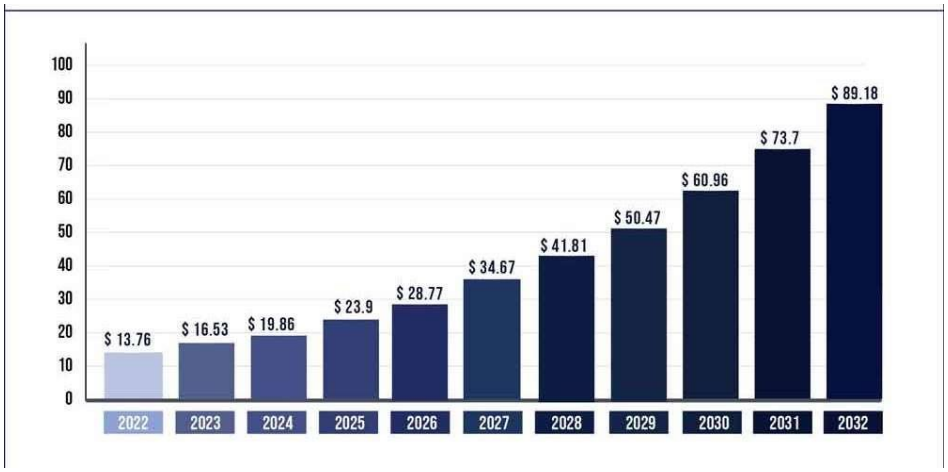

Figure 2: Green Technology and Sustainability Market Size to Reach USD 89.18 Bn by 2032 [25]

The advent of Industry 4.0 has also led to the development of a novel simulation modeling technique known as the Digital Twin. This encompasses the entirety of the product's life cycle, starting with the creation and testing of the original goods in a virtual setting. Each succeeding step builds upon the knowledge and data collected from the preceding phases [20-23]. The utilization of Digital Twin technology encompasses a broad spectrum of applications inside an organization. For example, an operator can develop expertise in managing virtual machines by using an in-line virtual machine until she has acquired the required skill and confidence to effectively operate the actual equipment. This reduces the probability of the operator causing damage to the instrument while simultaneously speeding up the learning process [24, 25]. Moreover, it can efficiently recognize and resolve practical issues by leveraging sophisticated machine-learning capabilities while simultaneously retaining optimal control. It is possible to integrate it into equipment to enhance its awareness of oneself, optimize its efficiency for specific employment cycles, diagnose and correct non-catastrophic flaws, and coordinate how it works with other devices with little operator involvement [26].

The implementation of blockchain technology facilitates the incorporation of data collected from Internet of Things (IoT) devices in precision agriculture. Furthermore, a wide range of data is gathered, including both organized and disorganized datasets. The data encompasses information on crop types and movement, nutrients in the soil and kinds, climate variables, GPS data and machine-generated data, including fertilizer rates and output data. By utilizing data analysis, precision agriculture can be achieved, leading to informed decision-making in farming. This pertains to situations that encompass substantial quantities of data. For example, BDA can assist farmers in effectively monitoring water resources and enhancing their agricultural yield by forecasting potential harmful occurrences in farming and selecting suitable fertilizers and pesticides to use [27]. In addition, agricultural companies may employ Big Data Analytics (BDA) to determine the exact quantity of food that has to be produced, preserved, and distributed. This can be advantageous in the development of an agricultural and nutrition security data system.

Various companies and organizations have developed additive manufacturing gear with diverse applications, such as producing pasta and confectionery. Table 1 presents a detailed analysis of the AM categories, commercial solutions, and food materials.

Table 1: Food Additive Manufacturing

ASTM Classification (AM Processes)	Commercial Technological Solution	Food Material
Powder Bed Fusion	Selective Laser Sintering	Sugar
Directed Energy Deposition	n.a. for food	n.a. for food
Material Jetting	Polyjet	n.a. for food
Binder Jetting	3D Printing – Inkjet Printing	Sugar, Protein powders
Material Extrusion	Fused Deposition Modeling (FDM)	Chocolate, Pasta Dough
Vat Photopolymerisation	Stereolithography (SL)	Eggs white, package
Sheet Lamination	Laminated Object Manufacturing (LOM)	n.a. for food

4. Material and Methods

This investigation has employed a mixed methodology approach due to the inclusion of both qualitative and quantitative features in the research questions. An embedded case study was used to determine the main digital technology implementation hurdles. This design has been employed to uncover possible uses and advantages that have arisen from the implementation of digital technologies.

The case study technique provides significant insights for theory creation and research propositions for future research [12]. As an additional benefit, this approach makes it possible to answer the questions "what" and "how," which not only offers a comprehensive perspective on the subject matter but also makes it easier to develop a picture that is as comprehensive as possible of the phenomenon that is being investigated [10]. When it comes to the study of phenomena in businesses, a case study is the method of choice because of the inherent characteristics it possesses, such as the convenience and flexibility it offers during the design phase [13, 14].

The utilization of questionnaires has provided us with the opportunity to include a quantitative viewpoint in this investigation. The dissemination of these questionnaires has made it possible for us to rank and evaluate the obstacles that have been discovered, so giving us an understanding of which ones are the most significant and influential.

In order to acquire a full and all-encompassing perspective on the phenomenon that is being investigated, a mixed methodology approach was selected. This approach utilizes both quantitative and qualitative methodologies. Different writers have brought attention to the fact that this method can improve the insights that are obtained from the research of a phenomenon, ultimately leading to a comprehensive comprehension [15, 16, 18]. For this investigation, a mixed approach was utilized in order to gain an understanding of the most significant and significant constraints that are preventing the development of digital technologies in developing markets.

Figure 1: Comprehensive explanation of each methodological step

In the qualitative portion of the research, when the single case study approach was utilized, the most significant shortcoming of the methodology manifested itself. According to a number of scholars, the findings of a single case study, despite the fact that they are intriguing for enhancing the current body of literature and providing more information for subsequent research, could hardly be considered generalizable or extensible. On the other hand, the single case study approach has the potential to be an effective answer in situations when the phenomena being investigated are uncommon or disruptive or when there is an absence of publications in the existing body

of literature [19]. In this particular instance, the extraordinary nature is due to the firm that is being analyzed. This organization stands out due to its varied commercial activities spanning multiple industries and its substantial utilization of Industry 4.0 technology, particularly noteworthy given its presence in a developing nation. Due to this element, the case analysis can provide diverse and comprehensive viewpoints from the different sectors in which the organization is engaged [20]. These insights will improve understanding of the advantages, disadvantages, and difficulties associated with the most pertinent IoT technology applicable in countries that are developing. Moreover, they can function as a blueprint for other enterprises and professionals who are keen on implementing digital technologies in emerging nations.

5. Results

5.1 Case study description

A renowned food and agriculture corporation conducted the research. The corporation in question is a food and agriculture company that is one of the largest private enterprises. Additionally, over 60% of the population are smallholder farmers, who contribute 23% of the country's GDP. The majority of multinational agro-food corporate giants, from input to retailer, have a business model that connects small-scale producers to their supply chain. In order to guarantee the integrity of the product and the supply, contract farming schemes are designed to optimize cycles and mitigate global market fluctuations.

We selected a firm that is leading the market to evaluate its capacity to disseminate sustainable development principles to its subsidiaries and partners. The many divisions of this corporation are involved in separate and independent industries. The firm operates in several sectors, including food and beverage, industrial gases, agriculture, mining, earthmoving, and energy. This case study provides a concrete and clear illustration of how businesses can improve sustainability through the unique design of their buildings. Its leadership in specific areas and presence in several others make it a potential source of inspiration for minor actors in the same country or other ones. The corporation's economic and social influence in the region could serve as a blueprint for different corporations and their affiliated branches.

5.2 Interview data collection

A case-study protocol was utilized to develop concise and logical criteria for defining the research variables, questions, processes, and possible sources of data. This ensured that data collecting was conducted in a standardized and dependable manner across all instances. The duration of the semi-structured interviews ranged from 45 minutes to 1 hour and 50 minutes. Subsequent interviews were required to fill in missing information and resolve any doubts. The comprehensive interview reports aided in the accumulation and synthesis of knowledge.

Structured interviews were carried out by interviewers with seven chief executive officers and senior managers who were chosen for their competence in the research subject (Table 2).

Table 2: Interviewees for the case study group.

Interviewee	Role of interviewee	Products under responsibility
1	Head of Agriculture	Alfalfa, corn, wheat, groundnut, sesame, chickpeas, greenhouse products
2	Head of Manufacturing	Flour, dairy, pasta, beverages products
3	Group Head of IT	–
4	Head of Strategy	–
5	Dairy Plant Manager	Pasteurised and long-life milk, plain and fruit yoghurt, cheese, cream, butter, and mish (a traditional delicacy)
6	Spray Dryer Plant Manager	Powder milk and gum arabic
7	Head of Human Resources	–

The engineering backgrounds of all respondents guaranteed the technical expertise and reliable, generalizable conclusions of the study. The following topics were addressed during the 50–100-minute English interviews conducted in the managers' offices:

- The firm has used Industry 4.0 technology across its entire value chain, including the use of KPIs, to assess the impact on low-skilled workers and the environment.
- Consider the difficulties related to the adoption of Industry 4.0 technologies.
- The advantages of employing I4.0 technologies and their influence on the organization's value chain's sustainability. Additionally, which technologies facilitate the expansion of companies and the promotion of gender equality?
- Software, techniques, and technologies that are appropriate for the agricultural and other industries of developing countries.

In order to guarantee reliable data analysis and eliminate prejudice, all interviews were recorded and documented. Data analysis necessitated transcription of each interview.

5.3 Analysis of interview data (coding)

Common categories must be created by human examination and classification of interview material. Initial data, first-cycle coding, second-cycle code, and classification were used to classify the themes. Value, process, evocative, and simultaneous coding were all part of the first cycle of coding. At first, it produced 129 IDs. A second categorization cycle resulted in a more precise and reduced list of categories, concepts, concepts, and statements after the coding and data were assessed and reorganized.

Focused coding was employed in the second cycle to identify the first cycle's most commonly occurring codes and create data corpus categories. The effectiveness of freshly generated codes being compared and applied to participant data was also assessed using this technique. To make the process more efficient, nine subcategories that shared traits with the 55-second-cycle codes were established. These differences were then classified as barriers and benefits.

5.4 Questionnaires—data collecting and rating

The seven CEO's who were involved in the interviews were also the ones who completed self-administered questionnaires. Additionally, four more managers participated in the questionnaire process. The purpose of the surveys was to confirm the impediments and assess how effective they were in limiting the adoption of I4.0 technology. The participants were instructed to evaluate each obstacle using a rating scale ranging from 1 to 10, where 1 indicated insufficient agreement and 10 showed strong agreement. To assess the efficacy of each barrier, we computed average ratings and standard deviations. The average values of all barriers varied between 10 and 6.6 for strong, 6.7 and 3.4 for moderate, and 3.3 to 0 for minor. The algorithm below was utilized to identify the barriers that respondents considered most important, and the average ranking for each obstacle was calculated.

Equation 1:

$$Average\ Ranking = \frac{x_1w_1 + x_2w_2 + x_3w_3 + x_{\mathrm{n}}w_{\mathrm{n}2}}{Total\ Response\ Count}$$

For w and x:

w = ranked position weight

x = answer choice response count

In reversal, the respondent's first-ranked choice was given the most weight, and their least-preferred alternative was given 1.

When used in this research to determine the position of the various factors or technologies that has contributed towards the sustainability of the environmental market through the use of digital technologies, this formula gives a weighted average ranking. In this case, the researcher employs it to arrange various digital solutions in order of their perceived relevance or effect. Every answer choice (x), is a particular technology or factor while the weight (w) is the rank position of that particular technology or factor. To obtain an average ranking, each response count is weighted by a factor and the products are summed, then divided by the total number of respondents. The use of this particular approach enables the researcher to make a more objective analysis of various digital technologies with a view of ascertaining the extent to which each of the highlighted technologies is perceived as important within environmental markets.

6. Discussion

The potential for the Internet of Things sensors to be employed in a variety of adaptable and flexible ways was demonstrated in the case study under examination. As has been shown in other research [13, 14, 19, 21] [10], these sensors are predominantly employed for soil monitoring. Nevertheless, it is also possible to combine them with various technologies to enhance their impact on sustainable metrics [23] and optimize their advantages [22]. The startup utilizes drones and Internet of Things sensors to deliver real-time data on soil qualities, including moisture levels. Managers can enhance their decision-making process by developing a digital terrain map that provides real-time information. This map enables them to determine the most suitable timing and length for

irrigating specific terrains. An algorithm that is specifically designed for machine learning facilitates this. This primarily results in a decrease in the consumption of water and other resources, as well as an increase in the quantity of harvest produced. On one side, this will improve environmental sustainability by reducing water consumption in regions with limited water resources and optimizing the use of fertilizers and minerals, hence reducing their environmental impact and minimizing product waste. Nevertheless, the reduction of occupations that necessitate the most effort and the emergence of new professions, such as those associated with BDA, will also affect social sustainability.

There are a few examples in the literature that demonstrate the potential of digital technologies to optimize livestock administration and enable workers to allocate their time to more beneficial activities [24]. Radiofrequency identification (RFID) devices are implemented in the agricultural sector to quantify and monitor the lifespan of livestock. This strategy has multiple advantages, such as enhancing milk productivity and facilitating the gathering of data in real-time on cattle, their lifespans, and dairy yield. Depending on the information that has been acquired, BDA offers the opportunity to improve the management of the cattle by determining the appropriate time and manner of feeding and monitoring their location. As a result, this improves the conditions of labor and optimizes food production, thereby promoting social sustainability. For instance, it obviates the necessity for individuals to embark on lengthy journeys to monitor the activities of animals and gather data [27]. Additionally, the Internet of Things is frequently implemented in the apparatus that this organization utilizes to establish connections with animals, including milking machines. The machine's parameters are monitored, and issues are prevented by the data collected. The utilization of I4.0 technologies in livestock offers a more comprehensive perspective on the diverse applications and benefits that could be attained [23]. Therefore, environmental sustainability is improved by ensuring that resources are utilized most efficiently and only when they are required. Additionally, this fosters the improvement of working conditions by frequently eliminating human interference [24].

7. Conclusion

With the ongoing global trend toward digitalization, we may expect the influence of Industry 4.0 technologies to become even more widespread. This is due to the fact that the impacts of these technologies are already being experienced in all sectors. These innovations can significantly enhance sustainability in society and the environment in developing countries, benefiting both the corporate sector and society at large. The beneficial impacts of I4.0 developments on sustainability have the potential to accelerate the adoption of socially and environmentally conscious corporate objectives. It is crucial to understand the significant influence that multinational firms exert on governments in emerging nations. When considering the impact of Industry 4.0 technology on sustainability, this statement is exact and correct.

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