A Review on Role of Advances in Computing in Achieving Sustainable Development Goals

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Abstract

This study investigates the role of digitalization and advanced computing technologies in enhancing sustainability across key sectors, including agriculture, water management, energy systems, climate research, and manufacturing. The objective is to assess how innovations like federated learning, blockchain, edge computing, digital twins, and quantum computing, with traditional methods such as artificial intelligence (AI), remote sensing, and precision farming, contribute to the achievement of the United Nations' Sustainable Development Goals. The study highlights the advantages of these technologies, such as enhanced efficiency, resource optimization, and data-driven decision-making. However, it also identifies challenges, including high implementation costs, data dependency, and gaps in digital literacy, which may hinder their widespread adoption. Additionally, the research presents recommendations for improving low-cost biodegradable sensors, explainable AI models, and hybrid energy systems to address these limitations. The findings emphasize the need for inclusive infrastructure development, effective policymaking, and collaborative efforts to maximize the potential impact of these technologies on sustainability. Overall, the study provides a comprehensive overview of the current landscape and suggests avenues for further progress in utilizing computing technologies to support sustainable development.

Keywords: Digitalization, Federated Learning, Artificial Intelligence (AI), Global Challenges, Efficiency and Optimization.

1. Introduction

The United Nations' Sustainable Development Goals (SDGs), adopted in 2015, provide a comprehensive framework to address global challenges such as poverty, inequality, environmental degradation, and climate change, with a target for achievement by 2030. These 17 interlinked goals promote complete, innovative solutions that aim to simultaneously advance economic, social, and environmental well-being [1]. Advances in computing, particularly in artificial intelligence (AI), data analytics, the Internet of Things (IoT), and blockchain, have emerged as powerful enablers in tackling these objectives. Computing technologies play a pivotal role by enabling real-time decision-making, optimizing resource management, and developing global collaboration, making them central to addressing the multifaceted challenges outlined by the SDGs [2].

For example, AI-driven precision agriculture allows farmers to optimize crop yields while reducing waste by utilizing real-time data on soil conditions, weather patterns, and crop health [3]. IoT sensors in water management systems help monitor and optimize water usage, leading to more sustainable practices in agriculture and urban settings. In energy systems, blockchain technologies have been deployed to create decentralized grids, facilitating more transparent and efficient energy distribution while reducing environmental impact. Furthermore, AI and machine learning models have been pivotal in advancing climate research, offering new insights into climate patterns and enabling better disaster response systems.

However, despite significant progress from AI applications in agriculture to blockchain-enabled supply chain traceability barriers to adoption remain [4]. These include infrastructure deficits, digital literacy gaps, and ethical concerns, along with high implementation costs that limit scalability, especially in underdeveloped regions. These challenges highlight the need for novel computing techniques and interdisciplinary approaches to ensure inclusive and sustainable solutions.

This review aims to consolidate the current state of advancements in computing for sustainable development, identify existing gaps, and propose new techniques to address these challenges. By exploring the intersection of computer science, engineering, and sustainability, this study emphasizes the importance of collaboration between governments, industries, and academia to fully harness computing's potential to achieve the SDGs and create a more equitable and resilient future for all [5].

2. Related Work

Table 1 summarizes the literature study on advances in computing in achieving sustainable development goals.

Table 1. Related Works to Advances in Computing in Achieving Sustainable Development Goals.

S. No.	Title of the Paper	Technique Used	Advantages	Limitations
1	"A Novel ICT Framework for Sustainable Development Goals" [6]	Integration of governance, sustainability, and data science with digital democracy	Improved digital infrastructure and strategic implementation of SDGs	Requires significant investment and policy alignment.
2	"Incorporating Geospatial Information into the Execution and Ongoing Evaluation of Strategies for Attaining Sustainable Development" Goals (SDGs) [7]	Geospatial Information Systems (GIS), Data Analytics	Enhanced monitoring of SDG indicators and effective strategy evaluation	Accessibility challenges in low-resource regions.
3	"Harnessing Artificial Intelligence to Optimize Financial Technologies for Achieving Sustainable Development Goals" [8]	Artificial Intelligence (AI), Financial Technologies (FinTech)	Boosts financial inclusion enhances transparency, and streamlines processes	Risk of algorithmic bias and potential privacy concerns.

4	“A Theory of Digital Technology Advancement to Address the Grand Challenges of Sustainable Development” [9]	Digital Technologies	Provides a theoretical framework for aligning digital innovation with SDGs	Limited empirical validation and scalability concerns.
5	“Building a sustainable future: The role of digital resources in achieving the Sustainable Development Goals (SDGs)” [10]	Digital Resources, Open Access Platforms Like - Linux, OpenDJ	Promotes education and collaboration for SDG progress	Digital literacy and infrastructure gaps in underserved areas.
6	“A panoramic view and SWOT analysis of artificial intelligence for achieving the sustainable development goals by 2030: Progress and prospects” [11]	AI, Strengths, Weakness, Opportunities, and Threats (SWOT) Analysis	Comprehensive analysis of AI's impact on SDGs, identifies strengths and opportunities	Lack of actionable steps and regional customization.
7	“Digitalization to achieve sustainable development goals: Steps towards a Smart Green Planet” [12]	Digitalization, IoT, GIS datasets.	Enhances SDG alignment across sectors through integration of digital tools	High resource consumption, limited access in developing countries.
8	“Metaverse as a cutting-edge platform for attaining sustainable development goals (SDGs)” [13]	Metaverse, Virtual Reality (VR), AI	Immersive educational and collaborative experiences for SDG advancement	High infrastructure requirements and inclusivity challenges.

9	Artificial intelligence for achieving sustainable development goals: Applications, techniques, and progress [14]	AI, Data Mining, Decision-Making Models	Increases efficiency in SDG-related applications, from agriculture to education	Ethical concerns, dependency on quality datasets.
10	Advancing in sustainable agricultural development and food security through machine learning: A comparative analysis of crop yield prediction models in Indian agriculture [15]	Machine Learning, Crop Yield Prediction Models	Accurate yield forecasting supports food security initiatives	Regional dependency and challenges in model generalization.

The Table 1 shows how advances in computing are contributing significantly to the accomplishment of the Sustainable Development Goals (SDGs) of the UN by addressing some of the most critical global challenges in agriculture, water management, energy, climate action, and industry. Techniques such as remote sensing, artificial intelligence, and blockchain have enabled significant progress by improving resource efficiency, enhancing decision-making, and enhancing transparency. These are closely aligned with SDG objectives such as ensuring clean water and sanitation (SDG 6), promoting sustainable energy (SDG 7), and combating climate change (SDG 13).

However, several limitations persist, hindering their widespread adoption. High infrastructure costs, data dependency, and the digital literacy gap create barriers, particularly in developing regions. For instance, while AI-driven precision agriculture optimizes food production, its reliance on advanced hardware and datasets limits its application in low-resource settings. Similarly, blockchain and smart grids promise improved energy and water management but are constrained by the high cost of implementation and technical complexity. Ethical concerns, such as job displacement due to automation and risks to data privacy, further emphasise the need for careful planning and regulation.

To fully realize the potential of computing in achieving SDGs, future efforts should focus on addressing these limitations through inclusive infrastructure development, digital education, and low-cost, scalable solutions. Emerging technologies like federated learning, edge computing, and quantum optimization provide promising pathways to overcome these challenges. Ultimately, the integration of computing innovations into global sustainability efforts can accelerate progress toward a more equitable, resilient, and sustainable world.

Federated learning, blockchain, edge computing, and digital twins each offer distinct advantages in addressing global sustainability challenges. Federated learning enables decentralized model training, ensuring data privacy by processing data locally, which is crucial in sectors like healthcare and agriculture. It empowers local stakeholders to develop robust models without sharing sensitive data, directly contributing to SDG 10 (Reduced Inequalities). Blockchain, on the other hand, enhances data transparency and security, making it ideal for resource management applications such as water and energy distribution. By ensuring the integrity of data across stakeholders, blockchain enhances trust and enables more efficient management of resources, supporting SDG 7 (Affordable and Clean Energy) and SDG 6 (Clean Water and Sanitation).

Edge computing reduces reliance on central infrastructure by enabling real-time processing at the device level, making it especially valuable in remote and resource-constrained areas. This technology supports SDGs such as SDG 6 (Clean Water) and SDG 2 (Zero Hunger) by providing immediate insights for water quality monitoring and precision agriculture. Digital twins, through simulations of real-world systems, allow for predictive maintenance and optimization of resources in industries like manufacturing and energy, helping to achieve SDG 9 (Industry, Innovation, and Infrastructure) and SDG 12 (Responsible Consumption and Production). Together, these techniques improve efficiency, optimize resource use, and enhance decision-making, driving progress toward sustainable development

3. Techniques Used

The benefits of computing can be improved by integrating new techniques and enhancements designed to overcome the shortfalls in existing solutions and increase their potential applications toward achieving the Sustainable Development Goals. One of these is federated learning [16], a technique allowing decentralized model training among numerous devices or locations without access to raw data. This tackles the concern for privacy and lets regions possessing diverse datasets develop strong models especially in areas of healthcare and agriculture. By empowering local stakeholders, federated learning makes the operations inclusive and moves toward SDG 10, Reduced Inequalities.

Another promising innovation is the application of blockchain in the transparent and accountable management of resources such as water and energy. Blockchain-based systems can log and share data in a secure manner across stakeholders, promoting trust and leading to fair resource distribution [17]. For example, blockchain can be used in peer-to-peer energy trading platforms that enable households to trade excess renewable energy efficiently. This helps not only to achieve SDG 7 (Affordable and Clean Energy) but also reduces reliance on centralized energy grids.

Edge computing is the transformative approach needed to overcome the challenge of connectivity in remote and resource-constrained areas [18]. In contrast to the traditional model of centralized cloud servers, edge computing performs processing at the device level, which reduces latency, cuts bandwidth costs, and decreases dependence on strong internet infrastructure. It is in applications such as water quality monitoring and precision agriculture that this technology has the greatest impact by providing real-time decision-making for underserved regions directly supporting SDG 6 (Clean Water and Sanitation) and SDG 2 (Zero Hunger).

The use of digital twins will help in resource optimization and lower environmental impacts. Creating virtual duplicates of real-world systems lets industries simulate a scenario, anticipate its outcome, and detect inefficiencies without any interruption in operations. Digital twins could be in full operation for these sectors in the future like manufacturing and energy to be used for enhanced sustainability, enhancing SDG 9 (Industry, Innovation, and Infrastructure) and SDG 12 (Responsible Consumption and Production).

To continue the democratization of advanced technologies, low-cost biodegradable environmental sensors could be created. These biodegradable or nanotechnology-developed sensors can offer an economical, eco-friendly way to develop needed resources for water, soil, and air monitoring in otherwise resource-constrained areas. Since it makes it more accessible for the collection of environmental data, this innovation supports SDG 13 (Climate Action) and SDG 15 (Life on Land).

Another important enhancement would be Explainable AI (XAI), which can also tackle issues of transparency and trust in decision-making systems [19]. With interpretable insights on AI-driven recommendations, XAI develops a better adoption of computing technologies in critical sectors such as energy management, agriculture, and healthcare. Such an approach improves not only stakeholder trust but also reduces algorithmic bias, supporting SDG 16 that is, peace, justice, and strong institutions.

Lastly, the use of quantum computing may mark a new dimension in solving complex problems across diverse sectors [20]. In optimization tasks ranging from power-grid management and supply-chain logistics to climate modeling, quantum algorithms are peerless at coming up with answers that are unattainable today through classical computing. As quantum computing becomes more widely available, it has the potential to speed progress toward achieving several SDGs SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). These new techniques and enhancements overcome existing limitations associated with scalability, inclusivity, and sustainability. Combining them allows us to work together to actualize the full potential of computing in creating a sustainable and equitable future.

Federated learning has been successfully implemented in healthcare, where decentralized data models allow for privacy-preserving training of AI models across hospitals. For instance, research by Google Health has demonstrated federated learning's application in disease detection, improving healthcare in underserved regions. Blockchain in water management, such as in the "WaterChain" project, ensures secure and transparent distribution of water resources, contributing to SDG 6 (Clean Water and Sanitation). Similarly, blockchain's role in peer-to-peer energy trading platforms exemplifies its impact on achieving SDG 7 (Affordable and Clean Energy) by promoting local energy trading.

4. Architecture

Figure 1 Generic Framework for Achieving SDGs using Computing Advance

4.1 Preprocessing

In the preprocessing stage, various advanced techniques work together to ensure that data is handled efficiently, securely, and effectively for sustainable development. Federated learning (FL) allows for decentralized model training, where data remains local to each node, preserving privacy while enabling the sharing of model updates for central aggregation. This ensures sensitive data is not exposed while still benefiting from collaborative learning. Blockchain plays a key role in verifying data authenticity, ensuring data integrity and transparency, which is especially critical in sectors like energy and water management, where data accuracy is paramount. Edge computing processes data locally on devices, reducing latency and bandwidth use by performing tasks like noise reduction, normalization, and data aggregation before sending only relevant data to the cloud. This enables real-time decision-making in remote areas with limited connectivity. Additionally, digital twins simulate real-world systems to generate synthetic data or enhance the quality of collected data by modeling real-time conditions, improving operational efficiency. Internet of Things (IoT) devices also contribute to preprocessing by filtering, aggregating, or compressing sensor data before transmission, reducing network load and ensuring efficient data handling. These techniques collectively support SDGs such as SDG 9 (Industry, Innovation, and Infrastructure) by improving data management processes, making them more secure, efficient, and capable of driving sustainability in various sectors. Figure 1 depicts the generic framework for achieving SDGs using computing advance.

4.2 Feature Selection

Statistical Techniques: Methods like correlation analysis or Mutual Information (MI) are used to identify the most significant features. Mutual Information:

$$MI(X,Y) = H(X) - H(X|Y) \quad (1)$$

Where H(X) is the entropy of X, and H(X|Y) is the conditional entropy of X given Y. Principal Component Analysis (PCA): A dimensionality reduction technique to reduce feature space while maintaining variance in the data. PCA Formula:

$$X' = XW \quad (2)$$

Where X is the original data matrix, and W is the matrix of eigenvectors. Quantum Computing: can enhance feature selection by using quantum algorithms like the Quantum Approximate Optimization Algorithm (QAOA) or the Variational Quantum Eigensolver (VQE) to identify relevant features more efficiently, especially for high-dimensional datasets. Feature selection techniques like Principal Component Analysis (PCA) and Mutual Information play a crucial role in optimizing data for decision-making. PCA reduces the dimensionality of datasets, making it easier to analyze and identify patterns that contribute to sustainability. Mutual Information helps in identifying the most relevant features by measuring dependencies between variables, ensuring that only significant data is used for further analysis. These techniques support SDGs like SDG 2 (Zero Hunger) by improving precision in agricultural practices, enabling better predictions for crop yields and resource usage, ultimately leading to more sustainable and efficient agricultural systems.

4.3 Model Building

In model building, AI and blockchain play crucial roles in improving resource management and decision-making across various sectors. Techniques such as Decision Trees (CART) are used for classification and regression tasks, enabling the prediction of outcomes based on historical data. Random Forests, an ensemble method, enhance prediction accuracy by combining multiple decision trees, while Support Vector Machines (SVM) maximize the margin between classes, ideal for binary classification problems. Neural Networks (Deep Learning) are particularly effective in identifying intricate patterns in unstructured data such as images and time series. Blockchain enhances model building by ensuring data provenance, transparency, and security, enabling decentralized and tamper-proof data sharing among stakeholders, thus making the training process more reliable and trustworthy. Additionally, Explainable AI (XAI) improves model transparency, allowing stakeholders to understand and trust the decisions made by AI systems, which is particularly important in high-stakes areas like healthcare or finance. These AI-driven models, in combination with blockchain, optimize resource allocation, reduce waste, and enhance sustainable practices, contributing to SDG 12 (Responsible Consumption and Production). Through the use of these advanced techniques, industries ranging from agriculture to energy management can improve efficiency, drive sustainability, and ensure more responsible resource utilization, ultimately supporting the achievement of the Sustainable Development Goals.

4.4 Evaluation

In evaluating model performance, various accuracy metrics are employed depending on the task at hand. For classification tasks, metrics like accuracy, precision, recall, and F1-score are commonly used. Precision measures the proportion of predicted duplicates that are actually duplicates, while recall measures the proportion of actual duplicates that were correctly predicted. The F1-score provides a harmonic mean of precision and recall, balancing both metrics for a more comprehensive evaluation. For regression tasks, Mean Squared Error (MSE) and R^2 are used, with MSE calculated as the average squared difference between actual and predicted values. To avoid overfitting and ensure the model generalizes well, techniques like k-fold cross-validation are employed. The confusion matrix is particularly useful for classification tasks, assessing model performance by analysing true positives, false positives, true negatives, and false negatives. Additionally, Explainable AI (XAI) can be incorporated to enhance interpretability and transparency, ensuring that the model's predictions and decision-making processes are understandable and auditable. This approach aids in identifying any biases or errors, ensuring more reliable and trustworthy outcomes. Together, these evaluation methods provide a robust framework for assessing model performance and ensuring that the model's decisions are both accurate and transparent, supporting better resource management and decision-making in sustainable development efforts.

5. Conclusion

Advances in computing have established themselves as indispensable tools in achieving the sustainable development goals by addressing critical challenges faced by various sectors. Technologies like artificial intelligence, IoT, and blockchain have brought improvements in resource efficiency, transparency, and accessibility with the current techniques. Still, obstacles of high implementation costs, dependency on robust infrastructure, and the digital divide have yet to be overcome, particularly in developing regions. This review paves way for innovations that can overcome these limitations and extend the scope of existing methods. Technologies such as federated learning and edge computing can reduce data privacy and connectivity issues, while blockchain and quantum computing optimize resource management and problem-solving in energy and manufacturing systems. Innovations like digital twins and biodegradable sensors provide sustainable, scalable solutions for environmental monitoring and industrial efficiency. Moreover, explainable AI creates trust and inclusiveness in decision-making processes, ensuring wider adoption across a variety of sectors. Combining these new developments with current computing approaches could overcome the challenges and hasten the progress toward a sustainable future. The attainment of the SDGs requires cooperation among governments, industries, and researchers to ensure that there is equal access, strong infrastructure, and inclusive programs on digital literacy. By closing these gaps, computing technologies can bring a transformational effect, creating a more resilient and sustainable world.

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